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A UDP-TRIZ method as a universal design approach for product design

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Abstract

To encourage the participation of individuals with diverse abilities in the community, universal design has been adopted as the foundation for creating user-friendly designs that include people of all ages, the disabled, and the elderly. However, the approach to universal design lacks a systematic and directed strategy for designers to ensure that their designs fit universal design requirements. Most manuals and guidelines focus on the built environment, and there is no specific guidance for product design. This situation is seen as an opportunity to introduce an approach for designers to approach universal designs effectively. Therefore, this research proposes an intervention tool for universal design. Universal design principles and TRIZ 40 creative principles are synergised and used in the design process to benefit one another mutually. A UDP - TRIZ methodology framework is introduced to a group of designers engaged in a series of design activities to create a product with a universal design for visually impaired persons in mind. This study demonstrates that this strategy can assist designers in understanding user-related problems, identifying innovations, justifying designs in terms of universal design requirements, and fostering the creative process.

Keywords: Product Design, Universal Design Principles, TRIZ.

1. Introduction

The Convention on the Rights of Persons with Disabilities and its Optional Protocol (A/RES/61/106) were enacted at the United Nations Headquarters in New York on December 13, 2006, and made available for signature on March 30, 2007. 82 parties signed the Convention, 44 parties signed the Optional Protocol, and one party ratified the Convention. On the opening day of a UN Convention, the number of signatories has never been higher. It is also the first comprehensive human rights treaty of the twenty-first century. The Convention went into effect on May 5, 2008.

Following the acceptance of this Convention, the respondent country must submit an appropriate law to protect the rights of individuals with disabilities. For instance, the Malaysian government passed the Persons with Disabilities Act 2008 in 2008. This law's primary purpose is to increase the well-being and involvement of people with disabilities in the community without excluding them. As a result of new laws and policies relevant to social inclusion and the prevention of discrimination, the design industry has been under pressure to build valuable and accessible products, services, and environments.

Erdtman et al. (2021) said in their study that universal design has its roots in architecture and design. American architect Ronald Mace coined the term "universal design" in 1985. Since then, the phrase 'universal design' has been extensively used as a design approach and concept in architecture and product design, with the intention of considering the needs of a diverse population. The term universal design originated in the United States and is known as Design for All in Europe and Inclusive Design in the United Kingdom (Clarkson & Coleman, 2015). In order to increase population diversity, the term "universal design" has evolved. Some critics dispute the use of the word "universal" and assert that no single design solution meets all user requirements. Nevertheless, Steinfeld & Maisel, (2012) defend the "universal" terminology in "universal design." The phrase "universal" should not be understood as a "single solution" but instead as a design objective integrating diverse people.

In a publication by Heylighen, (2014), the author states that UD has been criticised for aiming to obtain an

unachievable goal, as no design would be great for everyone. In response, modern conceptions of universal design do not allude to a single "perfect" solution but show UD as a process of continual quality improvement. Universal design is a prevalent practice within the built environment. A manual and guidelines were created using the universal design principle (UDP) proposed by Mace (1985) of North Carolina State University. Each manual and policy for universal design are exclusive and apply only to the country that gazettes it. Table 1 summarises the universal design manual and guidelines for Southeast Asia countries:

Table 1. Governance of universal design in ASEAN country

Malaysia	i. MS 1183:2015 – Specification for Fire Precautions in the Design and Construction of Buildings ii. MS 1184:2014 – Code of Practice on Access for Disabled Persons to Public Buildings iii. MS 1331:2003 – Code of Practice for Access of Disabled Persons Outside Buildings iv. MS 1184: 2014 Universal Design And Accessibility In The Built Environment - Code Of Practice v. GP015 – A *Garis Panduan Perancangan Rekabentuk Sejagat* (Universal Design) vi. Panduan Rekabentuk Sejagat (Universal Design) Kemudahan Rekreasi Taman Awam
Indonesia	Permen PUPR No. 14 / PRT / M / 2017 Concerning the Ease Requirements for Building Buildings
Thailand	Ministerial regulation on Facility in Building for Persons with Disability and Elderly B.E. 2548
Singapore	i. Guide to Universal Design index (UDi) 2022 ii. Universal Design Guide for Public Places 2016 iii. Universal Design Guide 2007 iv. Universal Design Guidelines (Commercial Buildings) 2006
Vietnam	i. Standard of Construction 01:2001 (Standard of construction assures the accessibility for people with disabilities) ii. Standard of Construction 265: 2002(roads and pavements- basic constructing principles for people with disabilities to approach)
Philippines	i. Batas Pambansa Bilang 344 Accessibility Law ii. Republic Act No. 7277 Magna Carta for the Disabled Persons and the likes
Cambodia	The guideline on Water, Sanitation, and Hygiene (WASH) for Persons with Disabilities and Older people
Brunei	DADG:2018 – Different Abilities Design Guidelines

The great majority of standards created in the field of built environment focus on the governance of facilities that are accessible to individuals with disabilities. There is no evidence of product design or transport design guidelines or manuals. This trend is significant because human interaction regularly involves products and transportation in addition to space and the environment. The seven universal design principles (UDP) are the foundation for all policies and guidelines. Steinfeld & Maisel, (2012) propose that UD, based on seven principles and eight objectives, is the ideal resource for designers to provide conceptual insight for tackling the issue and offering solutions that suit different sorts of users. In Table 2, Steinfeld & Maisel, (2012) present seven UD principles.

Table 2. Universal Design Principle (UDP)

UDP1	Equitable Use
UDP2	Flexibility In Use
UDP3	Simple & Intuitive
UDP4	Perceptible Information
UDP5	Tolerance for Error
UDP6	Low Physical Effort
UDP7	Size & Space for Approach & Use

Universal design guidelines are developed to ensure that products, environments, and systems are accessible and usable by people of all ages and abilities, including those with disabilities. The goal of universal design is to create inclusive spaces and products that eliminate barriers and accommodate diverse needs so that everyone can participate equally in society.

Universal design guidelines are developed to address the fact that many environments, products, and systems were designed with only certain types of users in mind, such as able-bodied individuals. This can create

barriers for people with disabilities, seniors, and others who have different needs or limitations. For example, stairs can be a barrier for people who use wheelchairs, and small text on a website can be difficult for people with visual impairments to read.

By developing universal design guidelines, designers and architects can create products and spaces that are more accessible and accommodating to a wider range of users. Universal design principles can be applied to everything from building design and transportation systems to technology and consumer products. Ultimately, the development of universal design guidelines is important because it helps to create a more inclusive and equitable society where everyone can participate fully and comfortably. By eliminating barriers and accommodating diverse needs, we can create a world that works better for everyone. Detail guidelines for each UDP are shown in Table 3

Table 3. UDP Guidelines

Principle	Guideline
UDP1 Equitable Use	1a. All potential users could use this product in essentially the same way, regardless of differences in their abilities.
	1b. Potential users could use this product without feeling segregated or stigmatized because of differences in personal capabilities.
	1c. Potential users of this product have access to all features of privacy, security, and safety, regardless of personal capabilities.
	1d. This product appeals to all potential users.
UDP2 Flexibility in Use	2a. Every potential user can find at least one way to use this product effectively.
	2b. This product can be used with either the right or left hand alone.
	2c. This product facilitates (or does not require) user accuracy and precision.
	2d. This product can be used at whatever pace (quickly or slowly) the user prefers.
UDP3 Simple and Intuitive Use	3a. This product is as simple and straightforward as it can be.
	3b. An untrained person could use this product without instructions.
	3c. Any potential user can understand the language used in this product.
	3d. The most important features of this product are the most obvious.
	3e. This product provides feedback to the user.
UDP4 Perceptible Information	4a. This product can be used without hearing.
	4b. This product can be used without sight.
	4c. The features of this product can be clearly described in words (e.g., in instruction manuals or on telephone helplines).
	4d. This product can be used by persons who use assistive devices (e.g., eyeglasses, hearing aids, sign language, or service animals).
UDP5 Tolerance for Error	5a. Product features are arranged according to their importance.
	5b. This product draws the user's attention to errors or hazards.
	5c. If the user makes a mistake with this product, it won't cause damage or injure the user.
	5d. This product prompts the user to pay attention during critical tasks.
UDP6 Low Physical Effort	6a. This product can be used comfortably (e.g., without awkward movements or postures).
	6b. This product can be used by someone who is weak or tired.
	6c. This product can be used without repeating any motion enough to cause fatigue or pain.
	6d. This product can be used without having to rest afterward.
UDP7 Size and Space for Approach and Use	7a. It is easy for a person of any size to see all the important elements of this product from any position (e.g., standing or seated).
	7b. It is easy for a person of any size to reach all the important elements of this product from any position (e.g., standing or seated).
	7c. This product can be used by a person with hands of any size.
	7d. There is enough space to use this product with devices or assistance (e.g., wheelchair, oxygen tank, or service animal).

2. Literature Review

Although the term UD is widely used in research, legislation, guidelines, and manuals, there is still variation in its understanding and use. Moore et al. (2022) and Van Der Linden et al. (2016) think that the low adoption of design for UD and application of UDP to solve a user(s) and customer(s) problem occurs because designers approach UD and UDP design with a particular mindset. How the design problems are processed and come to generate products that diverse populations can utilise based on their age, gender, and skills influence the distinct mentalities of designers.

Van Der Linden et al. (2016) claimed that there is insufficient information for architects to employ in their design practice. The information should be presented to allow designers to utilise it during the design process. To coordinate how designers comprehend design difficulties, it is necessary to supply relevant information so that designers may generate designs that fulfill the needs of users.

Product designers struggle to comprehend the difficulties faced by users with diverse abilities and interpret the UDP so that it can be used as a design solution tool. The vast majority of designers state that the UDP is unclear and that it is difficult to evaluate whether the design they have presented is appropriate for the problem they are attempting to solve (Shahrin et al., 2020). According to Yang et al., (2010), a comprehensive product development process is required to ensure that UD activities are correctly integrated into the product and that flexible and imaginative product concept development is thoroughly explored, resulting in genuinely beneficial outcomes for users.

The primary objective of universal design is to create products that individuals with diverse abilities can utilise. However, it generally encountered various constraints throughout product design and development to achieve UD objectives, resulting in less inventive design (Yang et al., 2010)Numerous articles demonstrated attempts to use TRIZ in multiple fields to perform the study's objectives. Typically, TRIZ integrated technical parameters and analysis tools into the process. (Abramov, 2017; Amer, Ong et al., 2019; Brad & Brad, 2015; Pelt & Hey, 2011; C M Yang et al., 2010; Chun Ming Yang et al., 2012)

The only evidence of the applicability of TRIZ to the UD method is a 2010 study by Yang et al., (2010). This study offered a TRIZ-based method for designing innovative products that includes UD principles. The author provided a newly created technique that begins with a description of a problem during the product's design and development, followed by an evaluation of the product's UD performance using the Product Performance Program tool. A 3-step inventive problem-solving procedure was then formulated as the problem statement. The contradiction Matrix of TRIZ was employed to identify proper inventive principles that could serve as resolutions, leading to improved or new product concepts used to determine acceptable ideas that could provide solutions and result in further or enhanced product concepts.

However, this study reveals a limitation: product designers must be trained in the TRIZ 3-step innovative problem-solving strategy to employ this methodology. It is not normal for trained product designers to use TRIZ as a problem-solving technique. Whilst formal training is required for the method, the proposed approach, including TRIZ, could reinforce the UD principles and generate more concrete and innovative solutions. On the other hand, this study also revealed how UD and TRIZ principles could work together to develop more original and creative solutions that fit UD objectives without compromising.

As a result, this study proposes an application of intervention tools for product designers that synergised UDP with TRIZ 40 inventive principles to improve the creative design process by utilising inventive principles suited for design solutions. This tool provides the designer with a quicker and easier method to identify UDP issue(s), or problem(s) and suitable TRIZ 40 inventive principles corresponding to the UDP and choose a practical generic solution to provide by TRIZ 40 inventive principles to propose a design solution.

The synergy between UDP and TRIZ was developed by a focus group discussion among TRIZ experts. The experts have concluded the synergy between UDP and TRIZ (Shahrin et al., 2020). This synergy is proposed to primarily be used when UD intervention in the design process is required. This synergy between UDP and TRIZ creative concepts will assist designers in generating ideas, validating design solutions, and developing universal design validation tools. This tool could provide designers with a much clearer understanding of challenges and their corresponding solutions in the form of TRIZ's 40 innovative principles, which have been mapped to match with the UDP. The synergy of UDP and TRIZ inventive principles is shown in Table 4.

Table 4. UDP-TRIZ table

Principle	Guideline	TRIZ 40 inventive principles
UDP1 Equitable Use	1a	6, 26, 33, 40
	1b	6
	1c	6, 5, 11
	1d	6, 5, 30
UDP2 Flexibility in Use	2a	6, 4, 7
	2b	6, 13, 17
	2c	6, 4, 7
	2d	6, 7, 15
UDP3 Simple and Intuitive Use	3a	3, 6
	3b	25, 6
	3c	25, 6
	3d	3, 6
	3e	23, 32
UDP4	4a	6, 18, 19, 32
Perceptible Information	4b	6, 18, 19, 32
	4c	6
	4d	6, 24, 26, 35, 36
UDP5 Tolerance for Error	5a	2
	5b	10, 16
	5c	2, 6, 9, 11, 22, 34
	5d	2, 9, 10, 23
UDP6 Low Physical Effort	6a	6, 4, 12, 15, 24, 28, 29, 39
	6b	6, 4, 8
	6c	8, 12, 14, 20, 27
	6d	20
UDP7 Size and Space for Approach and Use	7a	6, 1, 7
	7b	6, 37
	7c	6, 7
	7d	6, 24, 39

3. Methodology

The primary objective of universal design is to create a product that individuals with diverse abilities can utilise. Nonetheless, it generally encountered many constraints throughout product design and development to achieve UD objectives, resulting in less inventive design (Yang, 2010).

The synergy between UDP and TRIZ was introduced to resolve this issue. The designer will be able to recognise relevant UDPs to be enhanced and discover appropriate innovative principles associated with each UDP. Based on the offered inventive notions, this tool could assist the designer in identifying the most suitable option to use in a design. Additionally, the designer will have a significantly more precise notion from which inventive principles they can generate ideas. UDP-TRIZ can also be used to validate the submitted idea in pursuit of the UDP guidelines' goals and objectives.

To ensure the credibility of this study, all participants involved are product design practitioners. Three (3) junior designers and three (3) experienced designers were selected to perform in a design process, creating a universal design product. A case study of the design problem was provided, and the designers were required to develop a design solution for the case study's product. A framework of the proposed UDP-TRIZ method is illustrated below.

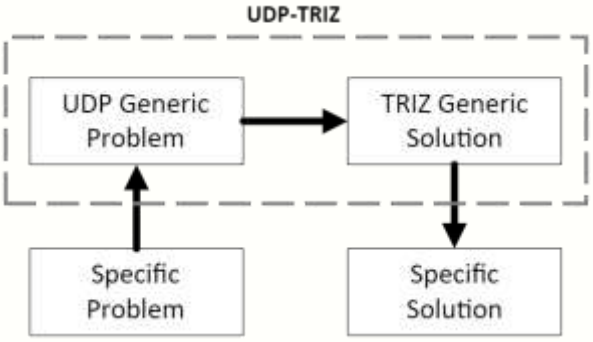

Fig. 1. UDP-TRIZ methodology framework

4. Results

In a design case study provided for designers by the moderator, each designer must propose a universal design kitchen knife considering the visually impaired person who will use it for daily purposes. Each designer must identify the issue(s) or problem(s) based on their knowledge and experience. Designers can use external tools such as web searching to research and brainstorm. The designer later tries to identify the related UDP with their design issue(s) or problem(s). Designers will identify UDP that is affected by the specific problems that have been identified in the brainstorming stage. The designer will match the appropriate theme of the specific problem with the available UDP as a generic problem. For instance, respondent #5 recognizes a specific problem with a need to improve how the product could communicate and guide visually impaired users and four related UDPs as the generic problem is selected based on

the specific problem. Respondent #5 identified UDP1 Equitable Use, UDP2 Flexibility in Use, UDP3 Simple & Intuitive Use, and UDP4 Perceptible Information as UDP generic problems. The respondent is confident these four identified UDP are fulfilling the theme of improving how the product communication and guidance can be improved. With the respective UDP as the generic problem is identified, the designers will then determine the corresponding TRIZ 40 inventive principles in the UDP-TRIZ tools, and the designers can select one or more inventive principles that are on designer consideration suitable to propose as part of the design. With TRIZ 40 inventive principles identified, the designer will be able to produce a specific design solution that will solve the identified specific problem and fulfill the universal design element of the product. The result of each designer using UDP-TRIZ is shown below in Table 5.

Table 5: UDP-TRIZ design proposal by respondents.

Respondent	Specific Problem	UD Generic Problem	TRIZ Generic Solution	Specific Solution
Respondent #1	Increase the safety of the users to hold and use the knife, focusing on protecting the sharp and risky part of the knife	UDP2a	#6 Universality	• Knives come with storage with a locking mechanism.
		UDP4d	#35 Parameter changes	•Remove the pointy end on the steel parts.
		UDP5b	UDP5b: #11 Beforehand cushioning	• Improving handguard • Embedded braille/tactile features to label the knife's size/type
Respondent #2	I am reducing the risk of injury and increasing safety by eliminating sharp features on the knife blade.	UDP6b	#6 Universality	• Remove the pointy end on the steel parts. • Improving holder to improve the ergonomic factor
		UDP6d	#20 Continuity of useful action	The designer wants to decrease the sharpness of the knives using the concept of pudding or steak knives. Users need to repeat the cutting motion before it will cut through.
		UDP7c	#6 Universality	Adding a thumb grip to improve product orientation when holding the knives
Respondent #3	Considering the visually impaired person uses touch sensory to guide them around the kitchen, a change of materials to increase safety to communicate with the visually impaired users on the risk part of the knife.	UDP5b	#11 Beforehand cushioning	Leaving only the sharp edges using steel materials. The material difference will allow visually impaired persons to safely explore the shape of knives.
			#10 Preliminary Action	The differences in materials will improve the awareness of visually impaired people identifying the knife using touch sense.
		UDP5c	#2 Taking out	Replace most of the material steels with wood but maintain the typical knife shape.
Respondent #4	Improve the ergonomics and performance of the knife's handle for the benefit of the users. The handle determines how the knife is used, as it is the most prominent component.	UDP7c	#6 Universality	• Adding a curve contour to knives spine area as tactile for the visually impaired person • Using memory foam-like materials to adapt different hand sizes and shapes

Respondent #5	The visually impaired person requires a preliminary action to communicate/instruct them. By standard, the usage of braille is a system to trigger/guide the user to do specific actions. The main concern is the safety of the users. Respondents want to implement these two criteria into the design.	UDP1a UDP1b	#6 universality #40 Composite Materials	The design for the knife should look like regular knives to include ordinary people, not just people with disabilities. Material selection to differentiate features on the handle.
		UDP2a UDP2b UDP2d	#6 Universality #4 Asymmetry #7 Nested Doll	The handle design is asymmetry and can be used on both hands. Safety features are retractable and can be stored inside the handle.
		UDP3a UDP3c UDP3d	#25 Self Service	Safety features should use a self-retract mechanism using a single push button on the handle. A mechanism for safety should be easy to use for both normal and impaired persons.
		UDP4d	#6 Universality	Tactile feature on the safety mechanism
Respondent #6	The primary factor to be imposed is user safety. The principal issue that should be highlighted is how the product communicates, and there is no visual demonstration training for visually impaired users.	UDP2b	#6 Universality	The product can be used regardless for normal or visually impaired persons.
		UDP6a	#4 Asymmetry #15 Dynamics	The handle design should be asymmetry to allow the visually impaired person to recognise the correct way to hold the knife. The grip contour should guide the orientation of the knife.
		UDP7c	#7 Universality	The product can be used regardless for the normal or visually impaired person.

Next, the designers present their designs visually using digital sketches. Researchers have taken the initiative to visualise the designs of the respondents in a 3D model. Table 6 shows the 3D illustration by each respondent. The specific solution for each design is labeled in the Fig. . ure.

Table 6. Design proposal using UDP-TRIZ

	**Respondent 1** a. Locking mechanism for safety b. Remove pointy features to reduce injury risk. c. Handguard improvement d. Braille for labeling and warning.
	**Respondent 2** a. Remove pointy features to reduce injury risk. b. Increase ergonomic features on the handle. c. Reduce the sharpness of the knife to avoid serious injury. d. Thumb grip to improve knife orientation.
	**Respondent 3** a. Using steel material only for cutting edges. b. Replace the steel material with wood to increase a visually impaired person's confidence to use touch sense to identify the knife. c. Maintaining the typical knife shape.
	**Respondent 4** a. Thumb rest to guide visually impaired persons in positioning their fingers. b. Memory foam material, to adapt users' hand size and shape.

	**Respondent 5** a. Maintaining the shape of the handle and using different materials so that visually impaired persons can identify the handle's features. b. Using asymmetry shape to differentiate the orientation of the knife and embedded retractable blade guard in the handle. c. Retractable guard using one push button to open and close. d. A button for a retractable guard comprised of distinct materials and tactile characteristics for simple recognition.
	**Respondent 6** a. This product can be used by any person regardless of ability. b. The handle should be asymmetry to allow the visually impaired person to identify the knife orientation. c. Grip contour should be designed to guide the visually impaired person to use the knife as per intent.

At the end of the design process, the researcher asked the respondents a series of questions related to their experience using UDP-TRIZ in their design process. All respondents agree that UDP-TRIZ improves how they understand the design problem related to universal design. One of the respondents claims that UDP-TRIZ enables them to understand precisely which aspect of the product they need to enhance to meet the UD. With TRIZ 40 inventive principles provided in UDP-TRIZ, respondents claim it helps them to realise that there is more potential improvement that could be considered to meet UD. All respondents are satisfied with their design and confident they could meet UD. According to the respondents, UDP-TRIZ allows them to justify the design produced and relate their design to the problems faced by users. These are helped by the systematic approach when using UDP-TRIZ to intervene in the design process when UD is required.

Aside from the benefits of UDP-TRIZ, which are highly beneficial to designers, the terminology employed in TRIZ 40 inventive principles is rather tricky for designers to comprehend. All junior designers concur that UDP-TRIZ may be improved by including a design solution case study or example as part of the TRIZ 40 inventive principles brief and examples, but only for UDP-TRIZ reasons. However, experienced designers in this study have contradictory opinions. They agree that, even though the TRIZ 40 inventive principles are difficult to understand, the main issues do not underlie the brief or examples provided by TRIZ. They claim that first-time users using TRIZ find some of the keywords of TRIZ 40 inventive principles confusing and unfamiliar. However, the brief given with the inventive principles is comprehensible. One of the experienced designers insisted that using the generic brief provided by TRIZ is adequate to comprehend for designers to generate ideas. Experience designers believe that if design examples are provided, UDP-TRIZ users (designers) will attempt to "play it safe" during design development by using existing examples and the creative process in design and development is absent. Consequently, it will create a similar and stagnant design.

5. Conclusions

Using the synergy between UDP and TRIZ 40 Inventive Principles, this study aims to produce an intervention tool for a universal design approach during design and development; designer response indicates a beneficial effect on their design process. This study presents a novel approach for designers to utilise TRIZ 40 inventive principles as one of the design process's tools. Using this UDP TRIZ for the first time challenges no difficulties for designers. The proposed intervention could stimulate the designer's ideation process throughout the design process's brainstorming phase. Most designers who participated in the experiment remarked that UDP-TRIZ expanded their perspective on problems. UDP-TRIZ also gives the designer a clear grasp of challenges and feasible solutions.

Using UDP-TRIZ, designers find it easier to justify universal design-related recommendations, particularly during the design concept creation phase. The conceptual design stage is crucial for designers to make decisions concerning universal design. This study demonstrates that UDP-TRIZ is integral to the creative components of idea generation. Although all designers employ UDP-TRIZ and provide the same case studies in the experiment, the findings collected from the design process demonstrate that UDP-TRIZ does not restrict the designer's ability to propose a suitable universal design solution.

Regarding design solutions that correspond to the universal design principles, neither of the designs

proposed by respondents is rigid. Each designer can offer a unique design based on knowledge of universal design principles. Given the possible use of the newly created UDP-TRIZ, designers can use this method to determine which TRIZ 40 inventive principles correspond to the universal design principles. It can also guide designers in proposing designs compliant with UD. This method can also be used as a validation tool to examine whether the design contributes to universal design.

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Unraveling the structure and trends of TRIZ approach in business and management: Bibliometric synthesis and future research directions

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Abstract

The present study aims to bridge the gap and offer guidance for individuals without technical training to comprehend and utilize the Theory of Inventive Problem Solving (TRIZ) in the realm of business and management. It provides a comprehensive overview of TRIZ methodology, its evolution, and how it has been adapted to address managerial issues. Additionally, the paper explores the prospects of TRIZ in business and management problem-solving domains. This review will facilitate the distinction between technical and non-technical creative TRIZ applications, empowering policymakers to make informed decisions. Bibliometric analysis methodologies are incorporated in the study using 253 publications obtained from the Scopus bibliometric search following a keyword protocol. Bibliometrix-R and VOSviewer software have been used for the intellectual analysis of top contributors, co-authorship, and citation analysis. A bibliometric review followed a detailed literature review, including other relevant articles, which further provided the theoretical background, focus areas, research gaps, and future research directions. Few TRIZ studies on non-technical core business problems focus more on the technical context. Company-based research on how different companies have used TRIZ and the type of strategy making the TRIZ methodology is also unclear. Previous researchers have studied management areas such as brand management, marketing segmentation, human resource retention, and product portfolio through the lens of TRIZ. However, financial aspects such as portfolio management, risk management, and strategic areas such as pricing policies have not received attention. The originality of this paper lies in the fact that it is the first bibliometric review of TRIZ literature in the field of business management, as well as the first attempt to review TRIZ to solve and manage non-technical problems. The paper highlights the need for more research on core business problems, financial aspects such as portfolio and risk management, and strategic areas such as pricing policies.

Keywords: TRIZ, bibliometric, business and management

1. Introduction

Genrich Saulovich Altshuller originally gave TRIZ, or Inventive problem-solving theory, in the soviet union in 1946 (Dung, 1995; Souchkov & Sutcliffe, 2007) as a problem-solving tool, particularly in the field of engineering; engineers developed TRIZ for engineers only. The theory emerges from investigating and evaluating over two lakh patents to formulate 40 specific principles used as solutions to most engineering problems (Stratton & Mann, 2003). Problems and solutions are replicated across industries according to TRIZ theory, as are patterns of technical evolution. In formulating inventive solutions, effects, and solutions from one industry are used to eliminate other industries' problems by following the process of abstraction (Jones et al., 2001). With its unique application style, the theory is a successful yet robust problem-solving tool for developing novel ideas and inventions. Many companies worldwide, including Samsung, Proctor and Gamble, Ford Motors, and Mitsubishi, have recognized TRIZ as the most effective problem-solving methodology (Ilevbare et al., 2013a; Souchkov & Sutcliffe, 2007). Due to its encouraging results, TRIZ has started applying in the business and management field for several years to solve non-technical problems. Darrel Mann's book "Hands-on systematic innovation for Business and Management" (D. L. Mann, 2002) and many of his published research papers cited in this study have also

promoted the TRIZ methodology in the business and management fields.

However, classical TRIZ focuses on identifying contradictions within a system or problem within the system that may be causing or exacerbating the problem and finding innovative solutions that eliminate those contradictions. A contradiction is a situation where two opposing forces work within a system, such as the need for speed vs. the need for accuracy. BusinessTRIZ, on the other hand, is a specific application of TRIZ principles to business problems. It involves using TRIZ methodology to identify and solve complex business problems, such as improving efficiency, reducing costs, and increasing revenue. The main difference between TRIZ and BusinessTRIZ is the focus of the methodology. TRIZ is a general problem-solving methodology that can be applied to various fields, including engineering, science, and even art. BusinessTRIZ, on the other hand, is a specific application of TRIZ to business problems. In addition, BusinessTRIZ often involves using specific tools and techniques tailored to the business environment, such as value stream mapping, process optimization, and lean management. While TRIZ and BusinessTRIZ share similarities in their problem-solving approach, they differ in their specific focus and application.

Previous review articles on TRIZ have predominantly focused on its technical applications and integration with other tools for process improvement. For example, (Sojka & Lepšík, 2020) conducted a literature review that specifically examined using TRIZ and other tools for process improvement. Their review provided a year-wise analysis, showcasing the different combinations of TRIZ with other tools. Similarly, (Chechurin & Borgianni, 2016) took a different approach by reviewing other review papers to explore the scientific literature about TRIZ. They aimed to assess whether the questions posed in those reviews were adequately addressed. While their focus was also on the technical aspects of TRIZ, their study contributed to understanding the existing literature and identifying any gaps or unresolved questions.

To understand the benefits and challenges associated with TRIZ, (Ilevbare et al., 2013b) conducted a review to identify these factors through surveys and collecting first-hand information. Although their study provided valuable insights into the practical aspects of TRIZ, it did not specifically address the application of TRIZ in the business and management domain. Furthermore, (Hua et al., 2006) conducted a literature review from 1995 to 2006 to explore the integration of TRIZ with other creativity tools, methods, and philosophies. Their focus was again on the technical aspects of TRIZ and how it could be combined with different approaches to enhance problem-solving.

Despite these previous review articles, there remains a gap in the literature regarding comprehending TRIZ theory from a business and management perspective. None of the reviewed papers or other existing review articles has specifically delved into understanding TRIZ with a business and management focus or without a technical orientation. Therefore, the present study aims to fill this gap and outline how individuals without technical training can comprehend and engage with the theory of inventive problem-solving (TRIZ) in business and management.

Existing research context

Quality Function Deployment (QFD), Six Sigma, Product Development, Product Design, Project Management, Decision-making, Conceptual Design, Ecodesign, and Eco-Innovation are all areas of research and practice that are important in business and management. However, these are technical areas of business. Each area contributes to the overall process of creating and delivering products and services that meet customer needs and add value to the organization.

Table 1. Existing research context of TRIZ as per literature base

Context	References
Quality Function Deployment (QFD)	(Putri et al., 2018); (S. Kim & Yoon, 2012); (Chang, 2012); (Tursch et al., 2015); (Hsia et al., 2015); (Shanmugaraja et al., 2012); (Brad, 2009); (Shanmugaraja et al., 2013); (Ferryanto, 2015); (D. Lee et al., 2020)
Six Sigma	(Shanmugaraja et al., 2013); (Soti et al., 2012b); (Shanmugaraja et al., 2012); (Ferryanto, 2015); (D. Lee et al., 2020); (Soti et al., 2012a); (K. Yang, 2005); (Abu Bakar et al., 2015); (Karnjanasomwong & Thawesaengskulthai, 2019); (Gitlow et al., 2013); (Muruganantham et al., 2013); (Muruganantham et al., 2014)
Product Development	(Amang) Kim, 2018); (Russo et al., 2011); (F. Y. Zhang & Xu, 2007); (Akmal et al., 2018); (Guo et al., 2020); (Hua et al., 2007); (Da Silva et al., 2020); (Tursch et al., 2015); (Ferryanto, 2015)
Product Design	(Hsieh et al., 2016); (Bigand et al., 2011); (C. M. Yang et al., 2010); (C. J. Yang & Chen, 2011a); (Mansor et al., 2017); (OuYang & Weng, 2011); (Shahin et al., 2013); (Kandukuri et al., 2021)
Project Management	(Nassar & AbouRizk, 2016); (Monteiro, 2012); (Gazem et al., 2018)
Decision-making	(Karaulova & Bashkite, 2016); (Nikulin et al., 2018)
Conceptual Design	(Moehrle & Paetz, 2014); (Ai et al., 2020); (J. Zhang et al., 2005); (Cao & Tan, 2007); (Sakao, 2007a); (Wu et al., 2021)
Eco-design	(Negny et al., 2012); (Vidal et al., 2015); (Tsai et al., 2011); (C. J. Yang & Chen, 2011a); (Russo et al., 2014); (Russo & Birolini, 2012); (Spreafico, 2021)
Eco-Innovation	(Negny et al., 2012); (Vidal et al., 2015); (Tsai et al., 2011); (Jones et al., 2001); (de Jesus Pacheco et al., 2019)

Source: *Authors' interpretation*

D. Mann et al. (2000a) outline TRIZ's application to non-technical issues. He believes TRIZ can define or resolve issues in non-technical sectors like business and management. The application of TRIZ to aid businesses in surviving in the E-business space is discussed by D. Mann et al. (2001). Ruchti et al. (2002) conclude that TRIZ can be very helpful for making better business decisions. D. Mann et al. (2002) describe a new Contradiction matrix aimed at using TRIZ in business (See section 4).

TRIZ was primarily created to create products, but it has since begun to be adapted for the development of processes. The majority of research is therefore based on functional business areas, either technical or operational. Therefore, this research aims to provide a comprehensive guide demonstrating TRIZ interventions in business and management. As a result, using bibliometric analysis and subsequent in-depth review, the study offers a brief outline of how TRIZ evolved from being an engineering subject to a management subject. The study aims to demonstrate why more research is needed in the context of non-technical areas of businesses and organizations. This is because most papers have focused on the operational aspects of business, which are entirely technical.

RQ1: What are the current publication and citation trends in TRIZ in the business and management field?

RQ2: What are the most influential TRIZ articles and publication outlets (Journals) in business and management?

RQ3: Which are the most prominent authors and countries in the domain of TRIZ in the business and management field?

RQ4: What are the trending and futuristic research topics within the TRIZ research in the business and management discipline?

RQ5: What are the key highlights of TRIZ in a non-technical context? (Business TRIZ, application areas, tools)

2. Review Methodology

Synthesizing existing research is vital for expanding the corpus of knowledge (Arora & Chakraborty, 2021). Such scholarly work follows a systematic and objective approach, usually called a

'systematic literature review' (Kraus et al., 2020). Snyder (2019) stated that a systematic literature review could "serve as a basis for knowledge development, create guidelines for policy and practice, provide evidence of an effect, and, if well conducted, have the capacity to engender new ideas and directions for a particular field" (p. 339). These works also help academics to map out new research avenues for the future by taking stock of the past literature (Bacq et al., 2021). Academics who have excelled in review methods (Palmatier et al., 2018; Paul et al., 2021; Paul & Criado, 2020) have categorised several variants of domain-based (concept, context, discipline, field, outlet) (Kraus et al., 2022) systematic reviews, namely, framework-based reviews, structured theme-based reviews, bibliometric variant, hybrid reviews, and conceptual reviews, etc. (W. M. Lim et al., 2022).

A bibliometric variant of systematic literature reviews is employed for quantitatively evaluating scientific research objectively and visually presenting it (Donthu et al., 2021). It effectively maps structural and dynamic aspects of scientific research, explaining how a given subject has developed from its origins in a particular domain (Cobo et al., 2011). Two primary analytical approaches are frequently used in bibliometric analysis, namely, (1) Performance analysis, an evaluative technique for measuring productivity and impact, and (2) science mapping, a relational technique for unraveling intellectual structure (Mukherjee et al., 2022).

2.1 Review procedure

This review examines the performance and science (intellectual structure) of the research domain of the employment of TRIZ methodology in business and management discipline. To endow a structure in our review, we follow and adopt the framework implemented by Tiwary et al. (2021) [See Fig. 1]. We utilised Scopus and WOS databases for the literature search as these two databases cover most of the quality peer-reviewed journals in business and management (Bramer et al., 2017). We used all possible keywords related to 'TRIZ' and the boolean protocol to search the relevant literature in the purview (See Table 2). In the first level search, 4118 articles were found collectively from both databases (Scopus & WOS). After that, several filters were applied to the dataset, including document type, subject type, and language filter (English only) (See Fig. 1). The application of filters and then the removal of duplicates led to the final dataset, comprising 253 peer-reviewed journal articles.

Several bibliometric techniques like performance analysis, co-word analysis, and enrichment technique (visualisation) were applied to the retrieved dataset (Mukherjee et al., 2022). These analyses were performed using software recommended by (Donthu et al., 2021), i.e., bibliometrix-R (Aria & Cuccurullo, 2017) and Vosviewer (van Eck & Waltman, 2010).

Table 2. Keywords used for extracting articles

Search keywords	Articles (final corpus)	
"TRIZ" OR "Business TRIZ" OR "BusinessTRIZ"	WOS	Scopus
	18	235

Source: *Authors' interpretation*

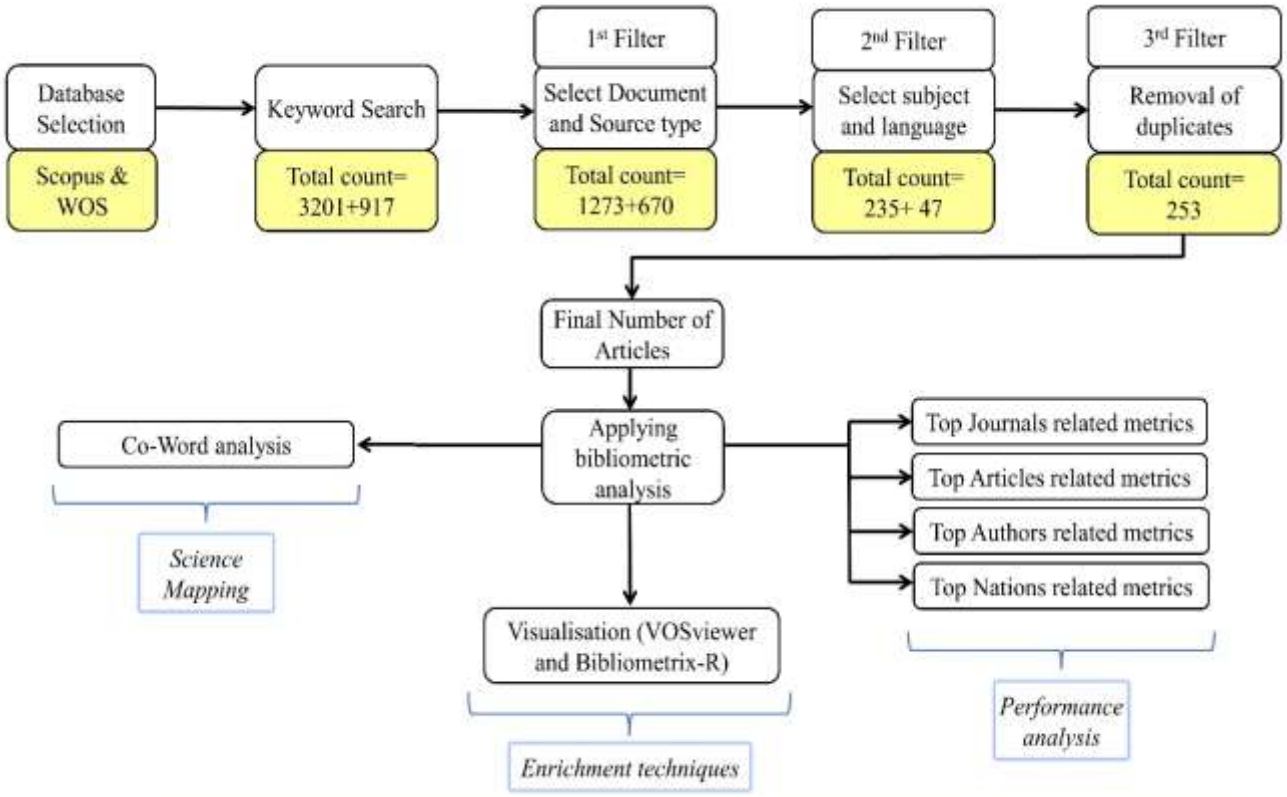

Fig. 1. Search and filtration strategy; ***Source:*** *Adapted from* Tiwary et al. (2021)

3. Results

3.1 Citation and publication trends (RQ1)

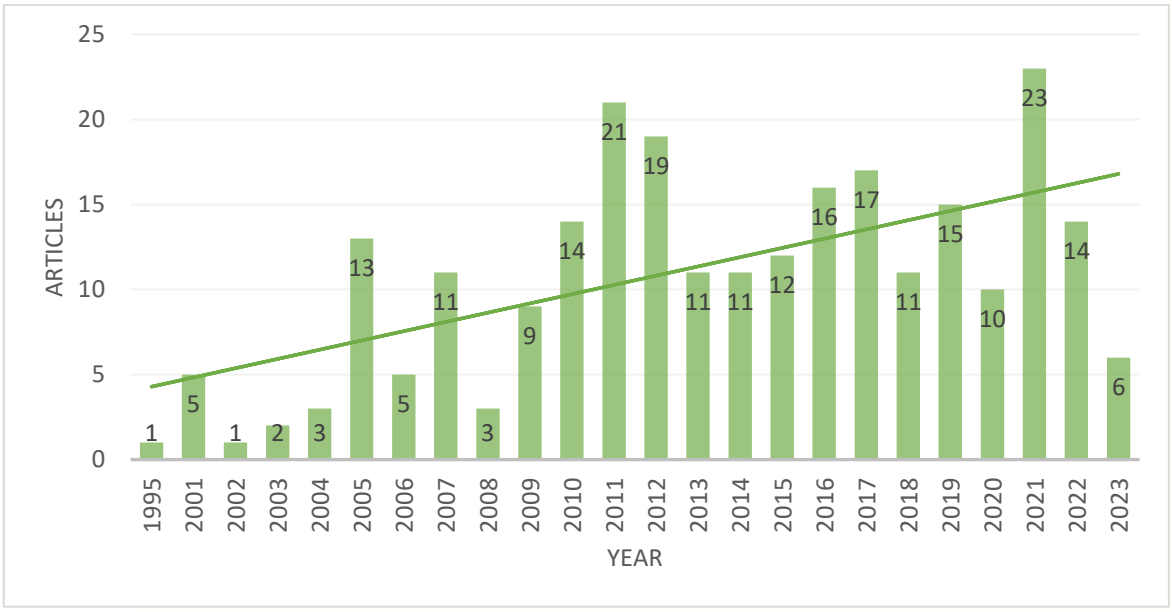

Fig. 2. Annual scholarly production; ***Source:*** *Authors' interpretation*

The publication and citation trends of TRIZ in business and management research are presented in Table 3.

In terms of publication, Panel A of Table 3 specifies that the coverage of TRIZ in business and management research spans 24 years (1995–April 2023) (NAY), comprising 253 articles (TP) that have been published in 78 different journals (outlets), with a production average of 6.61 publications per year (PAY). The significant percentage of total cited articles can be explained by the annual scientific production shown in Fig. 2, which shows that 196 articles have only been published in the last twelve years.

In terms of citation, the Panel B of Table 3 shows that the coverage of TRIZ in business and management research published between 1995 and April 2023 has garnered 3919 citations (TC), with a mean of 15.49 citations per publication (TC/TP), leading to the h index of 31, which indicates that 31 publications have garnered at least 31 citations.

Considering the above trend, it's evident that research work around TRIZ methodology has gained appreciation in recent years, especially in the year 2021. Businesses are now reimaging themselves after COVID-19, and the role of TRIZ becomes important in devising long-term sustainable strategies.

Table 3. Trends for citations and publications

Description	Results
Panel A. Publication metrics	
Total Publications (TP)	253
Total Cited Publications (TCP)	210
Total Sources (Journals)	78
Article (e.g., conceptual and empirical)	232
Review (e.g., critical and systematic reviews)	21
Number of active years (NAY)	18
Productivity per active year (PAY)	6.61
Panel B. Citation metrics	
Total Citations (TC)	3919
Average citations per publication (TC/TP)	15.49
h-index	31

Note: Period of coverage = 1995– April 2023
Source: Adapted from (Donthu et al., 2021)

3.2 Top Journals (RQ2)

Table 4. Top Journals publishing TRIZ research in Business and Management

Journal	Total publications	*h*	Total citations
International Journal of Systematic Innovation	56	5	86
Creativity and Innovation Management	21	11	337
Journal of Cleaner Production	16	12	547
Technological Forecasting and Social Change	13	8	380
International Journal of Product Development	13	6	288
International Journal of Production Research	8	7	502
International Journal of Productivity and Quality Management	8	5	78
International Journal of Six Sigma and Competitive Advantage	7	4	45
International Journal of Business Innovation and Research	6	5	51
Journal of Construction Engineering and Management	4	4	72

Source: *Authors' interpretation*

The top 10 Journals that have published the most articles on TRIZ in business and management research are presented in Table 4.

The table indicates that the 'International Journal of Systematic Innovation' has published the most articles (n= 56) with significant citations (n= 86). The second highest number of articles (n= 21) are published by the journal, 'Creativity and Innovation Management', garnering a high number of citations (n= 337). Other significant journals disseminating TRIZ research include the 'Journal of Cleaner Production', the 'International Journal of Business Innovation and Research' and the 'International Journal of Production Research'.

3.3 Top Articles (RQ2)

Table 5. Top Articles on TRIZ research in Business and Management

Article title	Author(s)	Total Citations
"A review of TRIZ, and its benefits and challenges in practice"	(Ilevbare et al., 2013c)	201
"A QFD-centred design methodology for environmentally conscious product design"	(Sakao, 2007b)	169
"Innovative product development process by integrating QFD and TRIZ"	(Yamashina et al., 2002)	161
"Enabling open innovation in small- and medium-sized enterprises: how to find alternative applications for your technologies"	(Bianchi et al., 2010)	146
"Computer-aided analysis of patents and search for TRIZ contradictions"	(Cascini & Russo, 2007)	119
"Accelerating preliminary eco-innovation design for products that integrates case-based reasoning and TRIZ method"	(C. J. Yang & Chen, 2011b)	118
"A TRIZ-based method for new service design"	(Chai et al., 2005)	111
"From TRIZ to OTSM-TRIZ: Addressing complexity challenges in inventive design"	(Cavallucci & Khomenko, 2007)	106
"Topic analysis and forecasting for science, technology and innovation: Methodology with a case study focusing on big data research"	(Y. Zhang et al., 2016)	103
"The theory of inventive problem solving (TRIZ) as option generation tool within cleaner production projects"	(Fresner et al., 2010)	90

Source: *Authors' interpretation*

The top ten articles for TRIZ in business and management research are presented in Table 5.

The table indicates that the article titled "A review of TRIZ, and its benefits and challenges in practice" by (Ilevbare et al., 2013c) is the TRIZ article from business and management discipline based on global citations (n= 201), followed by the article titled "A QFD-centred design methodology for environmentally conscious product design" by (Sakao, 2007b) (169 citations), and the articles titled "Innovative product development process by integrating QFD and TRIZ" by (Yamashina et al., 2002) and "Computer-aided analysis of patents and search for TRIZ contradictions" by (Cascini & Russo, 2007), each receiving over 100 citations.

3.4 Top Authors (RQ3)

Table 6. Top authors publishing TRIZ research in Business and Management

Author	Author's Affiliation	*h*	Total publications	Total citations
Tzong-Ru Lee	Marketing Department, National Chung Hsing University	4	8	40
D. Daniel Sheu	National Tsing Hua University	3	7	83
Martin G. Moehrle	University of Bremen	4	6	124
Darrell Mann	Systematic Innovation Network, Bideford, United Kingdom	3	6	97
Chun-Hsien Chen	Nanyang Technological University	2	6	9
Davide Russo	University of Bergamo, Italy	4	5	183
Arash Shahin	Department of Management, University of Isfahan	4	5	68
Runhua Tan	Hebei University of Technology	4	5	61
Yi Zhang	University of Technology Sydney, Australia	4	5	198
Alan L. Porter	Georgia Institute of Technology, Atlanta	3	5	171

Source: *Authors' interpretation*

Table 6 indicates that Tzong-Ru Lee from the National Chung Hsing University (UNM) is the most prolific author, with eight articles on TRIZ in business and management published in top journals. Martin G. Moehrle of the University of Bremen, Darrell Mann of Systematic Innovation Network and Chun-Hsien Chen of the Nanyang Technological University have six articles each, placing them third on the list of top contributing authors. On the list, the remaining authors have written five articles each. The domain has an immense scope to develop, particularly in terms of unique and rigorous research published in top-notch journals, as seen by the comparatively small number of publications linked with the top authors.

3.5 Top Countries (RQ3)

Table 7. Top countries disseminating TRIZ research in Business and Management

Country	Total Publications	Total Citations
China	75	928
USA	15	95
India	11	99
United Kingdom	9	343
Iran	8	78
Italy	8	339
Malaysia	8	98
Germany	7	345
Korea	7	103
Brazil	4	40

Source**:** *Authors' interpretation*

The top ten countries for TRIZ in business and management research are presented in Table 7.

As per the country metrics of 253 articles on TRIZ in business and management research retrieved from the Scopus and WOS databases, the top five countries disseminating research in the domain are

China (Seventy-Five articles), the United States (Fifteen articles), India (Eleven articles), United Kingdom (Nine articles), and Iran (Eight articles).

Based on the seminal papers and the above trends, it has been observed that TRIZ is being applied and integrated across a wide range of contexts and domains to foster innovation, improve problem-solving, and address challenges. Applied to various fields, including design, open innovation, patent analysis, complexity handling, and research forecasting, its versatility and a systematic approach make it suitable for many different applications. However, none of the papers specifically address business TRIZ or nontechnical domains.

3.6 Co-word analysis of keywords (RQ4)

The justification for employing co-word analysis is that an author's keywords adequately describe the topic of an article and reveal major topics of interest (Callon et al., 1983; Comerio & Strozzi, 2019). (Donthu et al., 2021) describe the assumption of Co-word analysis by stating that "words that frequently appear together have a thematic relationship with one another" (p. 289).

Fig. 3. presents the co-word analysis that displays our dataset's most recurring keywords. Using a threshold of 5 recurrences, We identified the 27 most frequently occurring terms out of 1275 keywords. As per our expectations, 'TRIZ', which forms the conceptual and theoretical background of all TRIZ-based research, arises as the most occurring term (n = 131). The current domain under review observes that the term 'TRIZ' is complemented by keywords related to business and management, such as 'product design' (n = 25), 'product development' (n = 13), 'quality function deployment' (n = 09), 'customer satisfaction' (n = 05), and 'decision making' (n = 08) (see Fig. 3). These terms appear together to show the relevance of TRIZ to business and management.

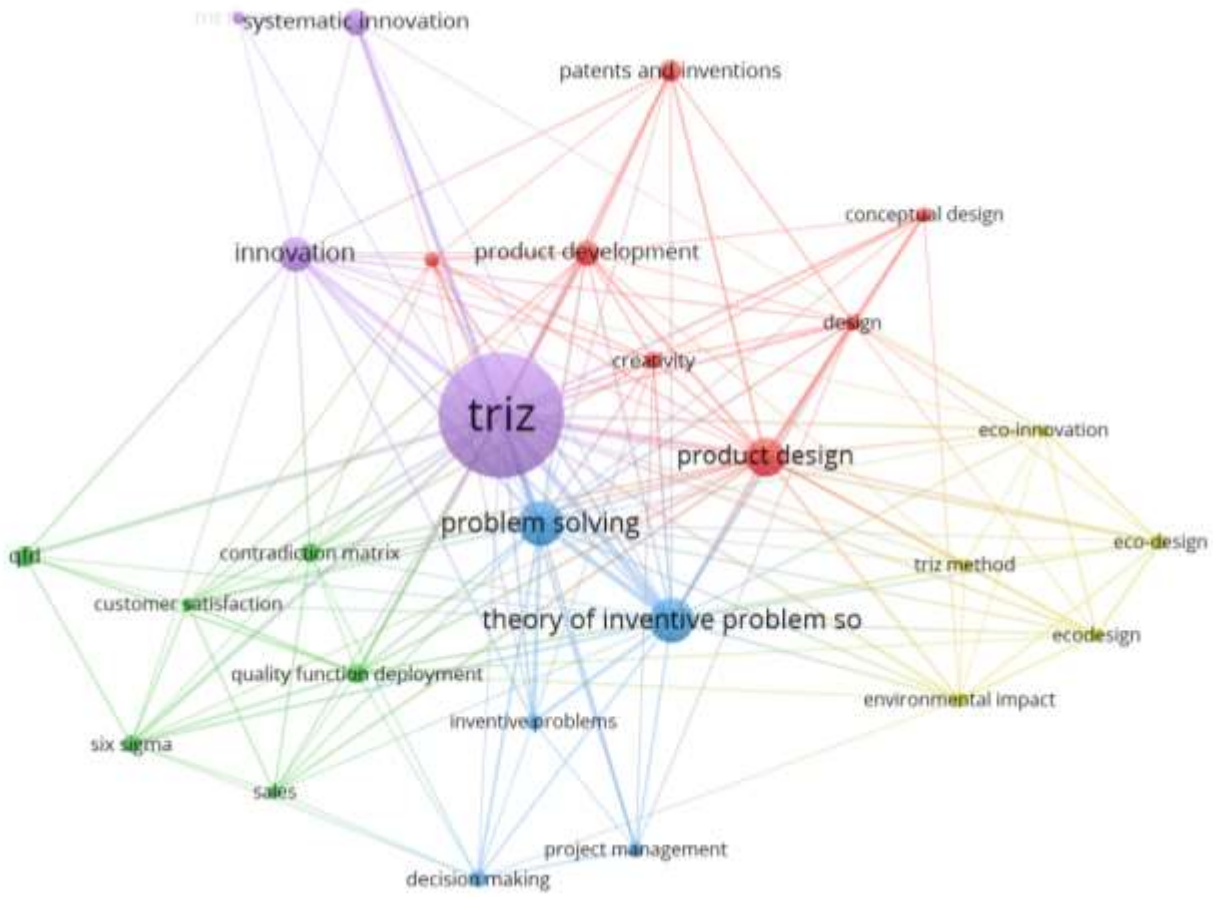

Fig. 3. Visualisation of Co-word network; ***Source:*** *VOSviewer*

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Moreover, we complement our co-word analysis with a word cloud formed using title keywords. This review employed the bibliometrix-R software to generate a word cloud.

The word cloud in Fig. 4 shows the frequency of terms gathered from the titles of the 253 chosen articles. When the displayed keywords are observed in the word cloud, the top keywords were all found to be connected to the research domain (TRIZ, innovation, design, service industry etc.).

Fig. 4. Word Cloud; ***Source:*** *Bibliometrix-R*

Furthermore, we also complement our co-word analysis with a treemap formed using abstract keywords. This review employed the bibliometrix-R software to generate a treemap.

The treemap in Fig. 5 shows the importance and occurrence of terms gathered from the abstract of the 253 chosen articles. Fig. 5 also displays the treemap depicting that “TRIZ” has 15% occurrences, whereas the keywords “problem-solving” and “product design” have 10% and 7% occurrences, respectively.

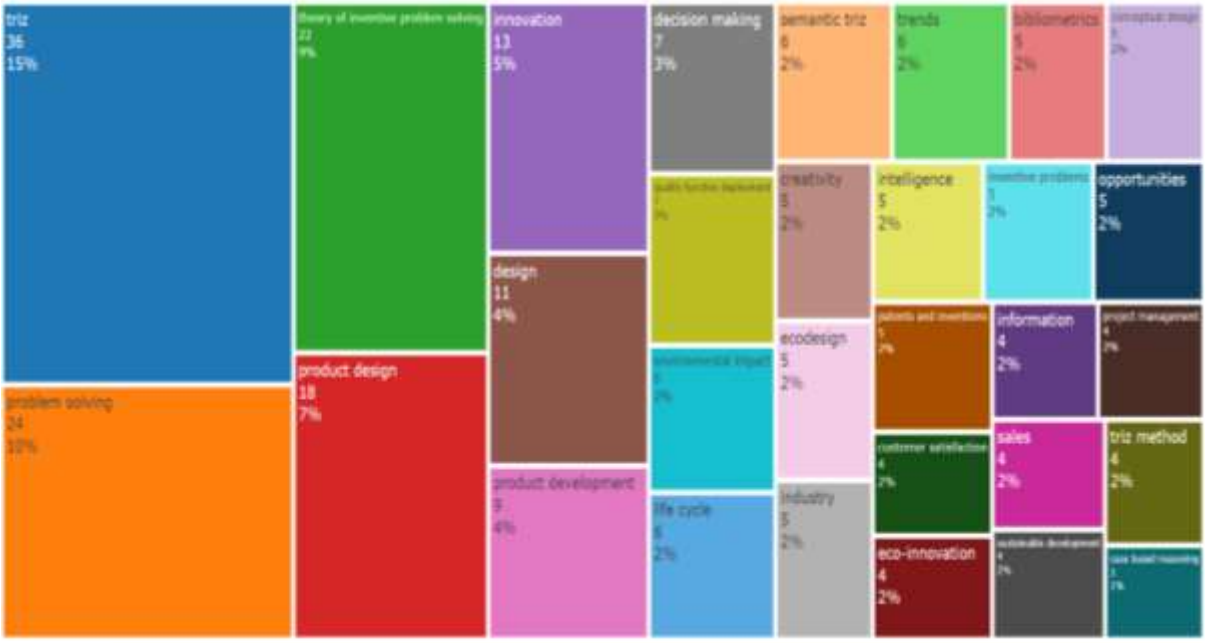

Fig. 5. Tree Map: ***Source:*** *Bibliometrix-R*

An analysis of the bibliometric data on TRIZ reveals that the focus of TRIZ is in the technical or engineering domain, with the majority of words (Fig. 4 and 5) showing usage in product design, product development, and innovation. To comprehend how TRIZ began as a problem-solving strategy in the business and management spheres, a thorough review of BusinessTRIZ has been done.

4. Conceptual Review (RQ5)

The hit-and-trial method is most commonly used to solve problems creatively. However, the method has significant limitations that limit its ability to generate innovative ideas, such as functional fixedness (psychological inertia), time waste, low ideas per unit of time, and, most importantly, no direct mechanism (Dung, 1995; Hentschel, 2009). TRIZ proposes overcoming these limitations, and compromise-based thinking approaches (D. Mann, 2001a). TRIZ is an idea-generation technology that supports creativity and innovation (Wang, 2019). The use of TRIZ is dependent on the nature of the problem. The TRIZ methodology is based on five problem-solving principles: contradiction, ideality, functionality, resource use (resource is anything in the system that is not being used to its maximum potential) and space-time interface (C. Lim et al., 2018). TRIZ works best in groups and prevents conceptual conflicts in individual reasoning.

Furthermore, it is appropriate for problems of a higher level of difficulty. The methodology is based on heuristics previously proven as certified solutions to problems associated with various categories (Schöfer et al., 2018). TRIZ involves systematically constructing system thinking through specified application methods (Da Silva et al., 2020; Dung, 1995). TRIZ is based on an abstraction process in which specific problems are abstracted into general problems, and then solutions are identified for those generic problems. Then, to meet the demand of the specific problem, these generic solutions are abstracted into specific solutions (Stratton & Mann, 2003).

Altshuller organized his knowledge of global patent literature into inventive problems by organizing them into contradiction tables, sets of inventive principles, and standard solutions to solve problems scientifically and innovatively in any field (Hipple, 2005). Based on the problem investigated, the methodology can be further classified into three major categories:

1. Standard Solutions: This category of Altshuller's methodology involves identifying and applying solutions successfully implemented in the past for

similar problems. These solutions are documented and cataloguised in a "standard solutions" database, which can be used to solve problems quickly.

2. Inventive Principles: This category involves using a set of 40 inventive principles developed by Altshuller to systematically generate new ideas for solving problems. These principles can be applied to various fields and industries to generate innovative solutions.
3. Contradiction Matrix: This category involves identifying and resolving contradictions that exist within a problem. Altshuller developed a matrix that contains 39 parameters, each with its own set of inventive principles to solve contradictions. By identifying the parameters and applying the appropriate principles, one can systematically generate solutions to complex problems.

4.1 Business TRIZ

The TRIZ toolkit originally comprised 40 principles to solve contradictions by matching 39 parameters. However, to apply the theory to business and management problems, Darrel Mann has proposed a generic matrix for technical, business, and software applications. Mann re-articulated the 39 parameters into 48 business parameters and re-explained the classical contradiction matrix based on "physical parameters", "performance-related parameters", "efficiency-related parameters", "ility (reliability, durability, etc.) related parameters", "manufacture-cost reduction parameters", "measurement related parameters" (D. Mann, 2005a). W. Edward Deming's concept that the production of goods and services is termed as a process, and the entire process is segmented based on certain attributes was acknowledged while formulating the business version of the contradiction matrix; "physical attributes", "time attributes", "risk attributes", "cost attributes", and "interface attributes" were selected to draw out 31 business-related parameters for the business contradiction matrix (D. Mann & Spain, 2008).

4.2 Business Contradiction Matrix

The 'Matrix for Resolving Technical Contradictions' was initially released as a 39x39 version in 1971 and was made freely accessible (Table 7; 1st column). It remained unchanged until the late 1990s when CREAX decided to update the tool. This effort resulted in the 2003 version, which notably expanded the matrix's parameters from 39 to 48 (Table 7; 2nd column). In 2006, a decision was made to reissue the Matrix once its accuracy dropped below 95% (D. Mann et al., 2005). This occurred in 2010, leading to the publication of Matrix 2010. By then, a significant part of the research had been automated, enabling the development of software tools to identify conflicts and contradictions. Matrix 2010 incorporated two additional parameters, reflecting the growing importance of addressing 'intangibles'. In 2018, the latest version (D. Mann, 2018a), Matrix 3.0 for business situations, was released, redefining the matrix's parameters from 31 to 45 (Table 7; 3rd column). And now, the most recent release, Matrix 2022, is an app. This app allows users to access the relevant frequency-impact graph for each matrix box, offering a more advanced and interactive experience (D. Mann, 2021).

However, the business version of the contradiction matrix works similarly to the traditional TRIZ contradiction matrix. The user is urged to consider the parameter they want to enhance and the parameter that will suffer due to the improvement. The numbers in the boxes that indicate the junction of the improving and deteriorating characteristics represent the creative techniques as TRIZ concepts that other management professionals have applied. The symmetrically constructed matrix also assisted in the abstraction process. The parameters for the business version of the contradiction matrix are segmented using "physical attributes", "time attributes", "cost attributes", "risk attributes", and "interface attributes" (D. Mann & Spain, 2008).

The business version of the Contradiction Matrix is a variation of the TRIZ Contradiction Matrix specifically designed to help businesses solve problems related to improving their processes, increasing efficiency, and reducing costs. While the traditional TRIZ Contradiction Matrix is focused on engineering and technical problems, the business version considers the unique challenges businesses face. It provides solutions that are more applicable to the business world.

The business version of the matrix also includes a different set of parameters than the traditional matrix. For example, instead of parameters related to mechanics or physics, it includes parameters such as "time," "information," and "cost."

Furthermore, the business version of the matrix emphasizes the importance of finding solutions that not only solve the problem at hand but also add value to the business. This is achieved by considering each solution's potential benefits and drawbacks and selecting the one that offers the best overall outcome for the business. Overall, while the business version of the Contradiction Matrix is based on the same principles as the traditional TRIZ matrix, it is adapted to meet businesses' specific needs and challenges and provides more relevant and applicable solutions to the business world.

4.3 TRIZ parameters

TRIZ parameters refer to a system's specific characteristics or attributes that can be modified or optimized to solve a problem. Several sets of TRIZ parameters exist, including the 40 Principles of TRIZ and the Contradiction Matrix. In the 1960s, the Soviet TRIZ research team created the Contradiction Matrix. It was merely a 39x39 matrix, as opposed to a 48x48 matrix, and it has quite a few empty squares where the study team lacked sufficient data to produce a statistically significant ranking of Principles. It has also been reported that Darrel Mann and Simon DeWulf updated the contradictions matrix with 50 parameters (D. Mann & Dewulf, 2016). Thirty-one parameters have also been rearticulated into 45 parameters per the updated business contradiction matrix.

Generic TRIZ parameters apply to various fields, including engineering, science, and arts & humanities. These parameters focus on improving a system's functionality and efficiency, including characteristics such as weight, shape, speed, and material properties. Business TRIZ parameters, on the other hand, are tailored specifically to business problems and processes. They focus on improving the efficiency and effectiveness of business processes and may include characteristics such as lead time, cycle time, cost, quality, and customer satisfaction. While both sets of parameters share some similarities, such as the emphasis on improving efficiency and functionality, they differ in their specific focus and application. Generic TRIZ parameters are more broad-based and can be applied to various fields. In contrast, Business TRIZ parameters are more tailored to the specific needs and challenges of the business environment.

Table 8. TRIZ parameters

Classical Contradiction Matrix Parameters (Domb et al., 2011)	**Re-sequencing Matrix Parameters (D. Mann & Dewulf, 2016)**	**Parameters identified for Business Matrix (D. Mann, 2005a)**
1. “Weight of moving object”	1. “Weight of moving object”	1. R&D Spec/Capability/Means
2. “Weight of stationary object”	2. “Weight of stationary object”	2. “R&D Cost”
3. “Length of moving object”	3. “Length of moving object”	3. “R&D Time”
4. “Length of stationary object”	4. “Length of stationary object”	4. “R&D Risk”
5. “Area of moving object”	5. “Area of moving object”	5. “R&D Interfaces”
6. “Area of stationary object”	6. “Area of stationary object”	6. Production Spec/Capability/Means
7. “Volume of moving object”	7. “Volume of moving object”	7. “Production Cost”
8. “Volume of stationary object”	8. “Volume of stationary object”	8. “Production Time”
9. “Speed”	9. “Shape”	9. “Production Risk”
10. “Force”	10. “Amount of Substance”	10. “Production Interfaces”
11. “Stress or Pressure”	*11. Amount of Information*	11. Supply Spec/Capability Means
12. “Shape”	12. “Duration of action - moving object”	12. “Supply Cost”
13. “Stability of the object's composition”	13. Duration of action - stationary object	13. “Supply Time”
14. “Strength”	14. “Speed”	14. “Supply Risk”

15. “Duration of action by a moving object”	15. Force/Torque	15. “Supply Interface”
16. “Duration of action by a stationary object”	16. Use of energy by moving object	16. “Product Reliability”
17. “Temperature”	17. Use of energy by a stationary object	17. “Support Cost”
18. “Illumination intensity” *(jargon)	18. Power	18. “Support Time”
19. “Use of energy by moving object”	19. Stress/Pressure	19. “Support Risk”
20. “Use of energy by stationary object”	20. Strength	20. “Support Interfaces”
21. “Power” * (jargon)	21. Stability	21. Customer Revenue/Demand/ Feedback
22. “Loss of Energy”	22. Temperature	22. “Amount of Information”
23. “Loss of substance”	23. Illumination Intensity	23. “Communication Flow”
24. “Loss of Information”	*24. Function Efficiency*	24. System-affected harmful effects
25. “Loss of Time” 26. “Quantity of substance/the matter”	25. Loss of Substance	25. System-generated side effects
27. “Reliability”	26. Loss of Time	26. “Convenience”
28. “Measurement accuracy”	27. Loss of Energy	27. Adaptability/Versatility
29. “Manufacturing precision”	28. Loss of Information	28. “System Complexity”
30. “External harm affects the object”	29. Noise	29. “Control Complexity”
31. “Object-generated harmful factors”	*30. Harmful Emissions*	30. Tension/Stress
32. “Ease of manufacture”	31. Object-Generated Side Effects	31. “Stability”
33. “Ease of operation”	32. Adaptability/Versatility	
34. “Ease of repair”	*33. Compatibility/Connectability*	
35. “Adaptability or versatility”	34. Ease of Operation	
36. “Device complexity”	35. Reliability	
37. “Difficulty of detecting and measuring”	36. Repairability	
38. “Extent of automation”	37. Security	
39. “Productivity” *	*38. Safety/Vulnerability*	
	39. Aesthetics	
	40. Object-affected harmful effects	
	41. Manufacturability	
	42. Accuracy of manufacturing	
	43. Automation	
	44. Productivity	
	45. System Complexity	
	46. Control Complexity	
	47. Ability to Detect/Measure	
	48. Measurement Precision	

Note: There are a number of parameters in the classic contradiction matrix that offer insights into optimizing the weight, length, area, volume, speed, force, stress, shape, stability, and strength of objects. As a business management tool, these parameters can be used to optimize product weights, process lengths, resource volumes, and speed and force of operations. They are useful for understanding business management strategies. They may help analyze and improve company operations, product development, supply

chain management, customer satisfaction, and overall performance.

Table 9. Following are the core articles focusing on conceptual learning of TRIZ in a Non-technical context

"An introduction to TRIZ: The theory of inventive problem solving"	2001	Creativity and Innovation Management	(D. Mann, 2001b)
"What is TRIZ? From conceptual basics to a framework for research"	2005	Creativity and Innovation Management	(Moehrle, 2005)
"The place of TRIZ in a holistic design methodology"	2001	Creativity and Innovation Management	(Knott, 2001)
"TRIZ: A creative breeze for quality professionals."	2006	Quality Progress	(Dew, 2006)
"TRIZ as an innovation management tool: Insights from academic literature"	2017	International Journal of Technology Marketing	(Teplov et al., 2017)
"TRIZ: Inventive Creativity Based On The Laws of Systems Development"	1995	Creativity and Innovation Management	(Dung, 1995)
"How Problems Are Solved in TRIZ Literature: The Need for Alternative Techniques to Individuate the Most Suitable Inventive Principles"	2018	Advances and Impacts of the Theory of Inventive Problem Solving: The TRIZ Methodology, Tools and Case Studies	(Borgianni et al., 2018)
"Can Altshuller's Matrix Be Skipped Using CBR and Semantic Similarity Reasoning?"	2018	Advances and Impacts of the Theory of Inventive Problem Solving: The TRIZ Methodology, Tools and Case Studies	(P. Zhang et al., 2018)
"TRIZ evolutionary approach: Main points and implementation"	2016	Research and Practice on the Theory of Inventive Problem Solving (TRIZ): Linking Creativity, Engineering and Innovation	(Berdonosov and Redkolis, 2016)
"Using TRIZ in management problems solving"	2021	Studies on Interdisciplinary Economics and Business	(Göçmen, 2020)
"Two Aspects of Function for Technical Systems"	2021	International Journal of Systematic Innovation	(Yong Won Song, 2021)
"Quantifying and Leading Innovation with TRIZ Within Competitiveness Strategies"	2018	Advances and Impacts of the Theory of Inventive Problem Solving: The TRIZ Methodology, Tools and Case Studies	(Brad & Brad, 2018)
"Using TRIZ in the social sciences: Possibilities and limitations"	2016	Research and Practice on the Theory of Inventive Problem Solving (TRIZ): Linking Creativity, Engineering and Innovation	(Schut, 2016)
"Systematic innovation for the retention and development of human talent"	2014	International Journal of Systematic Innovation	(C. Y. Huang & Abrego, 2014)
"An exploring of the path of management innovation based on conflict solving"	2007	Proceedings of 2007 International Conference on Management Science and Engineering, ICMSE'07 (14th)	(Dong-sheng et al., 2007)
"Someone, somewhere, really did already invent the wheel you're about to re-invent"	2005	7th International Value Conference 2005: Why Re-Invent the Wheel?	(D. Mann, 2005b)
"A or B' to 'A and B"	2001	Creativity and Innovation Management	(D. Mann, 2001a)

"Application of TRIZ Tools in a Non-Technical Problem Context"	2000	Systematic Innovation for Business Leaders' at TRIZCON2000.	(D. Mann et al., 2000a)
"Breakthrough Thinking With TRIZ For Business And Management: An Overview"	2007	ICG Training and Consulting	(Souchkov & Sutcliffe, 2007)
"Innovative Product Development and Theory of Inventive Problem Solving"	2008	TriSolver Consulting and TriS Europe GmbH	(Livotov, 2008a)
"Systematic Win-Win Problem Solving In A Business Environment"	2008		(D. Mann & Spain, 2008)
"TRIZ and Systematic Business Model Innovation"	2010	ETRIA Conference "TRIZ Future 2010"	(Souchkov, n.d.)
"TRIZ For Business: Application Of Rca+ To Analyse And Solve Business And Management Problems"	2007	TRIZ Journal	(Souchkov et al., 2007)
"TRIZ-based Innovation Principles and a Process for Problem-Solving in Business and Management"	2002	European TRIZ Association	(Ruchti et al., 2002)
"Using TRIZ to Overcome Business Contradictions: Profitable E-Commerce"	2001	Proceedings of TRIZCON2001	(D. Mann et al., 2001)

Source: *Authors' interpretation*

TRIZ provides 12 principles that address non-technical challenges encountered in business and management tasks. They serve as invaluable guideposts, illuminating the path to problem-solving mastery. These principles, rooted in the TRIZ methodology, provide a roadmap for navigating the complexities of business and management problem-solving. Individuals can better approach challenges creatively and strategically by engaging in these activities, resulting in innovative solutions and better decision-making (Ruchti et al., 2001). These include

1. **Combination and separation:** Combining and separating elements to achieve desired results.
2. **Symmetry and asymmetry:** Creating symmetry and asymmetry in elements is key to unlocking innovation.
3. **Homogeneity - Diversity:** Making the most of differences as a basis for ingenious problem-solving.
4. **Expansion - Reduction:** Optimal outcomes are driven by strategically expanding or reducing elements.
5. **Mobility - Immovability:** Applying immovability to elements to solve problems innovatively.
6. **Consumption - Regeneration:** Discovering new avenues by balancing element consumption and regeneration.
7. **Standardization - Specialization:** Achieving a solid problem-solving foundation by balancing standardizing and specializing elements.
8. **Action - Reaction:** Breakthrough solutions can be achieved by interplaying action and reaction within elements.
9. **Continuous action - Interrupted action:** Strategic lever between continuous and interrupted actions.
10. **Partial action - Excessive action:** Stimulating innovation by balancing partial or excessive action in elements.
11. **Direct action - Indirect action:** Investigating transformative possibilities in problem-solving via direct and indirect action.
12. **Preliminary action - Preliminary counteraction:** Finding effective pathways to desired results by navigating between preliminary action and counteraction.

The 40 inventive principles are further put into five categories providing a more streamlined and organized framework for understanding the different principles and their respective areas of focus.

Table 10. Inventive principles (Bozbura & Ersin, 2009)

Organizational Structure and Design	Talent Development and Empowerment	Change and Adaptability	Continuous Improvement and easurement	Strategic Alignment and External Considerations
• Segmentation • Taking Away • Local Quality • Asymmetry • Combining	• Universality • Nesting • Dynamicity • Equipotentiality • Self-Service	• Prior Counteraction • Prior Action • Early Cushioning • Otherway Round • Sphericity	• Partial or Excessive Action • Mechanical Vibrations • Periodic Action • Useful Action Continuity • Feedback	• Intermediary • Pneumatic and Hydraulic Structures • Changing Color • Strong Oxidizers • Inert Atmosphere • Composites

Source: *Authors' interpretation*

CreaTRIZ

CreaTRIZTM for Managers is a software tool for managers and businesses to eliminate contradictions (D. Mann & Dewulf, 2016). The underlying principle of the tool is that it abstracts and codifies the successful solutions or strategies of every field and makes them available to others for solving similar problems quickly (D. Mann, 2001a); (Zouaoua et al., 2010). Nevertheless, the problem with the tool is that it is not accessible openly to beginners of the TRIZ.

4.4 How has TRIZ been incorporated into different management functions?

Due to TRIZ's widespread applicability and strong potential for invention, the theory started applying to non-technical areas such as business and management (Ruchti & Livotov, 2001).

Table 11. Application of TRIZ in a non-technical context

"Collaborative tool for solving human factors problems in the manufacturing environment: The Theory of Inventive Problem Solving Technique (TRIZ) method"	2008	International Journal of Production Research	(Akay et al., 2008)
"Evaluating the impact of TRIZ creativity training: An organizational field study"	2012	R and D Management	(Birdi et al., 2012b)
"TRIZ for reverse inventing in market research: A case study from Wittenstein Ag, identifying new areas of application of a core technology"	2009	Creativity and Innovation Management	(Glaser & Miecznik, 2009a)
"Managing business model innovation: an innovative approach towards designing a digital ecosystem and multi-sided platform"	2021	Business Process Management Journal	(Hoch & Brad, 2021)
Applying TRIZ principles to construct creative universal design	2010	International Journal of Systematic Innovation	(Chun-Ming Yang et al., 2010)
"Developing a comprehensive brand evaluation system with the support of TRIZ to formulate brand strategies"	2017	International Journal of Business Excellence	(T.-R. Lee et al., 2017)
"TRIZ and the difficulties in marketing management applications"	2010	PICMET '10 - Portland International Center for Management of Engineering and Technology, Proceedings - Technology Management for Global Economic Growth	(Zouaoua et al., 2010)

"Marketing strategies of fishery products for supermarkets and farmers' markets in Taiwan"	2011	Journal of Food Products Marketing	(T.-R. (Jiun-S. Lee et al., 2011)
"TRIZ problem-solving model for multiple-to-multiple parameter contradictions using case-based reasoning"	2011	International Journal of Systematic Innovation	(D. Daniel Sheu & Chia Hung Chen, 2011)
"Negotiation of needs towards halal talents sustainability"	2022	Journal of Islamic Marketing	(Abdul Rahim et al., 2022)
"Design for the adjustable high heel"	2019	International Journal of Systematic Innovation	(Jyhjeng Deng & Teng-Hsuan Lin, 2019)
"The Effect of a Program Based on TRIZ Theory to Develop the Creative Thinking Skills Among Male Students with Mild Intellectual Disability"	2022	International Journal of Systematic Innovation	(Meshal Bader MalAllah et al., 2022)
"The sequence of strategies when establishing Taiwanese restaurant in Thailand"	2021	European Business Review	(T.-R. Lee et al., 2021)
"Application of TRIZ in Literature; an Algorithm for Systematic Story Writing Based on Mega Problems"	2021	International Journal of Systematic Innovation	(Ali Mohammadi & Ahmad Forouzanfar, 2021)
"Exploring the formulation of book pricing strategies in economics with a TRIZ approach to business management"	2020	International Journal of Systematic Innovation	(Su-Chen Huang, 2020)
"TRIZ/CrePS Approach to the Social Problems of Poverty: 'Liberty vs Love' Is Found the Principal Contradiction of the Human Culture"	2018	Advances and Impacts of the Theory of Inventive Problem Solving: The TRIZ Methodology, Tools, and Case Studies	(Nakagawa, 2018)
"Research on the strategy and implementation in stages of organizational learning based on TRIZ theory"	2009	IE and EM 2009 - Proceedings 2009 IEEE 16th International Conference on Industrial Engineering and Engineering Management	(Sui et al., 2009)
"Teaching disadvantage as an appearance of contradiction in basic TRIZ education"	2014	International Journal of Systematic Innovation	(Yuriy Danilovskiy et al., 2014)
"Innovative design of customized fashion handbags"	2013	International Journal of Systematic Innovation	(Lin Chin-Min et al., 2013)
"Enhancing workplace safety with TRIZ"	2012	2012 IEEE 6th International Conference on Management of Innovation and Technology, ICMIT 2012	(Thanabalu et al., 2012)
"Business model innovation of enterprises by physical contradiction means of TRIZ"	2009	Proceedings - 2009 International Conference on Electronic Commerce and Business Intelligence, ECBI 2009	(Yonghai & Jianhua, 2009)

Source: Authors' interpretation

Note; Based on the analysis of applications of TRIZ in non-technical contexts, the following insights emerge: Traditional TRIZ has been used in technical fields but has increasingly been applied to non-technical fields such as manufacturing, marketing, literature, education, fashion, workplace security, and business models. The tool promotes innovation in these fields as well as solving problems. The application of TRIZ in non-technical domains includes enhancing creative thinking, inspiring innovative designs, improving workplace safety, facilitating organizational learning, addressing cultural and social challenges, and formulating strategies. Researchers found that TRIZ is effective and versatile beyond technical

applications, demonstrating its adaptability and potential in non-technical contexts.

Darrel Mann 1999 identified the need for TRIZ theory for solving business and management problems as the technical and non-technical fields are two sides of a single coin (Slocum & Lundberg, 2001). In his study, D. Mann (2001a) presented the concept of 'win-win' situations for the business environment to overcome limiting contradictions by eliminating them rather than making compromises by giving an example of a contradictory situation between mass customisation and mass production. The different management functions that have harnessed the potential of TRIZ methodology are as follows:

- **Marketing:** TRIZ has also been used for marketing and branding strategies. (T. R. Lee et al., 2017) developed a brand evaluation system by combining TRIZ theories and brand-building theories such as Keller's brand-building stages, brand equity pyramid, brand report card, and balanced scorecard.
- **Sales and advertising:** A brief methodological description of TRIZ theory in marketing, sales, and advertising was given by (T. R. Lee et al., 2011). They performed a SWOT analysis to identify contradictions and understand the stores and their situation and then applied TRIZ to develop sound strategies for the commercial district. A questionnaire-based survey was also conducted to assess the viability of the proposed strategies.
- **Product customization:** From technology forecasting and placing products in the product lifecycle category according to technical or physical contradictions, TRIZ has now been used in customized fashion accessories such as handbags (Chin-Min et al., 2013) and pivotal high-heel shoes with dual functionality (Deng & Lin, 2019)
- **Human resource management:** C. Y. Huang & Abrego (2014) have even used TRIZ for human resource retention and development of human talent. A business contradiction matrix solved the human retention issues, abstracting problems through business parameters. Several tools of TRIZ were utilized, such as "nine windows' for problem analysis, function-attribute analysis for problem modelling and formulation, contradiction analysis to find cause and effect relationships and root problems, and finally, 40 inventive principles to formulate strategies for human retention and talent development.
- **Patent and inventions:** (Glaser & Miecznik, 2009b) harnessed the strength of reverse inventing to find additional business segments through patent literature databases. The company's core strengths and competencies have been identified in the process. Then by utilizing 39 TRIZ parameters, these strengths and competencies are matched with those principles to identify keywords for searching the patent database. Then target markets are selected according to the identified databases or customer segments included under those IPs. A similar case of patents and inventions was practised by D. Mann & Cole (2010) to forecast the worth of intellectual property by focusing on dynamization trends and evolution maps that would help companies to find out where their intellectual property is standing in the present and how will be its future trends and assessing the potential of future evolutions. The study is highly technical in assessing 3 million data points to develop algorithms for studying future evolution trends of IP held within the particular industry.
- **Business model innovation:** (Hoch & Brad, 2021) proposed an architectural framework for systematic business model innovations by combining a design science approach (DSR) and TRIZ to advance innovations by considering factors that affect the business internally and externally. Semi-structured interviews were conducted with professionals associated with the construction business to gain feasible solutions. The System operator technique (SOT) of TRIZ and the blue ocean framework were used for problem analysis, solution generation, and outcasting competition to conceptualize a framework for the business model.
- **Design and strategy:** The design domain provides a sequential picture of the innovation process and highlights the major innovation activities but does not show the strategic influences. TRIZ fills this gap. The strategic framework is addressed by models from the business and management domains, but they are too abstract to benefit business people. (Frobisher, 2021) bridged this gap through IDEFØ modelling proved in the electric car market. Fast Moving Consumer Goods (FMCG), Automotive, Agriculture, Fisheries, City Planning, and Sustainability can apply the innovation approach.

The 31 parameters explicitly designed for the business and management field have also been practised. (S. C. Huang, 2020) developed e-book pricing solutions by resolving contradictions based on 31 business parameters. However, the idea includes flaws, such as a company's financial inability because entrepreneurs must finance the price of outsourced R&D to bring scientific organizations on board. Likewise, Chybowska et al. (2019) illustrated the concept of Biz-TRIZ and demonstrated it through an SME and its associated challenges. TRIZ has a high potential in the creation phase of any service or product development, which creates a factor that necessitates investment. Rolls-Royce has picked TRIZ as one of 11 fundamental tools for Integrated Project Teams; the goal is to change people's minds, with around 200 people taught thus far. As a result, TRIZ is frequently done in groups at Rolls-Royce (Knott, 2001).

4.5 TRIZ methodology description for business and management-related problems:

Referring to T. R. Lee et al. (2011) and Moehrle & Wenzke (2006), the steps that are involved in applying the TRIZ technique to create inventive solutions to the problems are as follows:

1. The primary and foremost requirement is to analyze problems properly; there are also situations where appropriate data is unavailable. Then, in such situations, questionnaires-based surveys or in-depth interviews can be conducted better to understand the problems and target population concerning the problem. In addition to surveys and interviews, collecting data and information from various sources, including market research, customer feedback, and industry reports, is essential. This data can be used to understand the problem better and identify potential solutions.
2. However, as far as this review is concerned, TRIZ works on specific problems. Therefore, there has to be a refined problem statement formulated.
3. For further problem analysis, several tools are available (function analysis, su-field analysis, root conflict analysis, and cause-and-effect analysis). However, they require expert guidance to get accurate results and work best in teams. While expert guidance is necessary for some more complex analysis tools, online resources, and software programs can assist with problem analysis. These tools can help identify the problem's root cause and uncover hidden opportunities for innovation.
4. During problem analysis, contradictions are found. Business and management problems mainly contain physical or technical contradictions.
5. When contradictions are made available, one can relate them to the 31 parameters of business and management given by Darrel Mann (D. Mann, 2005a). In addition to physical or technical contradictions, business and management problems may involve contradictions between stakeholders, conflicting priorities, or resource constraints. Identifying these contradictions is essential to finding effective solutions.
6. Then, a business matrix based on 31 business parameters proposed by Darrel Mann can be referred to find out the suggested TRIZ principles as solutions. All the 40 TRIZ principles are explained in business terminology by (*The TRIZ Journal – TRIZ Methodology, Tools, Articles and Case StudiesThe TRIZ Journal | TRIZ Methodology, Tools, Articles and Case Studies*, n.d.). The 31 business parameters proposed by Darrell Mann cover a wide range of areas, including quality, cost, speed, innovation, and sustainability. Selecting the parameters most relevant to the problem being addressed is essential.
7. After identifying the relevant TRIZ principles, evaluating and prioritising them is essential based on their potential effectiveness in solving the problem. This requires understanding the resources available, the feasibility of implementing the solution, and the potential impact on the business. This step involves weighing the potential benefits of each TRIZ principle against the costs and risks of implementing them. It may be necessary to conduct a cost-benefit analysis or other feasibility studies to evaluate the potential impact of each solution.
8. Once the most promising TRIZ principles are identified and prioritized, developing and implementing a solution plan is essential. This involves determining the necessary resources, assigning responsibilities, and establishing a timeline for implementation. The implementation plan should be comprehensive and include details on how the solution will be executed, who will be

responsible for each task, and when each task will be completed. It is also essential to establish a system for monitoring progress and making adjustments as necessary.

9. Finally, evaluating the solution's effectiveness and making necessary adjustments is crucial. This may involve measuring the solution's impact on key performance indicators, soliciting stakeholder feedback, and making changes based on feedback and analysis. Regular evaluation and adjustment are critical to ensuring the solution remains effective. This may involve gathering feedback from stakeholders, analyzing performance metrics, and making necessary changes to the solution.
10. It is also important to note that TRIZ methodology is not a one-time solution but an ongoing process of innovation and continuous improvement. As such, businesses should incorporate TRIZ into their overall innovation strategy and regularly revisit and refine their solutions based on changing business needs and market conditions.

4.6 How can the data be collected to find out contradictions?

Lin Y.-J. and Deng J. (2018) used questionnaire-based interviews to find out the service quality required to be improved in convenience stores, in-depth interviews conducted to observe the problems faced by older people in taking off their shoes, interview experiments and usage of anthropometric data by (Hu S.-J., 2019) are some of the methods used to find contradictions. Where contradictions were known, value or functional analysis was used to improvise product usage (Lin M.-C., Hung Y.-C., 5 C.E.). Analyzing documents such as reports, financial statements, or customer feedback can provide insights into the challenges and contradictions within the business process. Benchmarking involves comparing a business process's performance to other similar processes in the industry. This can help identify areas where the process is falling behind and provide insights into potential solutions. Collecting data for finding contradictions in non-technical areas such as business and management requires a combination of quantitative and qualitative methods and an understanding of the process's specific challenges and goals.

4.7 Types of Tools

Two categories of tools are used to identify and solve problems: analysis and knowledge-based. Analysis tools and knowledge-based tools are used in different stages of problem-solving and innovation. Here's a brief overview of when each type of tool is typically used:

- Analysis Tools: Analysis tools are used primarily in the problem identification and definition stage of problem-solving. They are used to gather and analyze data about the problem and to identify its underlying causes and contributing factors. Common tools include root cause analysis, fishbone diagrams, Pareto charts, and statistical process control charts (Mueller, 2005).
- Knowledge-based Tools: Knowledge-based tools are used primarily in the problem-solving solution generation and selection stage. They are used to generate and evaluate potential solutions to the problem based on established knowledge and principles. Knowledge-based tools include techniques such as TRIZ, a systematic innovation methodology based on the analysis of patterns of problems and solutions, and design heuristics, which are rules of thumb for designing products and systems that have been effective in practice. TRIZ contains a strong knowledge base from different fields of science, such as geometry, chemistry, physics, and even biology (Dung, 1995). The most well-known creative thinking tools are creative problem solving, Synectics, TRIZ, and Six thinking hats (Puccio et al., 2006). TRIZ is applicable in problems that cannot be solved in a simple procedural way.

Table 12. TRIZ Tools in Non-technical Context

"The integration of TRIZ with other ideation tools and processes as well as with psychological assessment tools"	2005	Creativity and Innovation Management	(Hipple, 2005)
"Improving new product development innovation effectiveness by using problem-solving tools during the conceptual development phase: Integrating Design Thinking and TRIZ"	2020	Creativity and Innovation Management	(Da Silva et al., 2020)
"MorphoTRIZ - solving technical problems with a demand for multi-smart solutions"	2010	Creativity and Innovation Management	(Moehrle, 2010)
"The TRIZ resource analysis tool for solving management tasks: Previous classifications and their modification"	2005	Creativity and Innovation Management	(Mueller, 2005)
"Cause-and-effect function analysis"	2010	5th IEEE International Conference on Management of Innovation and Technology, ICMIT2010	(H. Kim et al., 2010)
"Lessons for TRIZ from Design Thinking and Lean 3P"	2018	Advances and Impacts of the Theory of Inventive Problem Solving: The TRIZ Methodology, Tools, and Case Studies	(Halas, 2018)
"New and emerging contradiction elimination tools"	2005	Creativity and Innovation Management	(D. Mann, 2005a)
"Systematic organizational conflicts identification and resolution using perception mapping and function relationship analysis"	2014	International Journal of Systematic Innovation	(Sheu & Tsai, 2014)
"A method for applying TRIZ to enhance brainstorming"	2011	51st Annual Conference of SAVE International 2011	

Source: Authors' interpretation

- Su-field (substance) analysis - This tool belongs to the Contradiction Matrix category, which identifies and resolves contradictions in a problem. This technique (also known as vepol analysis in Russia) is used to define problems into standard (Familiar) and non-standard (Unfamiliar) problems (Dung, 1995; Regazzoni & Russo, 2011).
- Functional analysis - This tool also belongs to the Contradiction Matrix category, as it is used to identify the functions required by a system and the potential conflicts that may arise between them. Function analysis assesses identifying contradictions within the system by presenting an interconnected diagram depicting the harmful and useful functions of the system (Moehrle, 2010). For companies' smooth application of function analysis, Ideation International (2000) has developed a software tool called 'Problem Formulator™' (Moehrle & Wenzke, 2006). Functionality is used in the early stages of the problem-solving process. The primary goal of functional analysis is to identify the functions a system requires and the potential conflicts that may arise between them. This process involves breaking down the system into its components and analyzing how each part contributes to its overall function.
- Algorithm for inventive problem solving (ARIZ) - This tool is part of the Inventive Principles category and is a systematic approach for generating innovative solutions to problems. Algorithm for inventive problem solving (ARIZ): When the problem is non-standard or unfamiliar, ARIZ is used as the technique also includes an element of psychology not just based on laws of evolution and technical systems (Dung, 1995; Navas et al., 2015).
- 76 Standard Solutions; 76 standard rules of TRIZ - These tools belong to the Standard Solutions category, which involves identifying and applying solutions that have been successfully implemented in the past for similar problems (Da Silva et al., 2020; Dung, 1995).

- 40 Inventive Principles - This tool is also part of the Inventive Principles category and involves using a set of 40 principles to generate new and innovative solutions to a problem. The tool comes under the idea generation phase and follows a divergent thinking style (Birdi et al., 2012a).
- Contradictions - This tool is part of the Contradiction Matrix category and involves identifying and resolving contradictions that exist within a problem. TRIZ works with three types of contradictions: administrative contradictions (where the problem is only known), technical contradictions (where a change in one characteristic degrades the other), and physical contradictions (where two mutually contradictory states are present within a system) (Dung, 1995; Ilevbare et al., 2013a). Contradictions can already be established where problems are known or articulated using any problem analysis technique, such as function analysis, cause and effect diagram, force field analysis, or root cause analysis (RCA).

Contradictory conditions: The main task of problem analysis is to identify contradictions and to do so, three conditions must be met:

- What is the desired problem characteristic?
- There is an established method for achieving that characteristic.
- Some deteriorating characteristics must result from using the traditional method (Moehrle, 2005).

"Contradiction's examples for e-business: I want lots of inventory to have many choices for my customers ready to ship as soon as the customer orders something, but I want no inventory to have no carrying costs, no warehousing costs, and no surplus inventory if a particular product is not popular.

Solution: A b-web consists of customers, suppliers, and the organizing company, linked so that a customer order triggers suppliers to provide the parts needed to build that specific order".

- Ideality - This tool also belongs to the Contradiction Matrix category. It involves identifying a system's ideal state and the contradictions between the current and ideal states. TRIZ methodology works on the principle of ideality (J. Zhang et al., 2005) and works for achieving ideal final results (IFR) without the least negative effects (Hipple, 2005). "The degree of ideality is defined as useful functionality of a system minus all negative factors that diminish its value and divided by costs" (Souchkov & Sutcliffe, 2007). Systems evolved to the level of ideality by resolving contradictions and using system resources (Hipple, 2005). The ideal final result in customer terms can be "ease of accessing products a service without harm and cost" (D. Mann et al., 2000b).
- Patterns of evolution or Evolutionary trends - This tool belongs to the Patterns of Evolution category, which involves identifying the trends and patterns of how systems evolve and using this knowledge to generate innovative solutions. According to TRIZ, the technical system operates on clearly defined patterns that evolve through time, allowing for predicting trends and optimum solutions to issues (Ilevbare et al., 2013a; Livotov, 2008b). Biological evolution, increasing ideality, dynamisation and controllability, complexity-simplicity, evolution with matching and mismatching elements, non-uniform development, the evolution toward micro-level and the use of the field, and decreased human involvement are among the eight original trends identified by Altshuller (Slocum & Lundberg, 2001).
- Perception Mapping Method - This tool belongs to the Functional Analysis category, which is used to identify the functions required by a system and the potential conflicts that may arise between them. Perception mapping is an exploration of how different perceptions interact with each other. According to Darrell Mann, "lead to" relationships and establishing "Perception Mapping" can link various perceptions from different departments. Perception Mapping differentiates three chain modes: loop, collector, and conflict, giving individual perceptions different weights. Finally, creative concepts and a contradiction matrix are employed to settle conflict using weights to forecast the importance of such viewpoints to the situation (Sheu & Tsai, 2014).
- Root Conflict Analysis - This tool also belongs to the Functional Analysis category and is used to identify the root causes of conflicts within a system. Root conflict analysis is also a tool that is quite effective for business and management problems. RCA+ provides all possible causal chains associated with a single problem statement and draws out the conflicts hidden within a single situation (Souchkov, 2005). RCA+ is a powerful

and direct technique for mapping contradictions. The RCA+ is a cause-effect tree diagram, with nodes stating positive and negative effects/causes. They are usually constructed in a top-down mode, starting with a generally negative effect and then moving downwards by unfolding a chain of causes that leads the broad negative causes until a conflict/contradiction is achieved (Hsieh et al., 2016, 2016; C. Y. Huang & Abrego, 2014; Sheu & Tsai, 2014; Souchkov et al., 2007).

4.8 How can TRIZ methodology be combined with other problem-solving tools?

Researchers have made substantial efforts to complement the hit-and-trial method to create innovative solutions through psychological operators that enable thinking outside the box (Dung, 1995). For, e.g. creativity tools like 'brainstorming', 'cause and effect relationship', 'morphological analysis' (Moehrle, 2010), 'six thinking hats', 'smart little people' (Ilevbare et al., 2013a) these tools stimulate solutions that already exist. However, these psychology-based tools can be combined with TRIZ tools to accelerate the idea-generation phase by incorporating 40 inventive principles; contradiction tables would help eliminate contradictions identified in the idea-generation phase (Hipple, 2005).

(Moehrle, 2010) developed the concept of MorphoTRIZ for solving technical problems by combining the properties of morphological analysis, which dissects a system into subsystems and finds solutions by combining these subsystems. In contrast, TRIZ assesses finding contradictions within a system and gives solutions by eliminating them. Function analysis served to connect tools between the two problem-solving methodologies.

Another systemic innovation technique is design thinking. Alternative product concepts are produced and assessed for further development and testing when the target market is defined during the new product development phase; due to their complementarity, Design Thinking (DT) and TRIZ are the problem-solving approaches of choice. TRIZ is best known for its idea generation and selection processes, where TRIZ has a robust set of analytical tools to guide teams toward the final product concept. While design thinking is the most widely used methodology for directing project teams toward end-users, it is best known for its idea generation and selection processes (Da Silva et al., 2020). However, TRIZ has gained an overriding advantage among all the tools and techniques for solving abstract problems with specified directing mechanisms (J. Zhang et al., 2005). Combining TRIZ methodology with other problem-solving tools can result in a more comprehensive approach to innovation and problem-solving. By leveraging the strengths of each tool, businesses can develop solutions that are both creative and technically feasible.

5. Discussion and Conclusion

TRIZ is primarily and commonly utilized in technical fields; it is used less frequently in business and management issues. The analysis of highly cited articles (RQ2) reveals that they primarily focus on technical areas of TRIZ, highlighting the dominance of such topics in the existing literature. While these seminal articles and reputable journals are valuable resources for researchers, practitioners, and educators seeking insights into TRIZ's applications, it is evident that the number of publications in purely non-technical fields is relatively limited (RQ1, RQ2). Despite applying the subject filter of 'business and management,' the retrieved articles mostly pertain to technical aspects of these fields. This underscores the importance of not solely relying on standard matrices but instead gathering ground-level information to understand the specific applications of TRIZ in non-technical contexts.

The analysis of prominent authors and countries in the domain of TRIZ in business and management (RQ3) provides valuable insights into the global impact and contributions made by various researchers and institutions. However, a concern arises regarding the unequal distribution of impact, especially in India, the country of origin of some authors. In India, TRIZ remains relatively unknown and exclusive, despite its proven effectiveness and usefulness in the business and management domain. The keyword occurrence (RQ4) and the prominence of generic terms such as "Design," "product design," and "problem-solving" may mislead researchers in identifying relevant articles in the non-technical context of TRIZ. Therefore, in Section 4 (RQ5), we made a deliberate effort to assist beginners in comprehending TRIZ in non-technical areas by providing a basic description of the methodology applicable in these domains. By doing so, we aim to bridge the gap between technical and non-

technical applications of TRIZ and enable a better understanding of its potential in various business and management scenarios.

There are several challenges associated with the application of TRIZ, including the fact that it is difficult to learn due to its structure, that it requires an unusual amount of time commitment, and that there is a great deal of ambiguity about how to apply the theory because every field has used it according to their field requirements (Ilevbare et al., 2013a). To solve problems with TRIZ methodology, one must draw the right conflicts in terms of industry parameters. That further poses a problem in applying TRIZ methodology in management (Pang et al., 2012). The management field is more complex and human-centric, which makes the application of TRIZ more complex (ZHANG & LI, 2015). Therefore, translating management conflicts in TRIZ parameters is a challenge for many.

After analyzing and reviewing the literature based on TRIZ, it has become evident that TRIZ has been modified and used in every field per the requirements. Due to its strong problem-solving and innovative idea-generation capability, TRIZ holds immense potential in almost every field. However, there is less research on core business problems, more of which are related to the technical context. Company-based research is also unavailable on how different companies have applied TRIZ and the type of strategy the methodology used. Studies have been conducted lately in some of the core business domains such as human resources (C. Y. Huang & Abrego, 2014) and customization of women's fashion accessories (Chin-Min et al., 2013); (Deng & Lin, 2019), but still, there is a dearth of studies following central business methodologies, 31 business parameters, and business contradiction matrix. For a brief understanding of TRIZ parameters in business and management, one can refer to the (TRIZ Journal – TRIZ Methodology Tools, Articles and Case StudiesThe TRIZ Journal | TRIZ Methodology, Tools, Articles and Case Studies, n.d.).

Experts can help beginners understand the nuances of TRIZ to make a non-technical person understand how the same 40 inventive principles can be used for solving non-technical contradictions analogously, which can be difficult to grasp without proper training and guidance. By working with an expert, beginners can gain a deeper understanding of the TRIZ methodology and learn how to use it in more complex and challenging situations. Subsequent research has thus far confirmed that the same 40 strategies are being used in achieving successful contradiction-breaking, win-win solutions in a business context; however, parameters have changed over time. Many TRIZ practitioners and experts continue to use and adapt the matrix for various industries and problem-solving contexts, and it remains an important part of the TRIZ methodology.

6. Future Research Directions

TRIZ is a core engineering methodology, while business is a human-centric approach. Therefore, there is difficulty in identifying the TRIZ contradictions in companies. Furthermore, because of this reason, we find a scarcity of research in understanding how businesses implement TRIZ applications. Therefore, future researchers can perform case studies on companies that use TRIZ methodology in their operations and provide an in-depth description of its application. The focus should therefore be on problem construction. Since business involves people and human-centred processes, human-centric approaches should be combined with TRIZ methodology to solve business and strategic management problems. A combination of design thinking with TRIZ would be the next big thing for innovations in business and management (Da Silva et al., 2020). As mentioned in the study, these approaches could include design thinking, six-hat thinking, and morphological analysis. To further explore the combination of TRIZ with human-centric approaches such as design thinking, six-hat thinking, and morphological analysis, future research could focus on the development of integrated problem-solving frameworks that blend TRIZ with these methodologies. The effectiveness of such frameworks could be tested in real-world business and management contexts through case studies and empirical research.

Root contradiction analysis or cause-effect chain analysis has been introduced to find contradictions in business and management problems. However, there is still a scarcity of papers in these areas. Through root cause analysis perception mapping, we can identify company and customer expectations and form a chain analysis describing the underlying issues. Research

could also focus on developing new techniques for identifying contradictions in business and management problems. For instance, researchers could explore the use of data mining and machine learning algorithms to automatically detect patterns and inconsistencies in large datasets related to business operations and decision-making. These approaches could be combined with root cause analysis and perception mapping to view the underlying issues comprehensively.

Brand management, marketing segmentation, human resource retention, and product portfolio are areas that previous researchers have studied. However, areas including financial aspects like portfolio management, risk management, or strategic areas like pricing policies have not been focused on yet. Future researchers can work on these areas as well.

Finally, future research could explore the role of TRIZ in facilitating organizational innovation and change. This could involve examining the use of TRIZ to identify opportunities for process improvement, organizational restructuring, and strategic innovation. Case studies of companies that have successfully used TRIZ to drive innovation and change could provide valuable insights into the potential of this methodology to transform businesses and management practices.

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Dynamic hand gesture tracking and recognition: Survey of different phases

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Abstract

Hand gesture plays an important role in controlling various appliances and gadgets nowadays. Recognition of proper gestures with the help of multiple techniques is vital for the hardware interfaced with it. Work has been done on various steps of the process of hand gesture recognition. Starting with video acquisition and pre-processing, hand detection and tracking, and feature extraction finally lead to classification and recognition. This paper provides a detailed review of state-of-art techniques used in recent hand gesture recognition techniques. We have also discussed the advantages and disadvantages of various techniques and the reason behind moving to another method. It is hoped that this study might provide researchers with a comprehensive description of the hand gesture recognition techniques that may help in pattern recognition, computer vision, and artificial intelligence.
Keywords: Computer vision, Hand Gesture, Hand Gesture Dataset, Hand Tracking, Machine learning, Recognition.

1. Introduction

In the growing world of artificial intelligence and image processing, the demand for controlling objects remotely and security has been raised a lot. Image processing needs to be done for visualization, sharpening of images & regeneration, retrieval of images, pattern measurement, and recognition of images. Many algorithms quickly detect and track various gestures in static conditions but do not support dynamic image recognition due to multiple challenges like invariant features, movement between gestures, automatic filtering, feature segmentation, matching techniques, mixed gestures, and complex dynamic backgrounds.

Early research on vision-based hand tracking and gesture recognition usually used markers or colored gloves (Mistry & Chang, 2009, Wang & Poppovic, 2009). Current research in vision-based hand tracking and gesture recognition techniques is more focused on using bare hands and identifying hand gestures without the help of any markers and gloves. However, obtaining highly accurate results is challenging for any vision-based approach (Rautaray, 2012). Systems using bare hands suffer from some difficulties, such as the user and camera needing to be independent and invariant against the dynamic background, transformations, and variable lighting conditions for real-time performance. Human hands can change their shape; therefore, there are chances of difficulty arising in detection and recognition. Work done addressing issues in the research articles related to vision-based recognition techniques helped the researchers identify the key issues and problems and work further on them to reduce and make them more user-friendly. This paper constitutes the research done in the existing literature about various steps to be followed in developing a robust hand gesture recognition system. This study will help to gain knowledge for the upcoming researchers about the process that needs to be followed to develop a system that dynamically recognizes hand gestures and can help in a wide range of applications.

The papers cited as references have been collected by first finding the literature associated with the topic. Various hand gesture recognition system steps have been categorized, and the related literature has been searched and analyzed. After the analysis, those papers were systematically evaluated based on the results and optimized techniques used in them. If the paper is found relevant based on the requirements, the paper is selected and cited. When collecting papers, several factors are considered, including the research question, the scope of the study, and the type of publication required. The search terms used depend on the research question and the scope of the study. A comprehensive list of relevant search terms is compiled, which may include keywords, phrases, and subject headings related to the research topic. The inclusion and exclusion criteria are developed to ensure that only relevant studies are selected for the analysis. The criteria may include factors such as the

type of publication, the date of publication, the study design, the sample size, and the quality of the study. After the initial search, the titles and abstracts of the articles are screened to determine their relevance to the research question. The full texts of the relevant articles are then retrieved and assessed for eligibility based on the inclusion and exclusion criteria. Finally, the selected articles are read in detail, and the relevant data are extracted for analysis.

The paper is organized as follows:

Section 2 gives an overall view of the hand gesture recognition system. Section 3 discusses various types of approaches used in Hand Detection. Section 4 presents different types of hand tracking methods. Section 5 provides a list of various features available in previous papers for the feature extraction stage. Section 6 presents classifiers used in machine learning for proper recognition of gestures. Section 7 provides a final summary of the survey.

2. Overview of the Hand Gesture Recognition System

Fig. . 1 shows various steps that play an important role in the Hand gesture recognition process. Gesture recognition involves tracking human gestures to represent them and convert them into meaningful commands Among the various phases of a hand gesture recognition system, video acquisition, and pre-processing steps depend on the applications for which the system is developed. For contactless handling of devices, proper tracking and recognition are required in which a pre-requisite condition of accurate image pre-processing and detection should be fulfilled. Extracted features should be meaningful and also need to justify the proper method of the recognition process.

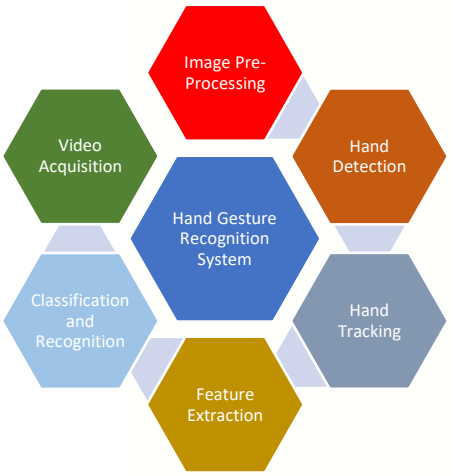

Fig. 1. Overall phases in a hand gesture recognition system

3. Detection

The hand gesture recognition system is initialized by the process of hand detection and extraction from the background. Successful execution of this step will lead to proper tracking and recognition of gestures. Skin color detection, 3D model-based, and motion-based detection are among the methods available in the literature. Fig. . ure 2 shows the various color detection techniques evolving with time.

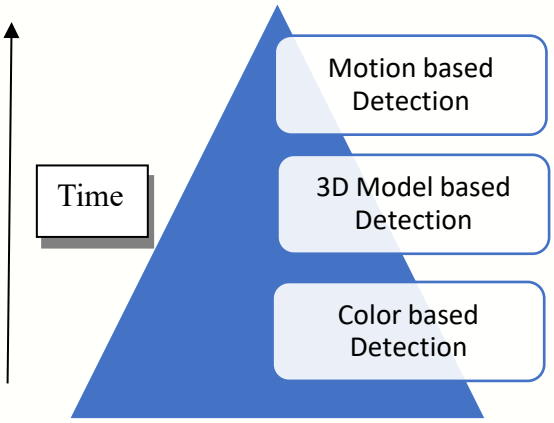

Fig. 2. Different Approaches for Detection

3.1Color based detection： The skin-colored region is extracted successfully from the input image to obtain many researchers' desired hands. Successful detection includes a proper selection of color models, and a variety of them are available, like Red-Green-Blue (RGB), normalized RGB, Hue Saturation Value (HSV) (Saxe & Foulds, 1996), YCrCb (Chai & Ngan 1998, YUV Yang et al., 1997), etc. The YCbCr color model distinguished skin-colored pixels from the background (Yu et al., 2010, Rekha & Majumder et al., 2011, Panwar & Mehra, 2011). The required hand portion was extracted using this color model, filtered by a median filter, and finally processed by a smoothing filter. (Malima et al., 2006) used the Red/Green ratio to determine the skin-colored regions for robotic application. Initially, the center of gravity of the hand was searched, and then the farthest distance from the center was calculated. In this way, the fingertips of the hand have been identified. Manigandan and Jackin (Manigandan & Jackin, 2010) used the same steps as (Malima et al., 2006), except the RGB input was converted to HSV color space before further processing. Fang et al. (Fang & Lu, 2007) applied the Adaptive Boost algorithm to detect hands from

the input image captured during image acquisition. This algorithm was able to detect the overlapped hand. The Haar-like features were extracted, and other processing, like face subtraction, skin detection, and a contour comparison algorithm, was used to detect the hand region (Dardas & Georganas, 2011). The experiments were carried out in a cluttered background.

However, using only color as information to segment the hand can create confusion between the background objects that have a color distribution similar to human skin. A way to minimize this problem is to use the background subtraction technique (Rehg & Kanade, 1994). The first frame of the video was considered the background for the entire processing of the system (Hsieh et al., 2012). The first frame did not contain the target hand. Then, this background was subtracted with the successive frames of the input video to detect the moving objects. Finally, skin-colored pixels were extracted using the CamShift algorithm to detect the hand from the objects. Tewari and Srivastava (Tewari & Srivastava, 2012) first converted the input RGB image to a grayscale image. The pixels of the hand regions could be extracted easily as it was carried out in a controlled environment where the signer used a black dress and black bandage with a black background. Salleh and Ramli (Ramli, 2012) used background subtraction to detect the hand. It was observed that there are three binary-linked regions, i.e., the face and two hands. The maximum values of the region connected were identified using binary linked object (BLOB) analysis to select the two hands. To solve the background subtraction problem when the camera and background are in a static position, some researchers (Utsumi & Ohya, 1998, Blake et al., 1998) have proposed to make dynamic corrections of background models.

Human skin color varies naturally, but skin color variations in images may also result from changing illumination conditions or camera characteristics. Therefore, the color-based approaches should also consider such problems for compensating such variability. Some researchers (Yang & Ahuja, 1998, Sigal et al., 2004) proposed a model for detecting skin color independent of the changes in illumination. Yoon et al. (Yoon et al.,2001) proposed various Hidden Markov Model (HMM) models for recognition systems having multiple hand gestures. Detection is done based on skin color and motion. Features used comprise combined and weighted location, angle, and velocity. A set of 2400 trained and 2400 untrained gestures have been used for training and testing.

Rahman, Purnama, and Purnomo (Rahman et al.,2014) proposed a new system combining two skin color models for each pixel, forming a vector containing Hue, Saturation, Cb, and Cr color elements. From the proposed detection models, 93.89% true Positif Rate and 10.75% false Positif Rate are calculated. This paper describes three categories of skin color detection. The Explicit Range method determines the pixel class for the predetermined color range. A nonparametric method calculates the variance of a single-color model but cannot handle all kinds of skin color distribution, and the third one is the Parametric method. The database consists of 50 images with varied sizes and ten images. The detection phase converts every pixel of an image from HSV to the YCbCr color model and forms a vector consisting of H, S, Cb, and Cr, which gives results in the form of mean and covariance. Mahalanobis distance (D) is calculated using threshold T=0.5Ţ. Yushan et al. (Yu et al., 2016) used a method in which the image is firstly pre-processed using Haar-like features. Pixel sum and difference of particular region are considered such that the image transforms to a gray image, and then the histogram equalization process is performed.

Kaur, Anuranjan, and Nair (Kaur & Nair, 2018) present a genuine time hand gesture recognition system that detects hand gestures in midair and controls the appliance corresponding to input gestures. Real-time hand detection is done with the help of the Histogram of Oriented Gradients (HOG) feature in MATLAB. Mayyadah et al. (Mahmood et al., 2018) considered approximately 200 images and captured data images with the help of HP pavilion dv6. In the detection phase, subtraction between the Region of Interest (ROI) background and ROI hand gesture is made, and afterward, the input image is transformed into a grayscale image. Maleika et al. ([Heenaye-Mamode et al.,2019) developed an application to categorize and recognize the classical “Bharatanatyam” dance hand gestures. A customized database of these dance movements was prepared with 900 images, among which 450 were for the training set. An equal number is taken for the testing set, consisting of 15 instances for each hand gesture. For the detection process, the use of Chain Codes along with a Histogram of Oriented Gradients (HOG) was proposed.

3.2 3D model-based detection：The advantage of the 3D hand models is that they support detection, which is view independent. Dimensions of the hand in the image should be adapted using 3D models with sufficient degrees of freedom. Image features are the basic

requirement for constructing feature models (Rautaray & Agrawal, 2015). Kinematic hand models employ point and line features to recover angles formed at the joints of the hand (Rehg,1995, Shimada,1998, Wu & Huang, 1999, Wuelt, 2001). There are various 3D models present in literature by researchers, along with their advantages and disadvantages. In some of the research, a framework having a deformable model is utilized to fit the hand 3D hand model to the available image (Lee & Kunii, 1995, Heap & Hogg, 1996). The image edge model gets attracted by the forces guiding the filling, and other balanced forces are available by which continuity and evenness are preserved among surface points.

3.3 Motion based detection: A few pieces of literature used methods using motion to detect hand. Motion information provides better results when combined with additional color cues and successfully distinguishes hands from other skin-colored objects (Cutler 1998, Martin et al.,1998). The system also works successfully under changes in illumination, but the camera and background require being static for easy detection of hand. The difference in the luminance of pixels from two successive frames of the input video is close to zero for pixels of the background. Thus, moving objects (hands) are detected well in a static background by choosing the appropriate threshold. A novel feature based on motion residue is proposed by Yuan et al. (Yuan, 2005). It is observed that hands are articulated objects, so they have non-rigid motion. Therefore, the hand is detected by exploiting the information that for hands, appearance among the frames changes more frequently as compared to other objects such as the face, clothes, and background. Spatiotemporal-based characteristics were generated from the video sequence (Yang, 2010). Frame differencing was performed between successive frames of the video sequence, and then skin filtering was performed to extract the skin-colored regions. Chen et al. (Kim, 2001) proposed combining skin filtering and motion information models. The detection phase included all the skin-colored objects like face and hand, and a suitable face detection algorithm resulted in the extraction of the face. The frame differencing was used to locate the moving objects in the surroundings. Finally, the results were combined to obtain the hand region. Aditya Ramamoorthy et al. (Chaudhurya, 2000) developed a recognition engine that recognizes dynamic gestures despite individual variations. For shape change detection, the centroid of the contour points is calculated, and the variance of the contour points from the centroid is obtained.

Table 1. Techniques Used in Detection

DETECTION		
Color based Detection	Background subtraction	Rehg et al., 1994
	HSV Color space	Saxe et al., 1996
	YCrCb color space	Chai et al., 1998
	YUV color space	Yang et al., 1998
	Dynamic correction of background models.	Utsumi et al., 1998
	Color system conversion from RGB to YIQ	Yoon et al., 2001
	Red/Green ratio to determine the skin-colored regions	Malima et al., 2006
	Adaptive Boost algorithm to detect overlapped hand	Fang et al., 2007
	YCbCr color model detects and extracts skin-colored pixels from the background	Yu et al., 2010
	RGB input was converted to HSV color space before processing	Manigandan et al., 2010
	Input RGB image to grayscale image	Tewari et al., 2012
	Maximum values of the region connected were identified using binary linked object (BLOB) analysis	Ramli et al., 2012
	A combination of two skin color models forms a vector containing color elements of H, S, Cb, and Cr for each pixel	Rahman et al., 2014
	Haar-like features like pixel sum and subtraction	Yushan et al., 2016
	Histogram of Oriented Gradients (HOG)	Kaur et al., 2018
	Difference between the ROI background and ROI hand gesture	Mahmood et al., 2018
	Combination of Chain Codes and Histogram of Oriented Gradients (HOG)	Yang et al., 2019
	RGB frames combined with hand segmentation masks	Garcia et al., 2021
3D model based Detection	Use of point and line features to recover angles formed at joints	Rehg et al., 1995
	Use of anatomical data of human hand	Lee et al., 1995
	Deformable model framework	Heap et al., 1996
	Construction of feature model correspondences	Rautaray et al., 2015
Motion based Detection	Employed changes in interframe appearance	Yuan et al., 1995
	Two successive frames pixel luminance difference	Cutler et al., 1998
	Centroid of the contour points and variance calculation	Chaudhurya et al., 2000
	Frame differencing	Kim et al., 2001
	Spatial information of hand	Bhuyan et al., 2006
	Use of spatiotemporal based characteristics	Quan et al., 2010
	Use of both color and motion features	Chen et al., 2018
	Angular-velocity method	Shantakumar et al., 202

Ratios of different variances of different shapes are calculated. It is observed that at the time of shape change, the ratio of the variance of the predicted and observed contours will be above the expected value. Based on a small area of 10*10 pixels, the mean and variance of hand color are estimated. Ghoan et al. (Bhuyan, 2006) describe a gesture recognition system that recognizes broad classes of hand gestures in a vision setup. Firstly, gestures having only one global motion are recognized with the help of spatial information of hand in the form of motion trajectory along with some static and dynamic features. The concept of object-based video abstraction is used for segmenting video frames. (Chen et al., 2018) proposed a hand-tracking method that uses the strategy of proposal selection based on temporal information, hand detection, and human pose estimation. Some of the important techniques have been categorized and shown in Table 1.

4. Tracking

The detection method can be used for tracking if it is fast enough to operate at an image acquisition frame rate. One of the most challenging tasks in a hand gesture recognition system is tracking due to the variable gesticulation speed of the users. The tracking system should be robust enough to perform well even when the hand moves quickly. Tracking provides the interconnection between the hand appearances of consecutive frames, thus generating the trajectory of a gesture. The features are extracted from this trajectory in the later stages. Tracking also maintains model parameter estimates and features that can be observed afterward (Rautaray, 2018).

4.1 Color based approach： (Guo et al., 2011) suggested a new hand-tracking system that uses skin filtering pixel-based hierarchical feature AdaBoosting and is used with background cancelation. (Koh et al., 2009) proposed a color model to track hand gestures with the help of skin. The active appearance model helps construct a hand appearance model that considers color and shape information. During the initialization of the system, Mahalanobis distance was used, which helps verify the user's hand and appearance model. The skin color model is constructed using Gaussian distribution.

Color histogram was extracted and used as the information to track an object (Comaniciu, 2003). Mixtures of Gaussians were used to develop the model for the color distribution of the object (Jepson, 2003, Zhou, 2004, McKenna, 1999). However, the drawback of this color-based technique is that it fails if there is the presence of things in the background with a similar color as that of the hand.

4.2 Probabilistic approach: In the last decade, many researchers have adopted probabilistic approaches to track hands (Binh, 2005, Imagawa, 1998, Isard, 1998, Shan, 2007, Weng, 2006, Zhang, 2009, Zheng, 2009). The blobs are computed in some literature (Binh, 2005, Imagawa, 1998), which is used for

tracking hands. The following location of the hand is predicted using the Kalman filter. The measurement noise used in the Kalman filter is assumed to be Gaussian for the system developed in these papers. Moreover, the gesticulation should be performed with constant velocity, which restricts the natural speed of the user. Multiple cameras were used to track the hand using a Kalman filter running in each video frame to estimate the hand postures (Utsumi 1999). Peterfreund (Peterfreund 1999) developed a robust technique to handle the cluttered background. The foreground can be separated from the background by combining the conventional image gradient with optical flow. (Asaari et al.) combined Adaptive Kalman Filter and Eigen hand features to track hands under various perplexing conditions. However, the algorithm is not successful in the presence of large-scale variations and changes in poses.

One of the methods to track the hand position is particle filters, in which the hand location is modeled with a particle set. The Condensation algorithm performs better than Kalman filters (Isard & Blake 1998). This algorithm performs well against cluttered and dynamic backgrounds. It uses "factored sampling," where a randomly generated set represents the probability distribution of possible interpretations. This algorithm uses visual observations and learned dynamical models to propagate this random set over time. (Mammen et al. 2001) extended the Condensation algorithm to detect target objects under occlusions. The same algorithm is combined with color information within a probabilistic framework by (Perez et al. 2002). This technique proposes a new Monte Carlo tracking algorithm.

(Bhuyan et al. 2006) proposed a new model-based method for tracking hand motion in complex scenes is being designed in this paper. The motion vector estimation process takes place in the type of tracking algorithm used. An object tracker forms the core of this algorithm which matches a two-dimensional binary model of the

gesture with subsequent frames using the Hausdorff distance measure. Frames are segmented in the gesture sequence to form object video planes where the hand is considered a video object. The hand pixels are assigned a binary value of '1', and the background pixels are assigned a value of '0'. Then, the trajectory is estimated using the centroid of the hand being detected by the above process.

4.3 Appearance based approach：(Comaniciu et al. 2003) used a color histogram to develop a hand tracker model. Hand detection is done by calculating color histogram, which is used as mean shift and locates hands in video frames and tracking. A new type of algorithm named CamShift (Continuous adaptive mean-shift) has been proposed as an enhanced form of mean shift algorithm used for object tracking (Nadgeri 2010, Bradski 1998).

This algorithm tracks the hand efficiently in normal backgrounds, but it does not provide an accurate result when the hand occlusion occurs with other skin-colored objects. The track window's size is adjusted by the CamShift algorithm. CamShift algorithm can track any feature distribution representing the target successfully (Bradski 2008). There are many techniques where the CamShift was combined with various other tracking methods, which led to improved tracking efficiency. For example, in literature (Wang 2010, Huang 2011), the CamShift algorithm was combined with the Kalman filter. The Kalman filter predicts the possible positions of a target, and then the CamShift is used to search and match the target in the predicted areas (Wang 2010).

(Shi and Tomasi 1994) chose high-intensity corner points as features for tracking the target object. This led to successful tracking and results, but as soon as the number of frames increased, feature points decreased. This can be due to illumination changes or changes in hand appearance. (Kolsch & Turk 2004) introduced an algorithm based on a tracker based on Kanade Lucas Tomasi (KLT). However, the KLT tracker does not yield good results at the time of hand shape change during gesticulation. (Porikli et al. 2006) proposed a tracker working on the concept of a covariance matrix (Tuzel et al.,2006), and the Riemannian manifold was used for modeling the updated mechanism. In their system, the target object was represented with a set of features as a covariance matrix. For every consecutive frame of the input video, a candidate region searched that had a covariance matrix similar to the target object. The model then receives the information and updates the system with the changes in the appearance of the hand. But this tracker will only respond if the target and background have a few variations. An Eigen space approach-based tracking system named Eigen tracking was developed by (Black and Jepson 1998). This tracker uses subspace constancy assumptions for estimating hand motion. This technique requires pre-training of the Eigen basis, which increases the tracking time of the system. Moreover, the Eigen basis needs to be updated. Thus the system cannot work in an environment suffering from illumination changes.

(Yushan et al. 2016) proposed a method that combines the CamShift algorithm and Haar-like feature detection. This method successfully gives output for tracking and classifying hand gestures in images acquired in a dynamic environment. During the initial stage, a Haar-like classifier is employed, which acquires the color of the hand. To track the acquired hand, Camshift, along with a 2-D Kalman filter, is used. This algorithm solves the problem of lost tracking due to hand occlusion and skin color disturbances to a great extent. A recognition rate of 99.5% is obtained by using the proposed system.

(Xiu, Su, and Pan 2018) Try to reduce problems in which accuracy decreases because of similar target color and background color or if the target is covered. The tracking algorithm is improved and is based on CamShift, which has the advantage of the Mean shift algorithm, in which the window size can be changed as the size of the target changes. The proposed algorithm starts with the Kalman filter, which tracks the target and stores its motion information by prediction method. The Bhattacharya coefficient is calculated using the image histogram features. If any target occlusion exists, the Kalman filtering algorithm will repeat itself and predict the target motion in the next frame. After this process, CamShift will try to find the target near the expected location by the probability distribution map of the image. The target's position can be accurately located by the size of the tracking window, which should exceed the threshold value to calculate the perfect target position. Fig. . 3 shows examples of some of the video gestures formed using tracking techniques.

Fig. 3. Tracking of some of the gestures

The problems in the previous two steps are resolved by improved CamShift, which means shift operation is used as a tracking principle. The last frame is used for the window position search of the next frame. If the background is, the same tracking fails as the background starts acting as a target. With the changes made in CamShift Algorithm, the background is changed due to the available value of thresholds for the camshaft window, which decides the background interference problem. If background interference is detected, the target contour is extracted by three steps:

- The image should be binary.
- Noise interference should be reduced.
- Canny edge detection is used for target detection.

(Chen and Zhu 2018) designed a hand tracker with the self-correcting capability to re-initialize the tracker position by integrating the human pose and hand detection information. Hand positions and an approximate center of the human body in the starting frame are used for initialization to give a perfect starting point. Hand tracker uses contour points and Harris corners, a pixel-based skin detection method to recover the tracked hand in subsequent frames based on information from the hand detector and wrist position estimator. Table 2 demonstrates the evolution of tracking methodologies used in Hand Gesture recognition systems.

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Table 2. Evolution of tracking methodologies used in Hand Gesture Recognition

TRACKING		
Color based approach	Gaussian distribution and Color Histogram	Comaniciu et al., 2003
	Use of color distribution of the object	Jepson et al., 2003
	Active Appearance Model and Mahalanobis Distance	Koh et al., 2009
	Skin filtering pixel based hierarchical feature AdaBoosting	Guo et al., 2012
Probabilistic approach	Kalman filter running in each frame of video	Utsumi et al., 1999
	Optical flow along with image gradient	Peterfreund et al., 1999
	Condensation algorithms	Isard et al., 1998
	Extended condensation algorithm	Mammen et al., 2001
	Condensation algorithm integrated with color information	Perez et al., 2002
	Computation of blobs and Kalman Filter	Binh et al., 2005
	Motion vector estimation	Bhuyan et al., 2006
	Adaptive Kalman Filter along with Eigen feature tracking	Asaari et al., 2015
Appearance based approach	High intensity with corner points is being selected as features for tracking the target object	Shi et al., 1994
	Camshift Algorithm	Bradski et al., 1998
	An Eigen space approach based tracking system	Black et al., 1998
	KLT tracker	Kolsch et al., 2004
	Covariance matrix representation	Porikli et al., 2006
	Riemannian manifold	Tuzel et al., 2006
	Adaptive mean shift	Nadgeri et al., 2010
	CamShift combined with kalman Filter	Xiangyu et al., 2010
	CamShift and Haar-like feature detection	Yushan et al., 2016
	Hand tracker having self-correcting capability that can re-initialize the tracker position	Chen et al., 2018

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5. Feature Extraction

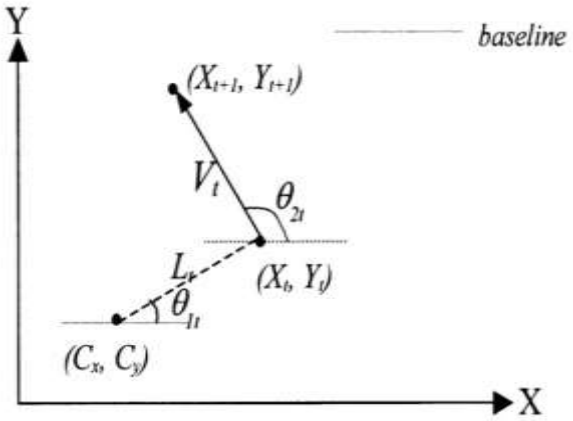
A proper feature matrix consisting of robust features is required for improved recognition. A few papers used a single feature to develop the gesture recognition system. (Elemicin *et al.2008*) tried to recognize both isolated and continuous gestures with the help of the orientation feature. With the help of this feature, gesture motion direction can be calculated using trajectory points. The quantization process used code words from 1 to 18 on the orientation angle. (Kao and Fahn 2011) also used the orientation feature to design a real-time hand gesture recognition system. Gestures were classified using HMM after the quantization process.

Location, orientation, and velocity features were among the most used features by researchers (Bhuyan 2008, Bhuyan 2014, Li 2016). (Xu *et al. 2015*) proposed a novel hand gesture recognition system for robotic applications using features like orientation, chain code by 1-8 code words, location, and velocity. (Yoon *et al.* 2001) used a combination of location, orientation, and velocity, as shown in Fig. . 4. The orientation feature calculates the direction of gesture motion from the center to all

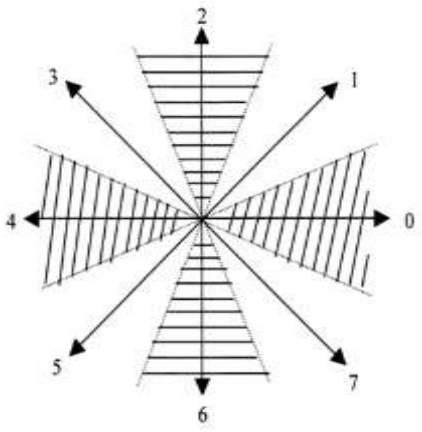
gesture points in the trajectory and between the trajectory points. (Elmezain *et al.* 2009) proposed the use of two location features and three orientation features which were combined with velocity features.

Many researchers have tried to improve the system's performance by combining multiple features. (Bhuyan *et al. 2006*) used static and dynamic features to construct the feature matrix, which helps recognize the gestures. A few static features include trajectory point selection, location, trajectory length, orientation, and location features. The number of significant curves start, and end of the gesture trajectory forms the orientation feature. The dynamic features include the velocity and acceleration features. Fig. . ures 4 and 5 show samples of some of the features extracted and used in the feature extraction process.

(Bhuyan *et al.* 2008) increased features to be included in the feature matrix they used (Bhuyan 2006), like the standard deviation of the speed feature for gesture recognition. A conditional Random Fields (CRF) based classifier model was proposed, which helped recognize continuous hand gestures (Bhuyan 2014). In Fig. . 5, a technique was used in which the ellipse was adjusted over every six trajectory points named as ellipse fitting technique. From the ellipse, features such as orientation and major axis length of all ellipses were extracted. The positioning feature was extracted where the start and end position of the gesture trajectory was found and divided into top, middle, and bottom horizontal sections. For isolated gestures, 96% recognition accuracy was achieved. A combination of two types of features: hand shape and hand direction, was used by (Li *et al.* 2016). Hand shape includes the distance between the fingers of the hand, and hand direction feature includes acceleration, velocity, and orientation features



(a)



(b)

Fig. 4. Feature extraction (a) three features: location (Lt), orientation (θ1t, θ2t), and velocity (Vt) (b) chain code

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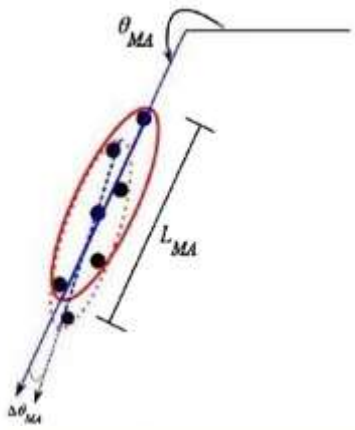
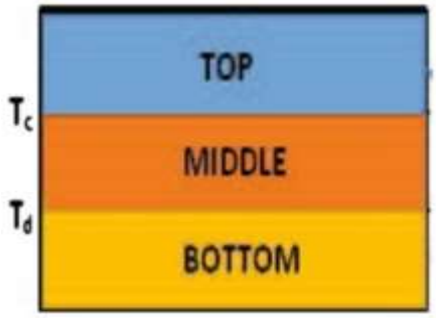


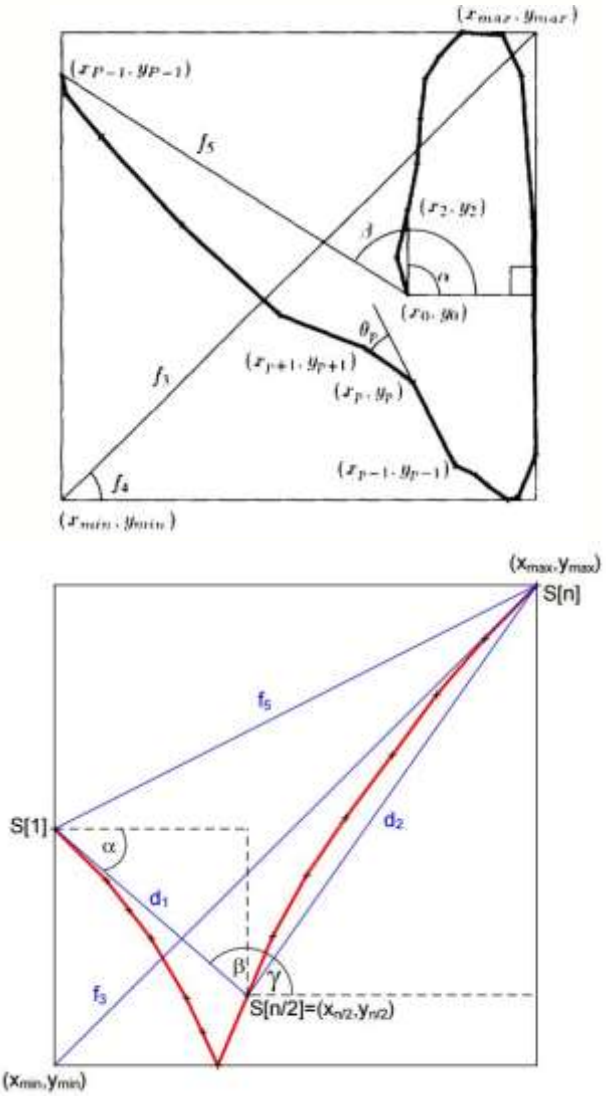
(a)



(b)

Fig. 5. Feature extraction (a) orientation of the major axis of the ellipse (b) region to indicate the position of the hand

Rubine developed 13 features (Rubine 1991), as shown in Fig. . 6(a). The features are: initial angle sine and cosine along the x-axis (cosα, sinα), bounding box length and angle (f3 and f4), first and last point distance (f5), total traversed angle and gesture length, sine-cosine angle of the angle between first and last point (cosβ, sinβ) and duration of the stroke. Features of Rubine 1991 were extended by (Signer *et al.* 2011), and 11 new features were added to the feature list provided by Rubine. Some of these are the direction of the first and second half of the stroke (sinα and cosγ), the number of breakpoints available, distance from the start to center point to the diagonal (d1/f3), distance from the beginning to the end-point to diagonal (f5/f3), the total number and total length of gestures and stroke distance from each other along with straightness as shown in Fig. . 6(b).



(a) (b)

Fig. 6. (a) Rubine features [(b) E-Rubine features

Another important extracted feature is stated as the start of the dynamic gesture or end of the same, which is determined by multiple centroids overlapping each other, stating the stationary position of the hand. Another feature is the coordinate vector of the centroid, which is associated with each gesture, especially alphabetical letters that indicate a timing sequence starting with 1. According to the thumb rule, 5-second gestures have been used where a complete gesture is recorded in 5-12 s including all hand positions at 30 frames per second.

Gesture recognition faces problems like occlusion, and to solve this problem, a new feature Comp-LOP, has been developed (Cen 2017). The new feature extracted is a complex form-local orientation plane (Comp-LOP) based on complex form. This feature provides a more

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elaborated version of the orientation using the complex form with an angle of 45°. It is better than a histogram of oriented gradients and local binary patterns. It reduces the occlusion problem as the representation of orientation pixels gives a precise direct relationship between them. (Tang *et al*. 2018) used the corner point positions of arbitrary trajectories as structured information and assigned different weights to feature space. Position and orientation features are combined with a Dynamic time warping approach to make trajectories more discriminative.

(Singla *et al.2019*) have taken the normalized sequence of captured 3D space coordinates as input, and the sequence of features is computed along the trajectory. Gesture direction, curvature, aspect, curliness, slope, and lines are some of the features that have been calculated and used to develop feature space and recognition. (Misra *et al.2019*) presented novel spatiotemporal trajectory features that provide output as the gestures' structural values. These features include Area of two-halves (ATH), Local geometrical area ratios (LGAR), and curve-area features (CAF). The gesture is divided into two halves equally, and the Area of each half gives the output as an ATH feature. For calculating the LGAR feature, the ratio between enclosed areas in each case of the stroke length is measured. The Area between them is the starting point, and the first point representing a sharp transition is measured as CAF. Some of the features used in existing literature have been tabulated in Table 3.

Table 3. Various features used in the Feature Extraction process

FEATURES	
Initial angle sine and cosine along the x-axis (cosα, sinα), bounding box length and angle (f3 and f4), first and last point distance (f5), total traversed angle and gesture length, sine-cosine angle of angle between first and last point (cosβ, sinβ) and duration of the stroke	Rubine et al., 1991
Location, orientation, and velocity feature combination	Yoon et al., 2001
The direction of the first and second half of the stroke (sinαand cosγ), number of breakpoints available, distance from the start to centre point concerning the diagonal (d1/f3), distance from start to the end point with respect to diagonal (f5/f3), the total number and total distance of gestures and stroke distance.	Signer et al., 2007
Orientation Feature	Elmezain et al., 2008
Length of trajectory, selection of trajectory points, location, orientation features; significant curves and orientation of start and end of the gesture trajectory, Standard deviation of the speed feature	Bhuyan et al., 2008
Distance between centre to trajectory points and start point to trajectory points	Al-Hamadi et al., 2009
Quantized orientation feature	Kao et al., 2011
Orientation between consecutive trajectory points (1-8 code words), location, and velocity	Xu et al., 2014
Orientation of the major axis of each ellipse, major axis length of each ellipse	Bhuyan et al., 2014
Distance between the fingers of the hand; acceleration, velocity, and orientation features	Li et al., 2016
Centroid coordinate vector	Prashan et al., 2017
Complex form-local orientation plane	Cen et al., 2017
Corner point positions of arbitrary trajectories	Tang et al., 2018
Gesture direction, curvature, aspect, curliness, slope, and linearity.	Singla et al., 2019
Area of two-halves, Local geometrical area ratios, and curve-area features	Misra et al. 2019
Euclidean Distance, Instantaneous velocity, and polarity	Yadav et al., 2021
Shape matching, Velocity change, Displacement of centroid between successive frames	Choudhary et al., 2021

6. Modelling And Recognition of Gestures

Researchers have worked and addressed recognition techniques which are as follows a) Hidden Markov Model (HMM) b) Neural Networks c) SVM d) k-NN e) Finite State Machine (FSM) f) Classifier fusion g) Naïve Bayes and Extreme Machine Learning (ELM) Neuro-Fuzzy (NF) and Voronoi based Classifier.

6.1 Hidden Markov Model： After the introduction of HMM in the early 1990s quickly became one of the most widely used recognition methods due to its inherent solution to the segmentation problem. In the HMM model, Markov chains are used simply as finite-state automata with a probability value associated with each arc (Rabiner 1986). Circular segment likelihood estimations leave a single state whole to one state. A Markov chain without the above Markov chain restriction is an HMM (Charniak 1993). HMMs are non-deterministic as the same output symbol represents more than one arc. An HMM can be defined as a combination of states which comprises the initial state, output symbols, and state transition.

With regards to hand motion acknowledgment, each state represents a lot of conceivable hand positions. (Chen *et al.2003*) distinguished the best probability signal model using HMM-based recognizers. Patterns having fewer likelihood values were filtered out using an HMM-based threshold model, and the hand movement direction was used for representing the sequences of gestures.

(Marcel *et al.2000*) extended the HMM algorithm, which resulted in the development of the Input/output Hidden Markov Model (IOHMM) used for hand gesture recognition. The IOHMM uses supervised discrimination learning with input/output sequences, observations, and gesture classes. IOHMM directly models posterior probabilities as compared to the HMMs. However, they performed the experiments for only binary classes. (Just and Marcel 2009) performed experiments for an extensive database with 7 to 16 classes. The study resulted in the recognition of all types of hand gestures. A comparative analysis of HMM and IOHMM established that for a large number of classes, HMM performed better than IOHMM.

Conditional Random Fields (CRF) is a widely used tool nowadays. It is advantageous compared to HMM because CRF does not consider solid independent assumptions about the observations and can be trained with fewer samples than HMM (Yang 2006). (Beh *et al.2014*) used HMM as the classifier. The hand motion trajectories are a combination of straight and curved segments. A state-splitting algorithm was proposed by (Siddiqi *et al.2007*) based on an expectation-maximization algorithm. A method was developed by (Ulas and Yildiz 2009) to find the optimum structure of HMM. For this purpose, they increased the number of states, subsequently measured the possible values, and tried to find the optimal structure.

6.2 Neural Networks： Neural Networks are upcoming classifier models that provide good pattern recognition results (Bishop 1995 [98], Haykin 2009, Bamwenda 2019 [100]). Gradient features per alphabet from the hand gesture images can be trained, tested, and validated using Artificial Neural Networks (ANN) (Bamwenda 2019 [100]). Artificial Neural Networks (ANN) refer to the simulations performed on the computer to complete several machine learning tasks such as pattern recognition, clustering, and classification. The time delay neural networks (TDNN) are one of the latest available models, which are counterfeit neural systems working with constant information making the engineering versatile to online systems and henceforth favorable to continuous applications. For 2D motion trajectories, TDNN networks have been used (Suykens 1999, Gopalan 2009). TDNN supports dynamic order as there is a little window of the information movement design. A process based on a double-channel convolutional neural network (DC-CNN) is suggested to improve the recognition rate (Mohammed 2011). The steps include the preprocessing, removal of noise and edge location of images to obtain hand-edge pictures. CNN separates the hand motion and edge pictures and denotes them as two different information channels. Each channel has a different weight but the same number of convolutional layers. Lastly, all the features are fused, and the Softmax classifier classifies the output.

6.3 Support Vector Machine： SVM is a supervised learning model in which optimization of class separation hyperplane such that there is the maximum distance between the hyperplane and the available pattern. The class separation hyperplane is optimized to maximize the space between the pattern and the hyperplane separating the classes (Dominio 2014, Thirumuruganathan 2010). (Gopalan and Dariush 2009)

cropped the regions corresponding to the extracted skin-colored pixels. Some of the extracted features include distance and angle, which utilize contour

points by connecting each other through an inner shape distance context algorithm, leading to the recognition of gesture by SVM. In the testing stage, the detected hand gesture is classified by a multiclass SVM classifier. A recognition rate of 96.23% under diverse, challenging environments like variable illumination, dynamic background, etc., was obtained.

A Library of SVM (LIBSVM) was used to recognize hand gestures (Dominio 2014). The parameters used for SVM were Radial Basis Function (RBF) as the kernel function. A grid search approach and cross-validation on the training set tuned the other classifier parameters. (Parama Sridevi *et al.* 2018) presented a new sign language interpreter which verbalizes American Sign Language. Features of real-time video sequences of hand gestures were compared with the stored features of database images for better accuracy. MATLAB is used for generating output and depends on predicting the values representing the highest resemblance. This model also helps fill the communication gap between speaking and hearing-impaired people and those without them. For classification purposes, Quadratic SVM is used, which provides about 85% accuracy.

6.4 K-Nearest Neighbour：This method classifies objects based on feature space training examples. K-Nearest Neighbor (k-NN) is a kind of instance-based learning in which the function is approximated locally, and all computations are delayed until classification (Ge 2008, Oka 2002). This classifier solves classification and regression problems using supervised machine-learning methods. This algorithm assumes that similar things are available in close proximity and thus captures the idea of similarity. Training and testing have been done for different values of K. The k-NN algorithm must be run several times to select the correct and appropriate value of K. The value of K, which reduces the number of errors while making predictions accurately, is selected. The value of K is chosen to be odd if the numbers of classes are odd to avoid the situation of the draw of votes.

The maximum vote of its neighbors characterizes an object, and the item is allotted to the class that belongs to its k closest neighbors where k is a positive number. If k=1, an object is assigned to its nearest neighbor class. Relapse also uses a similar technique and allows the property estimation for the item to the normal estimations of k closest neighbors. The neighbors are taken from items of the correct order. Euclidean separation can be used to distinguish neighbors and leads to the nearby structure of the information.

6.5 Finite State Machine：FSM is a technique that consists of a finite number of possible states. It can help develop a tool for solving problems and describing solutions for developers and maintainers. The gestures were decomposed into four fixed-order distinct phases resulting in the development of an FSM model for classification (Davis 1994). A sequential signature of hand motion is extracted, after which the hand gestures are classified using an FSM (Yeasin 2000). The dominant motion was estimated from an image sequence using motion energy. The FSM model was developed using the positions of the user's hand and head centers (Hong 2000). For the recognition of a continuous hand gesture recognition system, features like hand motion chain codes, the relation between the two hands according to their position, and the relation between face and hands were given as input to the dynamic Bayesian network model (Suk 2010).

6.6 Classifier Fusion：Recognition accuracy obtained by traditional individual classifiers can be improved using classifier combining techniques (Thai 2012, Kang 2009). (Dinh et al. 2006) developed a hand gesture recognition system that used a cascade of classifiers trained by AdaBoost and Harr wavelet coefficient features. (Burger et al. 2008) recognized hand shapes by proposing a belief-based method for SVM fusion. This method outperforms the classical methods by reducing the mistakes by 1/5.

A combination of HMM and Recurrent Neural Networks (RNN) was used by (Ng *et al.2002*), which provided improved performance compared to the performance of the individual classifier, such as HMM or RNN. Features used are based on Fourier descriptors and act as input to the RBF network. HMM, and RNN take motion information and pose likelihood vector from the RBF network as input. The final result is obtained from the combination of the classifiers' outputs. A combination of AdaBoost and rotation forest was used by (Wang *et al.2012*) for the recognition of hand gestures. Improved performance of the fusion technique is being observed. A combination of HMM and ANN models is being proposed and provides better results by improving the accuracy by 2-3% (Corradini 2002).

6.7 Naïve Bayes and ELM： (Singha et al.2016 [122]) classified dynamic gestures using the Naïve Bayes classifier based on the Bayes theorem, which operates independently between the features. Assuming the feature vector represented by x = [xa… xn] T and the class one of c classes w1…wc. For the model proposed, n=40 and c=40. Minimum classification error is assured

if the class with the largest posterior probability P is decided upon. Kernel and multivariate multinomial distribution (MVMN) are the two distributions that can be used in the training phase to obtain the highest accuracy model. A cross-validation process using 5-fold was also performed for testing. Extreme Learning Machine (ELM) based classification uses the feed-forward neural networks and nonlinear mappings that use a gradient descent approach for weights and bias optimization (Mohammed 2011, Liu 2016, Chen 2015).

6.8 Neuro-fuzzy classifier (NF) and Voronoi diagram-based classifier (VDBC)： A new type of classification model named Voronoi diagram-based classifier (VDBC) and neuro-fuzzy (NF) classifier was proposed, and the accuracy was improved (Misra 2019). Multiple layers like fuzzy membership, fuzzification, defuzzification, normalization, and output are present in the neuro-fuzzy classifiers. NF model is developed by the linguistic hedges (LHs) formed by the fuzzy sets. VDBC uses the ad-hoc approach of classification in which all the classes are handled at the same time. VDBC is designed using the Voronoi diagram model in which the training space is divided into multiple regions with a seed set which is S = s1, s2… sn, also known as discriminative functions.

(Yang and Liu 2019) have tried to improve the recognition accuracy by introducing an online classifier that adjusts each feature value in the tracking target model in accordance with the object change and situation. The learning algorithm produces a sequence of classifiers, which are F= (f_1……f_T), where the video image frame becomes accessible one frame by one frame. Using the first frame information, f_1 is trained, and f_i (for $i > 1$) is the i-th classifier learning after seeing the i-th frame image. Table 4 shows different classifiers used in the recognition methods of hand gesture recognition systems.

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Table 4. Different Classifiers used in the recognition method

RECOGNITION		
HMM	Use of Markov Chain having probabilistic value	Rabiner et al., 1986
	HMM without Markov chain restriction	Charniak, 1993
	HMM based threshold model	Lee et al., 1999
	Input/output Hidden Markov Model (IOHMM)	Marcel et al., 2000
	HMM based recognizers for identifying the best likelihood model	Chen et al., 2003
	Conditional Random Fields (CRF)	Yang et al., 2006
	Expectation-maximization algorithm	Siddiqui et al., 2007
	Comparison of HMM and IOHMM model	Just et al., 2009
	Optimum HMM by incrementing the number of states	Ulas et al., 2009
	Use of HMM as a classifier	Beh et al., 2014
Neural Networks	Dynamic TDNN	Yang et al., 1998
	Time delay neural networks	Ahuja et al., 2002
	Artificial Neural Networks	Bamwenda et al., 2019
	Double Channel CNN	Wu et al., 2019
Support Vector Machine	Multiclass SVM classifier	Suykens et al., 1999
	Class separation hyper plane	Hsu et al., 2002
	Library of SVM (LIBSVM)	Dominio et al., 2014
	Quadratic SVM	Sridevi et al., 2018[121]
k-NN	k-Nearest Neighbor (k-NN) (Lazy or instance-based learning)	Thirumuruganathan, 2010
FSM	FSM model by decomposing the gestures	Davis et al., 1994
	FSM model by temporal signature of hand motion	Yeasin et al., 2000
	FSM model with the help of the position of centers of user's hand	Hong et al., 2000
	Dynamic Bayesian network model	Suk et al., 2010
CLASSIFIER FUSION	HMM and ANN based models	Corradini, 2001
	Fusion of HMM and Recurrent Neural Networks (RNN)	Ngand et al., 2002
	Boosted cascade of classifiers trained by AdaBoost and informative Haar wavelet coefficients	Dinh et al., 2006
	SVM fusion (Belief based)	Burger et al., 2008
	Traditional Single classifier	Hai et al., 2012

	AdaBoost and rotation forest fusion	Wang et al., 2012
	Naïve Bayes and ELM	Singha et al., 2016
	NF and VDBC classifiers	Misra et al., 2019

7. Conclusions

Hand gesture recognition has great potential to extend the application in contactless Human-computer interaction (HCI), which is currently done with the help of keyboards, mice, or joysticks. To increase flexibility in the application for disabled people, these systems provide a good and developing platform. HCI systems will be easy to use; user-friendly and can provide easy access to a vast range of applications.

The initial step in any hand gesture recognition is to detect and extract the hand from the background. There are various difficulties during this phase, such as a cluttered background, illumination problems, occlusion, etc. The second problem is the tracking of the hand. To achieve the correct gesture trajectory, the hand must be tracked correctly in every video frame. This phase is affected by different scenarios like varying gesticulation speed and pattern.

The third problem is detecting and removing unwanted hand movements, which may be intentional (self-co-articulation) or unintentional (hand trembling). Detecting these unwanted strokes will make the system easier to recognize. The fourth problem is to develop a robust feature set for the system. The last issue is to develop a system that should be able to recognize a continuous sequence of data that are connected by self-co-articulation, movement epenthesis, and other unwanted hand movements.

Multiple researchers worked to solve these issues differently. This paper briefly surveys most of the significant work carried out in hand gesture recognition. The various models proposed by the researchers to design the hand gesture recognition system and the techniques to improve the performance have been presented. This survey has tried identifying more than one hundred and thirty research publications. A lot of potential is present in the hand gesture recognition system inspiring the researchers to design efficient and accurate gesture recognition systems.

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Design of tofu pressing tool based quality function deployment: A case study

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Abstract

This paper aims to design an innovative tofu pressing tool using the Quality Function Deployment (QFD) to increase the productivity of tofu in Small and Medium-sized Enterprises (SMEs). A case study was carried out at the Wardi Tahu enterprise in Indonesia. The QFD method was adopted in this study to integrate the customer's needs into the design process for the tofu press device. The House of Quality (HoQ) was developed to determine the relationship between technical characteristics and the customer's needs to obtain the design decision for the tofu pressing device. The determination design of the tofu press tool resulted in an innovative pneumatic system: tofu mould covers with perforated plates, removable tofu mould covers, corrosion-resistant materials, electric actuators, simple switching system, hygienic, modular design, formability and machinability, and easily accessible components. As a result, in this study, a pneumatic system tofu pressing machine has advantages over a manual tool, such as no longer need to lift a bucket filled with water as ballast, being easy to operate, being safe when operating, and simple, the tool can press faster, corrosion resistant and hygienic material of tool, easy to clean tool, increase the amount of production and hygiene process of tofu production.
Keywords: Customer voice, innovative design, quality function deployment, tofu pressing tool.

1. Introduction

The high demand for tofu makes the development of the tofu-making industry more rapid. This can be seen from a large number of tofu-making industries, both at home scale with a small number of workers and large-scale industries with a larger number of workers, where the tofu production process generally still uses traditional tools (Soares et al., 2019). The tofu production process begins with the selection of soybean raw materials, soaking, grinding, cooking, filtering, clumping, pressing, printing, and cutting. One of the processes of pressing tofu that is still carried out by many SMEs (Small and medium-sized enterprises) is the traditional process of using river rock or a bucket filled with water, which this traditional process of pressing tofu takes a long time. Other tools use levers and human power as actuators during the pressing process, so they are less effective in terms of time and effort. Therefore, an innovative design of a tofu press tool is needed to suit the needs of SMEs, which are expected to be able to help SMEs increase the productivity of tofu production. One design method that accommodates customer needs is Quality Function Deployment (QFD) method.

The Quality Function Deployment (QFD) is a tool that helps translate consumer language into a product that truly meets consumer needs (Jaiswal, 2012). The QFD is a methodology for translating consumer wants and needs into a product design that has certain technical requirements and quality characteristics (Aydin et al., 2023; Rahman et al., 2023; Yang et al., 2022). The basic target of QFD is to motivate product developers through a systematic method of transmitting the voice of the customer to designs so that an evaluation of potential responses to meet universal consumer wants and needs is obtained. This is important because almost all organizations (businesses) experience competition, such as price changes, new product introductions, or product innovations on existing products. Some of the advantages of implementing QFD are: improving product quality, increasing customer satisfaction, improving communication, increasing productivity, increasing product excellence, shortening time to market, reducing design

budgets, and increasing company profits (Asfia et al., 2021; Wolniak, 2018; Zengin & Ada, 2010).

There are several important aspects of the QFD system (Govers, 2001), such as the main focus of QFD are customer needs and consumer expectations for the product. Usually, QFD is based on projects and the use of cross-functional teams, which states that all members involved in the product development organization influence the product. One of the QFD tools is the House of Quality (HoQ), which is a graphical technique for defining the relationship between customer desires and products or services (Nugroho & Susilowati, 2022; Aghdam et al., 2015; Kuei, 2002). The HoQ is compiled from the level of interest by consumers, the level of customer satisfaction, technical parameters, the relationship between consumer interest attributes and technical parameters, analysis of the relationship between technical parameters, the value of the level of technical importance, and the value of the level of relative technical importance, which can be seen in one scheme (Prasad, 1998; Wicaksono et al., 2021).

The use of the QFD method with a house of the quality tool has been carried out by several previous researchers to link customer desires with product design (Sivasankaran 2021; Arifin et al., 2021; Bigorra & Isaksson, 2017; Mesbahi et al., 2020; Pardosi & Susilawati, 2023; Yohanes & Azhar, 2023; Sidanta, et al., 2016). Research results on Pardosi & Susilawati (2023) designed an areca nut peeling machine based on the Quality Function Deployment (QFD) and HoQ method to optimize the areca nut peeling process. Yohanes & Azhar (2023) used the Quality Function Deployment (QFD) method to design biomass stove products and the House of Quality matrix was used to analyze people's wishes associated with the design features of biomass stove products. The research conducted by Sidanta et al. (2016) designed a tofu pressing machine using Quality Function Deployment (QFD) and Teorija Rezhenija Izobretatelskih Zadach (TRIZ) method. However, it was a manually press machine, which manually processes that takes quite a long time to produce the tofu. Considering operating time is very important, with good time management, can increase the amount of production. Maukar et al. (2019) developed a tofu device in the form of a multi-level wooden box. In the wooden box is carried out the process of pressing tofu, filtering tofu wastewater, printing, and cutting tofu. This device can replace the process of compacting, pressing, filtering, printing, and cutting tofu in one system. However, it uses manpower to operate the device. Using human power as a compressive force is less efficient because the force exerted is not constant. Each human being does not exert the same force on the pressure lever. Therefore, the purpose of this study is to design an innovative pneumatic system for tofu pressing tools using the Quality Function Deployment (QFD) method to help increase tofu productivity in SMEs (Small and Medium Enterprises. A case study was conducted in a tofu factory on an SME scale in Pekanbaru City, Indonesia.

2. Method

This study adopted the QFD method using the HoQ tool approach. The research was conducted at the Wardi Tahu factory, a Small and Medium Enterprise scale factory in Pekanbaru City, Indonesia. The tofu production process in the case study used traditional tools, especially for pressing, still using a 25 kg water bucket as the ballast. The bucket was filled with water until it was complete. The pressing process that used this bucket still has drawbacks and a low level of security. Tofu mold containers still used wood, which was the wood material that quickly weathered caused by the water used. Therefore, this research designed an innovative tofu press tool that can make it easier for the tofu industry players to ease the work in the tofu pressing process according to customer wishes (the case study was conducted in the Wardi Tahu factory). The use of Quality Function Deployment (QFD) in this design process was to determine the needs of the tofu pressing tool required by the Wardi Tahu factory.

The census sampling method was used in this study. The census was a sampling technique when all members of the population were used as samples (MacDonald, 2020; Skinner, 2018). The samples in this study were all employees of the Wardi Tahu factory with 8 respondents, 5 men and 3 women. This sampling was carried out for all employees in the case study according to the census sample method. Direct interviews with tofu-making workers carried out the identification of consumer needs. This interview was conducted to obtain the needs of tofu-making workers for tofu press tools. In the interview, statements were obtained from tofu pressing workers. It can be seen in Table 1.

The results of the interpretation of consumer needs were used in determining product attributes. A closed questionnaire was made from the results of interviews that produced interpretations of needs and product attributes.

Table 1. Identification of consumer needs in a case study.

No.	Statement	Interpretation of needs
1	The slip when lifting a bucket filled with water as a ballast resulted in an injury to the operator	Safe tools to used
2	Lifting a bucket filled with water causes pain in the body	Convenient tool to use
3	The ballast takes a long time to finish pressing	More efficient ballast
4	Weathered mold cover	Requires a material that resistant to water
5	Clean the old mold cover	Easy-to-clean mold cover material
6	Small-size mold requires a lot of tofu mold	Additional dimensions according to production needs

The closed questionnaire research related to consumer needs consists of 6 questions, which were answered by respondents using a Likert scale (Mushtaha et al., 2022; Akdağ et al., 2016). This study adopted a 5-point Likert scale: (1) Not important, (2) Less important, (3) Important, (4) Very important, (5) Extremely important. The six consumer needs were used as the basis for the questions in the research questionnaire:

1. Tool was easy to operate.
2. Tool was safe when operated and simple.
3. Tool can press faster.
4. Corrosion-resistant and hygienic material.
5. Easy to clean tool.
6. Increase the amount of production.

The questionnaires were distributed to Wardi Tahu staff and management, where all employees served as resource persons to fill out the questionnaire. After obtaining the voice of the customer from the closed questionnaire, a house of quality was built. The stages of building a house of quality:

1. Determine the technical characteristics.

Technical characteristics were: the way and how the voice of the customer was executed. In other words, the characteristic of the technique can be achieved by the engineer to fulfil the consumer's desire.

2. Determine the relationship between technical characteristics.

The relationship between the technical characteristics was obtained through the distribution of the questionnaire to experts. At this stage, the relationship between each of the existing design characteristics was determined to analyse whether there was a contradictory (negative) relationship between these technical characteristics. The level of relationship between technical characteristics and the customer's needs was described as the level of relationship between each of the existing technical characteristics. The following symbols were used (Cohen, 1995):

+ = level of strong positive relationship (value 4).
+ = moderate positive relationship level (value 3).
O = no relationship (value 2).
- = medium negative relationship level (value 1).
- = level of strong negative relationship (value 0).

The relationship between the technique characteristics produced a degree of difficulty, which was a value in the difficulty level of a technical characteristic (Table 2).

Table 2. Level of difficulty (Cohen, 1995).

Level of difficulty	Statement
1 – 5	Easy
6 – 10	Quite easy
11 – 15	Difficult
16 – 20	Very difficult

Determining the relationship between technical characteristics and the voice of the customer was the distribution of questionnaires to produce a degree of importance. It became the importance level value of the technical attributes. The questionnaire started from a scale of strong, medium, weak, and not related at all. The assessment was based on the rules (Cohen, 1995):

Value 5: indicates a strong relationship.
Value 3: indicates a moderate relationship.
Value 1: indicates a weak relationship.
Value 0: indicates no relationship at all.

The relationship between technical characteristics and the voice of the customer produced a degree of importance. The degree of importance was a value of the level of importance of technical attributes (Table 3). Determining the relationship between technical characteristics and the voice of the customer was the distribution of questionnaires to produce a degree of importance. It became the importance level value of the technical attributes. The questionnaire started from a scale of strong, medium, weak, and not related at all. The assessment was based on the rules (Cohen, 1995):

Value 5: indicates a strong relationship.
Value 3: indicates a moderate relationship.
Value 1: indicates a weak relationship.
Value 0: indicates no relationship at all.

The relationship between technical characteristics and the voice of the customer produced a degree of importance. The degree of importance was a value of the level of importance of technical attributes (Table 3).

Table 3. Level of importance (Cohen, 1995).

Level of importance	Statement
1 – 5	Not too important
6 – 10	Quite important
11 – 15	Important
16 – 20	Very important

Finally, the House of Quality (HoQ) was constructed based on the sequence's priorities, design targets, and demand fulfilment embodied in the technical specifications of the latest design development.

3. Result and Discussion

Table 4 displays the outcomes of the research questionnaire data collection. The amount of relevance for each consumer demand was computed using the Likert technique, which involved adding up all of the respondents' preferred values for each item. The level of relevance was calculated based on the total values.

The customer's voice was determined via distributing questionnaires. Table 5 shows a recapitulation of open questionnaire findings from highest to lowest ratings. Technical characteristics were arranged based on consumer needs resulting from a closed questionnaire.

The determination of technical attributes was four criteria: materials, control systems, design concepts, and drive resources. Based on the four criteria, the feature of the technique obtained 9 points of technical attributes as follows:

1. Corrosion resistant material
2. Hygienic
3. Formability and machinability
4. Modular design
5. Components are easy to find
6. Mould cover using a perforated plate
7. Simple switching system
8. The mould cover was effortlessly off
9. Electric actuator

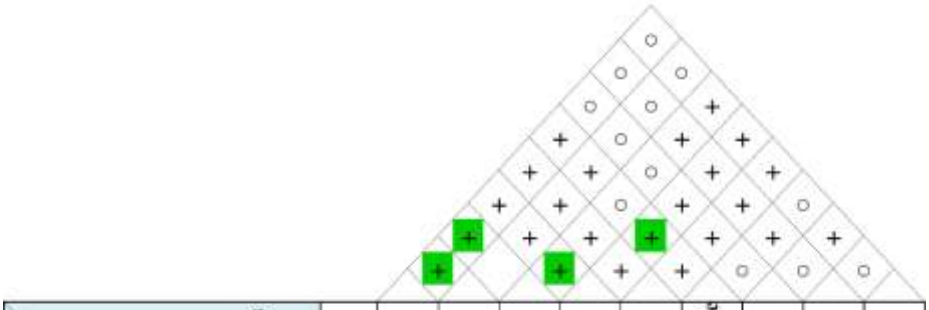
The expert gave a scoring to determine the relationship among the technical characteristics, between the customer's requirement and each technical attribute. Fig. . ure 1 shows the results of assessing the relationship between technical characteristics.

The final HOQ results show the priority of technical characteristics. The priority order of technical attributes from highest to lowest values; can be seen in Fig. . ure 2. The value of the most importance level to less importance level of technical characteristics priority was:

1. Cover of tofu mould using a perforated plate
2. The lid of the tofu mould was easy to remove
3. The material was resistant to corrosion
4. Electric actuator
5. Simple switching system
6. Hygienic
7. Modular design
8. Formability and machinability
9. Components were easy to find.

Table 4. Questionnaire summary result in the case study.

Respondent	Result of Questionnaire					
	The tool was easy to operate	The device was safe when operational and simple	The tool can press faster	Tool material was corrosion-resistant and hygienic	The device was easy to clean	Increasing the amount of production
Respondent 1	5	5	5	4	4	5
Respondent 2	5	5	4	4	4	5
Respondent 3	5	5	5	5	5	5
Respondent 4	5	5	4	4	3	5
Respondent 5	5	5	5	5	5	5
Respondent 6	4	4	3	3	3	4
Respondent 7	5	5	5	5	4	5
Respondent 8	5	5	5	4	5	5
Total	39	39	36	34	33	39



Customer Requirements \ Functional Requirements		Corrosion resistant material	Hygenic	Formability and machinability	Modular design	Components are easy to find	Mold cover using a perforated plate	Simple switching system	Mold cover is easy off	Electric actuator
Tools that are easy to operate	39							5	5	5
Tool that is safe when operated and simple	39							3	3	3
Tools can press faster	36			1	1		5	1		5
Corrosion resistant and hygienic material	34	5	5	3	5	5	5			
Easy to clean tools	33	5	5	3	3		3		5	
Increase the amount of production	39	3		1		1	1			
Relative Weight		452	335	276	304	209	488	348	477	420

Fig. 1. House of Quality (HoQ) in the case study.

The technical characteristics used as the basis for the innovative design of the tofu press tool. The electric actuator functions as a source of propulsion for the device. The operation of the tofu press tool is designed to use a pneumatic system. Based on the HoQ and priority of technical characteristics, the design of the tofu press tool is shown in Fig. . ure 3.

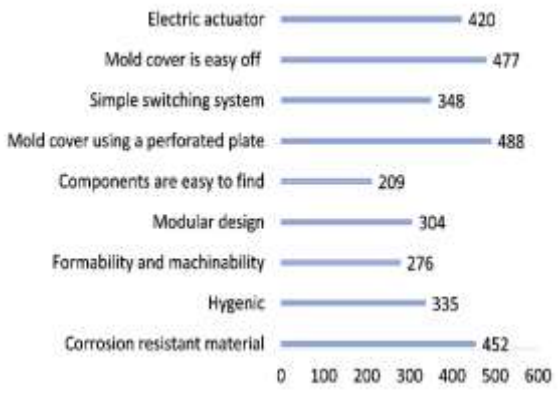


Fig. 2. The value of priority technical characteristics.

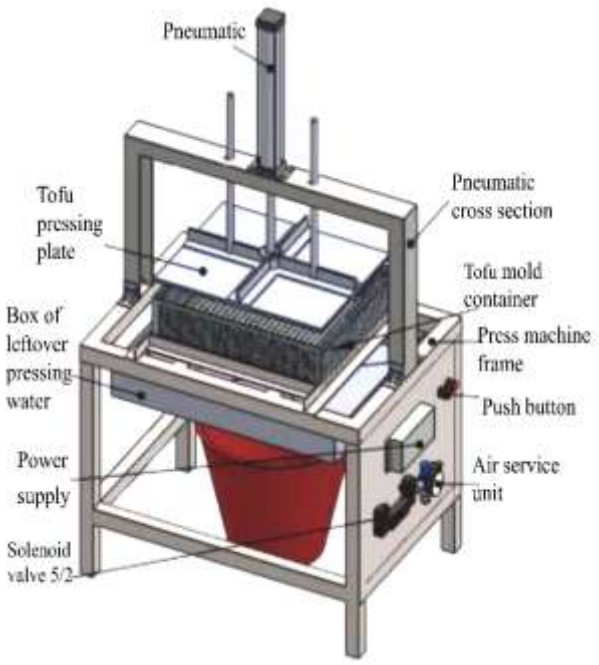


Fig. 3. Design of a pneumatic system of tofu pressing tool.

The stainless steel was the material for the pneumatic system of the tofu pressing tool. Stainless steel has various advantages as being rust-resistant and easily cleaned. The application of this material answered the consumer's needs for materials that were resistant to corrosion and hygienic, as well as for tools that were easy to clean. The pneumatic type was SC 32x500 of pneumatic standard cylinder, double acting type cylinder. A double-acting pneumatic cylinder has two ports that allow pressure to pull the piston in the opposite direction to that created by the first port, otherwise known as fast travel and outward stroke. The pneumatic press referred to the consumer's need for a tool that was safe when operating and simple.

The height of the tofu press tool structure was 700 mm, 650 mm wide, and 1000 mm long (Fig. . ure 4). The machine structure height of 700 mm can make it easier for the operator to fill the tofu essence during the pressing process. The structure width of 1000 mm can increase the size of the tofu container compared to the old tool was too small. The iron plate that was on the top side of the frame served to hold the tofu container. Hence, it remained a flashlight with the tofu pressing plate.

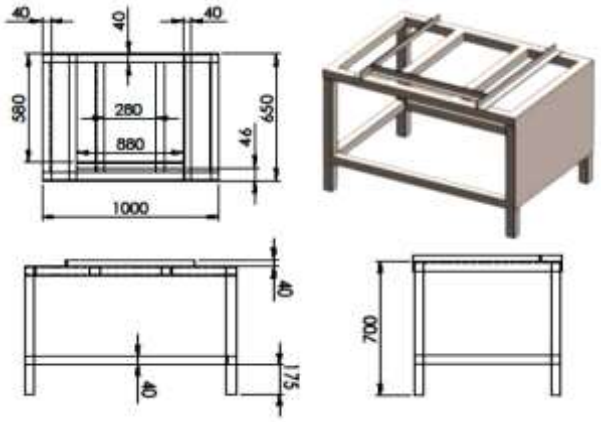


Fig. 4. Design of tofu press machine structure.

Previously, the tofu mould container size was 500 mm x 500 mm. According to customers' needs in the case study, this increased the production output. Therefore, the new design of the tofu mould container size was modified to 580 mm x 880 mm (Fig. . ure 5a). Increasing tofu container size can raise the amount of tofu production. The container for the tofu mould is divided into two parts. The first part was the cover for the tofu mould with a height of 150 mm and the base for the mould with a high of 50 mm. The purpose of dividing this into two parts was to make it easier for the operator when cutting tofu. It was suitable according to consumer needs and awarded the first preference (Table 5), which was an easy-to-operate press tool. The material used in the tofu mould container of a perforated stainless steel plate with a thickness of 5 mm. The hole in the tofu mould container was to speed up the separation of water and tofu starch during the pressing process.

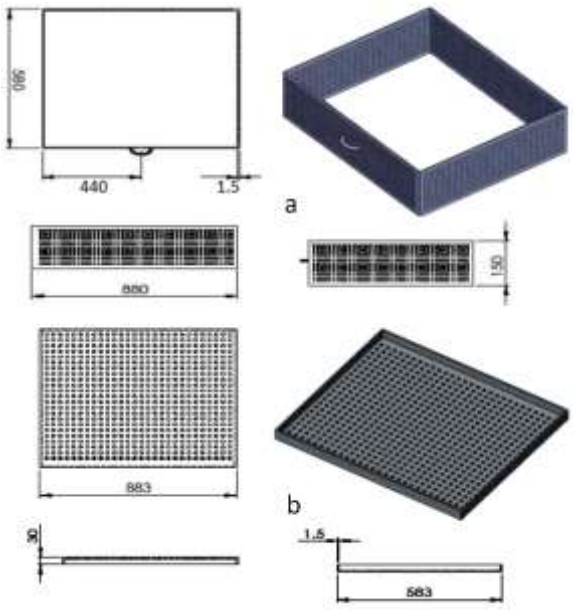


Fig. 5. Design of (a) tofu mould container cover, (b) tofu mould container base.

The box functions as a reservoir for water from tofu starch, which was squeezed out during the pressing process. So, it did not get scattering and can be directed to the bucket. The box size was 920 mm x 600 mm. The box of water left over from pressing functions as a reservoir for water from tofu starch. The size of the remaining pressed water box was determined proportionally to the size of the press machine frames. The design of the remaining pressed water box can be seen in Fig. . ure 6.

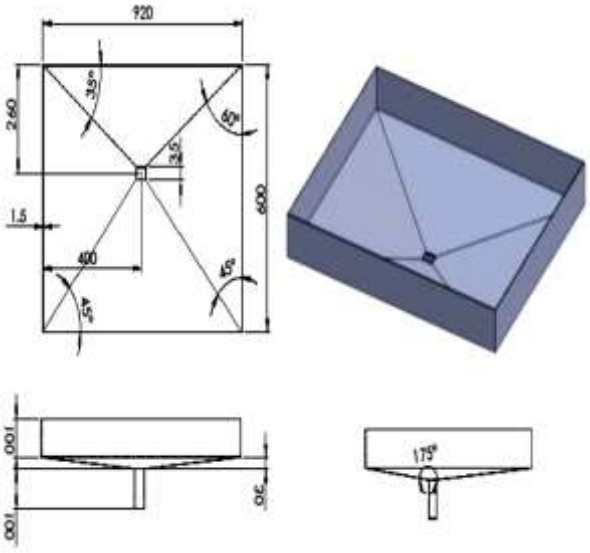


Fig. 6. The box of reservoir for water tofu starch.

The tofu pressing plate functions to transform the pneumatic thrust to all sides of the tofu container during the tofu pressing process. The design of the plate for press tool tofu can be seen in Fig. . ure 7. The size of the tofu pressing plate was 877 mm x 577 mm.

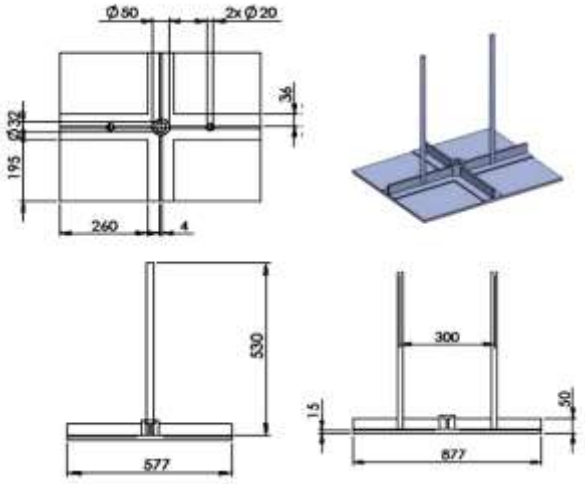


Fig. 7. The plate of the tofu press tool.

The pneumatic support pole served to support the pneumatics. The size of the pneumatic support pole was 1000 mm long, 50 mm wide, and 700 mm high. The design of a pneumatic support pole for press tool tofu can be seen in Fig. . ure 8. The size of the pneumatic support rod with a length of 1000 mm was proportional to the length of the machine table. The width of 50 mm was obtained from the dimensions of the U-channel iron used, and the height of 548 mm was obtained from the piston rod length of 500 mm plus the final result of pressing, which was 25 mm (thickness of tofu) and the size of the pressing plate that has been installed with a pneumatic cylinder, which was 23 mm. The pneumatic support pillar served to support the pneumatic cylinder. The pneumatic support pole design can be seen in Fig. . ure 8.

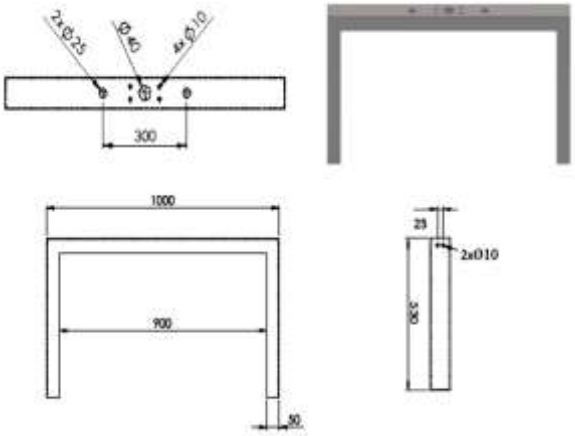


Fig. 8. The pneumatic support pole of the tofu press tool.

To assess the final result of a product as a good design value category consists of three elements must be met, functional, aesthetic, and economic (Zengin & Ada, 2010; Han et al., 2021; Candi et al., 2017). The function and aesthetic elements are often called fit-form-function, while the economic element is more influenced by price and purchasing power. Therefore, the functional element has been fulfilled with benefits for tofu entrepreneurs who still use the traditional pressing method. This study resulted in a pneumatic system tofu pressing machine design that can benefit tofu entrepreneurs such as: no longer need to lift a bucket filled with water as the ballast, easy to operate the tool, the tool is safe when operated and simple, tools can press faster, corrosion resistant and hygienic material of tool, easy to clean tool, increase the amount of production, and hygiene process of tofu production. This tofu press device design can combine several processes to save time in the production process of tofu as compacting and pressing tofu, and filtering out excess water. In addition, workers do not directly touch the tofu in the pressing process and filter out the leftover tofu. Sub-sequence, it can improve hygiene in tofu products.

The aesthetic element has been fulfilled with the appearance of a pneumatic system tofu pressing machine that looks modern. Whilst, the economic factor can be assessed after calculating the cost, which can be conducted in future studies.

4. Conclusion

The purpose of this study was to design an innovative pneumatic tofu pressing machine using the Quality Function Deployment (QFD) method as a case study. Based on the result in the case study obtained voice of the customer, namely: the tool was easy to operate, safe, and simple; the tool could press faster; the materials were corrosion resistant and hygienic; easy to clean, and increased the amount of production. Then, the technical characteristics, which were parameters of importance level of an innovative pneumatic system tofu pressing machine design, namely: the cover of the tofu mould using a perforated plate, the cover of the tofu mould can be removed, the material was resistant to corrosion, electric actuators, simple switching systems, hygienic, modular design, formability, and machinability, and easy to find components.

The priority of technical characteristics based on the level of importance was the tofu mould cover using a perforated plate value of 488, the tofu mould cover can be removed value of 477, the material that was resistant to corrosion value of 452, the electric actuator value of 420, the simple switching system value of 348 and the hygienic

value of 335. This level of importance shows the most important thing in the design process of a pneumatic system tofu pressing machine. Further research can be carried out on design development, both in terms of the shape and size of a pneumatic system tofu pressing machine as well as the production cost analysis, manufacture, and test of the pneumatic system for the tofu pressing machine.

Acknowledgment

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Cotton leaf disease classification using YOLO deep learning framework and indigenous dataset

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Abstract

Cotton is one of the economically significant agricultural products in the world and is among the key export resources in Pakistan. Despite the significant pest control techniques and mechanisms, the cotton crop is highly prone to bacterial and viral plant diseases that significantly reduce its yield. Early detection can enable the identification of infected field patches and plays an important role in controlling the spread of the disease. This paper presents the automated classification for bacterial blight and curl virus in cotton plants through the customized implementation of a state-of-the-art YOLO deep learning framework. The disease classification is performed on YOLOv5, and its performance is compared against YOLOv6 and YOLOv7. The transfer learning of the pre-trained model is facilitated through an indigenous image dataset collected from local agricultural fields in Sindh, Pakistan. Different augmentation techniques are employed to increase the size and diversity of the dataset. The employed model is evaluated for various performance metrics, such as accuracy, mean average precision, and confusion matrix. The results indicate 92% accuracy in disease classifications. The confusion matrix analysis indicates up to 100% true positive rates for curl virus, and an 88% true positive rate for detecting bacterial blight and healthy leaves. An inference time of 25 milliseconds indicates fast prediction suitable for on-field real-time applications and potential incorporation of the model in the point of care testing (PoCT) devices.

Keywords: Cotton disease classification, deep learning, real-time detection, YOLO.

1.Introduction

Agriculture is a driving force behind the economic growth of a country and its success is highly dependent on the quality and quantity of its agricultural harvests. Cotton cultivation stands out as a major contributor to both the economy and industries of a nation. Not only does it provide essential fiber, but it also generates oil and protein, making it a valuable commodity on a global scale (Bodhe et al., 2018). However, the cotton crop is vulnerable to a variety of plant diseases that have caused a significant decline in its yield and productivity in recent years. These diseases often manifest as visible symptoms on the leaves of the plant, and while farmers have traditionally relied on their observations for diagnosis, this method is prone to inaccuracies and can result in the overuse of pesticides. This, in turn, can lead to further reductions in crop yield and potential harm to the environment. It is, therefore, of utmost importance to find an accurate and efficient method for diagnosing cotton crop diseases. In recent years, various machine-learning techniques and tools have been widely used to perform the automated detection of plant diseases in cotton crops (Ahmed, 2021; Kumar et al., 2021; Prashar et al., 2017; Zekiwos & Bruck, 2021). The development of a reliable model that can diagnose cotton crop diseases with precision and speed is crucial to prevent the spread of diseases in the early stages and to ensure the right amount of pesticide is applied to affected plants.

This work presents the automated cotton plant disease classification method based on you only look once (YOLO) deep learning model. Compared to the existing works, the presented work uses the locally collected dataset combined with the dataset available from online resources and performs the detailed implementation of YOLOv5, and compares it with YOLOv6 and YOLOv7. The subsequent sections are distributed as follows: Section II presents the review of existing literature on plant leaf classification. Section III discusses the methodology of the presented implementation, and Section IV presents and discusses the results.

2.Literature Review

The detection of crop plant diseases has been explored using various techniques and methods. Following is a brief review of existing relevant literature work.

Ashourloo et al., 2016 used machine learning algorithms such as partial least square regression (PLSR), ν

support vector regression (v-SVR), and Gaussian process regression (GPR) methods to detect wheat leaf rust disease (Ashourloo et al., 2016). They evaluated the impact of the training data on the results and explored the influence of disease symptoms on the prediction performance of the ML algorithms. The performance of the machine learning methods is compared with the spectral vegetation indices (SVIs). Rothe et al.,2012 introduced a pattern recognition-based method to identify and classify cotton leaf diseases such as Bacterial Blight, Myrothecium, and Alternaria (Rothe & Kshirsagar, 2012). They collected images from the local fields and performed image segmentation techniques to extract features for the training of an adaptive neuro-fuzzy inference system. The proposed method achieved an accuracy of 85%. Arsenovic et al., 2019 presented a hybrid model known as Plant Disease Net to detect and classify different diseases (Arsenovic et al., 2019). They developed a dataset comprising 70,000 images and applied augmentation techniques to expand the data set. The images were captured under diverse weather conditions, at different angles, and during various daylight hours. The accuracy achieved with the hybrid. Xu et al., 2018 developed a method to detect and quantify cotton flowers, or blooms, using color images captured through an unmanned aerial system (Xu et al., 2018). They collected aerial images of the field for four days and applied a CNN model to identify cotton blooms.

Jubayer et al., 2021 employed YOLO v5 technique to identify different types of molds grown on various food surfaces. They developed a dataset comprising 2050 images and trained the YOLO v5 algorithm (Jubayer et al., 2021). The proposed technique gave better accuracy as compared to the YOLO v3 and YOLO v4. The proposed YOLO v5 model gave precision and recall of 98.1% and 100% respectively. Qian et al., 2022 employed a deep-learning (DL) approach using YOLOv5 to detect Cotton root rot (CRR) infected areas in a cotton field (Qian et al., 2022). They demonstrated the real-time capability of the algorithm by deploying it on a computing platform such as the Pascal GPU of the NVIDIA Jetson board. The GPS information can be extracted from CPR regions and the generation of the optimal path for the management practices is possible. The proposed method can be helpful for the precise application of fungicides in cotton fields. Wang et al., 2022 proposed a plant disease detection and classification approach based on an optimized lightweight version of the YOLOv5 model to enhance the speed and accuracy of disease classification (Wang et al., 2022). They introduced an Improved Accuracy and Speed Mechanism (IASM) to reduce model size. The optimized model was compared with the other mainstream models and the optimized model showed a performance improvement of 11.8% in operation time and 3.98% in accuracy. The model has achieved an accuracy rate of 92.57% on the custom dataset. Another research presented a lightweight detection model called Apple-YOLO, specifically designed for real-time detection of apple leaf diseases on mobile terminals (Li et al., 2022). They used digital image processing and mosaic data augmentation techniques on the AppleSet8 dataset to enhance the model's robustness and generalization capabilities. The results showed that the mobile-based Apple-YOLO model achieved a mean average precision (mAP) of 96.04%, an impressive inference speed of 34 frames per second (FPS), and a compact size of only 5.33 ME (model efficiency). It indicates its suitability for real-time detection of early apple leaf diseases in practical scenarios. Jhatial et al., 2022 proposed a deep-learning model for the early identification of rice leaf diseases using Yolov5. The model was trained on a dataset of 400 images of rice leaves infected with diseases. The results showed that the DL model has precision, recall, and mean average precision (mAP) values of 1.00, 0.94, and 0.62, respectively (Jhatial et al., 2022). Xue et al., 2023. proposed YOLO-Tea, an enhanced version of YOLOv5 for the precise diagnosis of tea tree leaf diseases and insect pests. The proposed model outperformed Faster R-CNN and SSD. However, the study lacks a comparison with other cutting-edge models and does not address the constraints of employing YOLO-Tea in real-world circumstances. Further research is required to determine how well YOLO-Tea holds up under various environmental circumstances (Xue et al., 2023). Zhu et al., 2023 proposed the Apple-Net model for the detection of apple leaf diseases. The Enhancement Module (FEM) and Coordinate Attention (CA) methods were used to enhance the conventional YOLOv5 network. They showed that Apple-Net has a higher mAP@0.5 (95.9%) and precision (93.1%) as compared to four classic target detection models (Zhu et al., 2023).

Table 1. Comparison of different deep learning implementations for plant leaf disease detection.

Author	Year	Model(s)	Accuracy	Data Size	Data Source
Ashourloo et al.	2016	PLSR, ν-SVR, GPR	93%	175 images	Indigenous
Rothe et al.	2015	Adaptive neuro-fuzzy inference system	85%	-	Online
Arsenovic et al.	2019	Hybrid model of Yolo and AlexNet	93.67%.	70,000 images	Online
Xu et al.	2018	CNN	94%	28,000 images	Indigenous
Jubayer et al.	2021	YOLOv5	98.1%	2050 images	Indigenous+Online
Qian et al.	2022	YOLOv5	93%	-	Indigenous
Wang et al.	2022	Optimized lightweight YOLOv5	92.57%	3265 images	Indigenous+Online
Li et al.	2022	Apple-YOLO	96.04%	587 images	Indigenous
Jhatial et al.	2022	YOLOv5	62%	400 images	Online
Xue et al.	2023	YOLO-Tea	82.6%	450 images	Indigenous
Zhu et al.	2023	Apple-Net	95.9%	12,500 images	Online
This Work	--	YOLOv5, YOLOv6v YOLOv7	Up to 92%	5046 images	Indigenous+Online

The use of deep learning models for detecting plant diseases has been investigated in numerous studies. Several of these studies utilized publicly available datasets and achieved good accuracy by employing techniques such as YOLOv3. However, the limited availability of appropriate image datasets has posed a challenge for many researchers in this field. Furthermore, the studies comparing the performance of YOLOv5, YOLOv6, and YOLOv7 on custom datasets are largely missing in the literature. Therefore, more investigation is required to determine the performance of these models on unique datasets with sufficient sample sizes and to compare the latest deep learning models such as YOLOv5, YOLOv6, and YOLOv7.

3. Methodology

The YOLOv5 object detection model is among the most recent innovations in the YOLO architecture. The model employs a single-stage object identification strategy and uses transfer learning by combining a backbone architecture that pulls information from picture frames. The backbone characteristics are combined in the neck and relayed to the network head, where the model forecasts the object's position and class. One of the most notable features of the YOLOv5 model is its computational efficiency, which is accomplished by reducing the number of parameters and processing as compared to state-of-the-art real-time object detectors.

This work employs a transfer learning-based YOLOv5 model to distinguish between diseased and healthy cotton plant leaves. Our methodology consists of six essential consecutive steps. The first step involves the sourcing of a dataset from the local agricultural field which is combined with a dataset available online and is used to train and validate the model. In the second step, we utilize Roboflow to annotate all images in the dataset with their corresponding classes. This step involves both box annotation and polygon annotation to reduce noise in the datasets. The third step consists of implementing the data augmentation techniques while the fourth step implements the model. The last step involves the testing and validation of the implemented model and its comparison with YOLOv6 and YOLOv7.

3.1. Dataset Collection

The dataset is sourced in two different ways. A significant part of the dataset was collected from local sources, while another part was obtained from online sources. A total of 1000 images were captured from the local agricultural fields in southern Sindh, which consisted of images representing healthy leaves, and images of the cotton plant leaves infected with bacterial blight and curl virus.

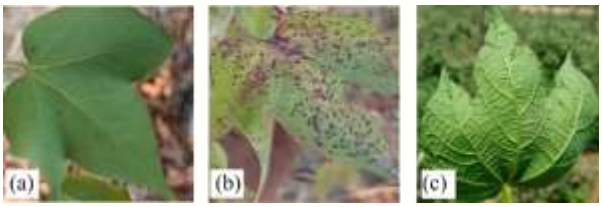


Fig. 1. Sample images from the locally collected dataset showing (a) healthy leaf, (b) bacterial blight, and (c) curl virus in cotton crop plants.

Fig. 1 shows the sample images for each of the categories. Another 1000 images representing the same properties were collected from Kaggle (Cotton Disease Dataset | Kaggle, 2022), GitHub, and Google. To avoid the size inconsistencies in collected images, all the images were downsized to a fixed resolution of 642×642 pixels.

3.2. Dataset Annotation

Image annotation is essential before performing the training of a deep learning model. A deep learning model learns using features extracted from the images and the labels associated with them (Haque et al., 2022). Throughout the training process, a deep learning model acquires insights from the features of the labeled images. Therefore, the quality of the feature labeling greatly influences the accuracy of a model. We used Roboflow, an open-source framework, to perform the annotation. The annotation involved the manual selection of bounding boxes in the dataset images and the assignment of labels to each of the bounding boxes. Fig. 2 shows the set of images annotated using Roboflow. The total dataset is divided into training and testing datasets. The training dataset contains 70%, while the testing dataset is 30%. Since the presented model is trained for three different classes, each bounding box is assigned one of three labels (healthy, bacterial blight, or curl virus). The annotation file generated using Roboflow contains five parameters for each dataset image, representing, class label, coordinates for the bounding box center, and width and height of the bounding box. Labeling is performed on both testing and training datasets to ensure that the model has a comprehensive understanding of the different classes of images.

Fig. 2. Output of Roboflow showing the annotated sample images from the dataset.

3.3. Dataset Augmentation and Splitting

The amount and diversity of the dataset are directly proportional to the performance of a model. The large number of samples solves the over-fitting issue of the model and helps to develop a model for the generalized scenarios in real-time testing. The lack of data may result in an under-fitting problem during training (Mathew & Mahesh, 2022). However, collecting a large amount of data for model training is a complicated process. Data augmentation is a practical and widely used tool to increase the size of the dataset and solve the over-fitting issue. Geometric image transformation is one of the prominent. The amount and diversity of the dataset are directly proportional to the performance of a model. The large number of samples solves the over-fitting issue of the model and helps to develop a model for the generalized scenarios in real-time testing. The lack of data may result in an under-fitting problem during training. However, collecting a large amount of data for model training is a complicated process.

Data augmentation is a practical and widely used tool to increase the size of the dataset and solve the overfitting issue. Geometric image transformation is one of the prominent methods used for data augmentation. We use four different geometric image transformation processes (rotation, flipping, shear, and saturation) to perform the data augmentation which is shown in Fig. . 3. The augmentation provided a total of 5046 images covering all three classes. The resultant dataset is then divided into training and validation datasets with a 70:30 ratio.

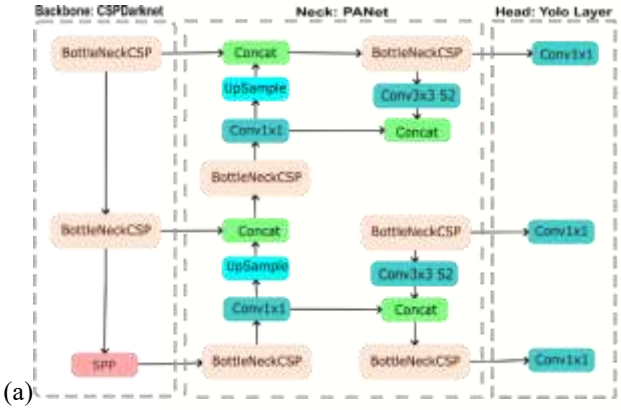
Fig. 3. Shows the samples of augmented dataset images, (a) original sample image, (b) counterclockwise rotated, (c) flipped vertical, (d) vertically rotation within ±15°, and (e) Vertical shear within ±15°.

3.4. YOLOv5 Architecture

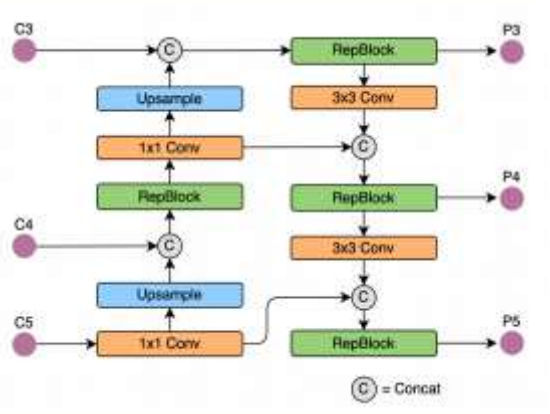
YOLOv5 (Jiang et al., 2021) is the upgraded version of YOLOv4 that provides high detection accuracy and inference speed as compared to the previous and latest YOLO versions such as YOLOv6 and YOLOv7 when trained on custom datasets (Olorunshola et al., 2023). The YOLO network is made up of three parts: (1) CSPDarknet as the backbone, (2) PANet as the neck, and (3) YOLO Layer as the head. The data is first processed by CSPDarknet for feature extraction, then by PANet for feature integration. Finally, the YOLO Layer provides detection results (class, score, location, and dimensions) for the provided input. Fig. 4 shows the overall architectures of different YOLO versions.

The main difference between each YOLO version is relays on the Backbone, Neck, and Prediction layers. The backbone is the first part of the YOLO model that extracts features from the input image. The backbone in YOLO v5 is the CSPDarknet53, which is a variant of the Darknet53 architecture. The backbone in YOLO v6 and YOLO v7 is the CSPDarknet53-L2, which is a more efficient variant of the CSPDarknet53 architecture. The neck is the part of the YOLO model that connects the backbone to the head. The neck in YOLO v5 is the PANet, which is a pyramid feature network. The neck in YOLO v6 and YOLO v7 is the BiFPN, which is a bi-directional feature pyramid network. Head The head is part of the YOLO model that predicts the bounding boxes and class labels for the objects in the input image. The head in YOLO v5 is the YOLOv3 head. The head in YOLO v6 and YOLO v7 is the YOLOv4 head.

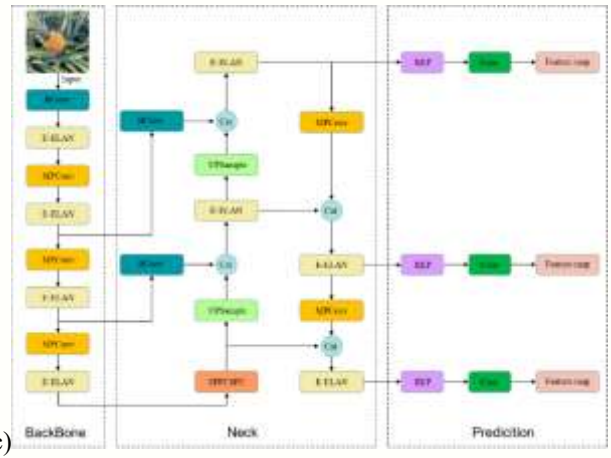
YOLO v5 uses a CNN architecture called EfficientDet. EfficientDet is a very efficient architecture, with fewer parameters and a higher computational efficiency than other CNN architectures. This makes it possible for YOLO v5 to achieve state-of-the-art results on various object detection benchmarks. For example, in the PASCAL VOC object detection benchmark, YOLO v5 achieved a mAP of 80.2%, which is better than the mAP of 79.5% achieved by YOLO v6 and the 78.9% achieved by YOLO v7. This shows that YOLO v5 is a better object detection model than YOLO v6 and YOLO v7.



(a)



(b)



(c)

Fig. 4. Architecture of different YOLO models, (a) YOLOv5, (b) YOLOv6, and (c) YOLOv7

3.5. Model Training

The training of YOLOv5 involves multiple steps. First, the YOLO environment is created by cloning the GitHub source and establishing a dedicated directory in Google Drive with the necessary structures and pre-trained weights. In the next step, a dataset folder is established with the predetermined subfolders to store images and associated labels for training and test files. The label files are formatted to include the class identification number and the normalized values for the bounding box representing its center coordinates, width, and height. A YAML file is set up to specify the paths to training and test data, the number of classes, and the labels for each class.

The model is then trained by executing the model training script with defined hyper-parameters such as image size, number of epochs, and batch size. At the end of the training procedure, the weights of the trained model are stored and later used for employing and testing the model. We used the Adam optimizer with the Swish activation function. The number of hidden neurons used is predefined by the architecture. The hidden layers include Convolutional, Activation (Swish), Downsample, and Fully Connected layers. The output layer provides bounding box coordinates, class predictions, and confidence scores for detected objects. A batch size of 32 was used.

4. Results and Discussion

The developed YOLOv5 model was trained for three classes: healthy leaf, bacterial blight, and curl virus. The model was compared to the YOLOv6 and YOLOv7, which were also trained through the procedure explained in the previous section. The models were trained on Nvidia Tesla T4 GPU available through Google Colab (Welcome To Colaboratory - Colaboratory, n.d.).

Precision, recall, and F-1 scores are among the key indicators to assess the performance of a deep learning model. The recall is determined as the ratio of positive samples that were accurately classified as positive to the total number of positive samples. The recall of the model measures its capability to recognize positive samples.

The more positive samples are identified, the higher the recall will be (Wang et al., 2022b). The F1-score consolidates a classifier's precision and recall into a single metric by determining their harmonic mean. Its primary purpose is to contrast the performance of two classifiers. The precision and recall can be mathematically represented using the following equations:

$$\text{Precision} = \frac{\text{TP}}{\text{TP} + \text{FP}} \quad (1)$$

$$\text{Recall} = \frac{\text{TP}}{\text{TP} + \text{FN}} \quad (2)$$

Where TP is the number of instances when the targeted classes are correctly identified, FP is the number of occurrences when the specified class is incorrectly identified, FN indicates the number of unidentified diseased and healthy parts, while TN represents the number of times when the model accurately categorizes the negative dataset as negative.

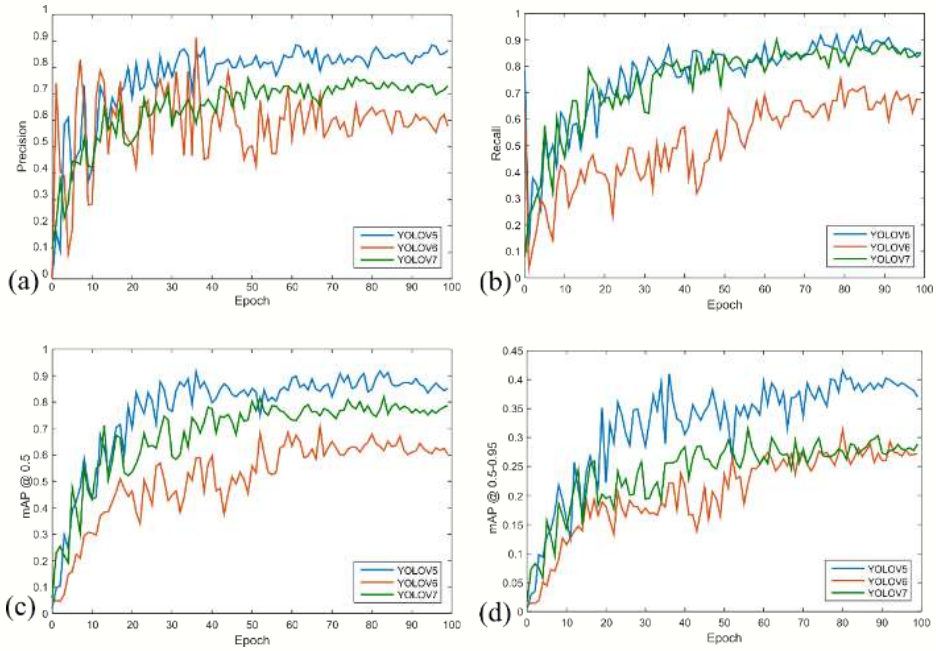


Fig. 5. Shows (a) Precision vs epoch, (b) Recall vs epochs, (c) mAP @0.5 vs epochs, and (d) mAP@ 0.5.0.95 of YOLOv5, YOLOv6 and YOLOv7.

Fig. 5 shows the comparison of important performance metrics of three implemented models for the detection of cotton plant diseases. The results indicate a noticeable positive slope with fluctuations in precision and recall for the first 30 iterations while a stable response is observed between 30 to 100 iterations. Fig. 5(a) indicates high precision, up to 92%, for YOLOv5 whereas YOLOv7 shows the lowest precision among all three models. Fig. 5(b) shows an identical recall trend for YOLOv5 and YOLOv6 while YOLOv7 depicts lower recall. Similarly, the mean average precision (mAP), shown in Fig. 5(c) and Fig. 5(d) is also higher for YOLOv5 when compared to the other two models. Fig. 6(a) shows the recall against confidence curves for three classes and their average. The result shows a higher confidence value. Similarly, Fig. 6(b) shows a direct relationship between precision and confidence for all three classes. The results indicate 100% precision for the confidence value of greater than 70%.

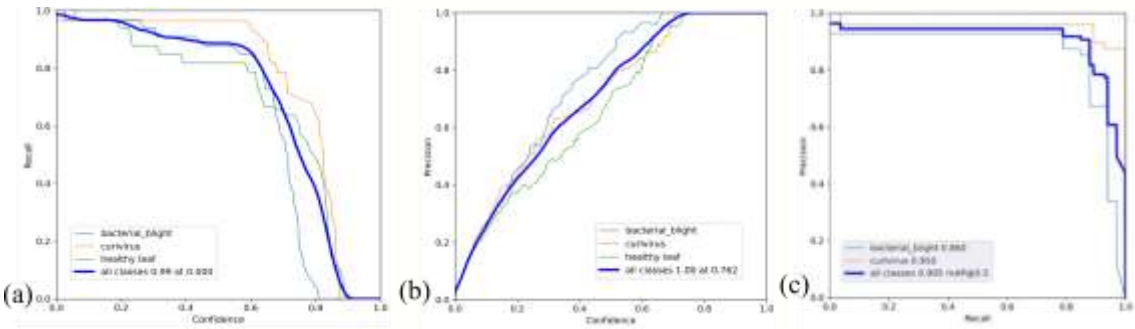


Fig. 6. (a) shows recall vs. confidence, (b) shows precision vs. confidence, and (c) shows the precision vs. recall for the implemented YOLOv5 model.

The present study shows the implementation of the multi-class problem that includes three classes, bacterial blight, curl virus, and fresh leave. The confusion matrix of the implemented YOLOv5 model is presented in Table 2, which shows 88% true positives for healthy leaves and bacterial blight whereas 100% detection accuracy is achieved for the curl virus. The inference time for all implemented models is < 25 milliseconds, which indicates that the proposed models can be easily implemented for real-time applications.

Table 2. Confusion Matrix of the YOLOv5 Model

	Bacterial Blight	Curl Virus	Fresh Leaf	Background
Bacterial blight	0.88	0	0	0.20
Curl Virus	0	1.0	0	0.10
Fresh leaf	0	0	0.88	0.70
Background	0.12	0	0.12	0

5. Conclusion

We proposed and demonstrated the implementation of cotton plant disease detection using YOLO deep learning framework and indigenously sourced dataset. The dataset annotation was performed using Roboflow while different geometric image transformation techniques were employed to perform the dataset augmentation. The augmented dataset was used for training three different YOLO versions. The precision and recall analysis indicated that YOLOv5 performing better than its advanced versions. The confusion matrix for YOLOv5 indicated higher detection accuracy, greater than 88% for healthy leaves, curl virus, and bacterial blight. The low inference time showed a higher detection speed suitable for real-time applications. The custom-trained model can be successfully employed on mobile and embedded computing platforms to enable fast and reliable testing of cotton plant diseases and curtail their potential spread well in time.

The current implementation shows great promise for disease detection in cotton crops through real-time classification. However, the present work also has some limitations. Our current local dataset is only limited to 1000 images. The performance of a deep learning model highly depends on the size of the dataset. Further work on sourcing the dataset from different localities of the region will further improve the accuracy and performance of the model. Another important limitation is processing power. The current implementation uses the Google Colab GPUs and Laptop CPU for training and testing respectively. However, for practical implementation, it is important to implement the model-embedded processing units. Future deployment of the presented implementation on FPGA or mobile processors will further improve the practicality of the study for disease detection in the field.

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Towards a robust solution to mitigate all content-based filtering drawbacks within a recommendation system

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Abstract

Recommendation systems deliver a method to simplify the user's desire. Recommendation systems are now commonly used on the Internet. It helps suggest items in various categories, including e-commerce, medical, education, tourism, and industrial. The electronic commerce sector has taken a big place in our daily lives as an active research tool, which helps people find what they are looking for. This paper presents a new contribution based on the combination of different algorithms to find a suitable solution to all the drawbacks of content-based recommender systems. The main contribution of this research lies in how to solve each problem and move on to the next. This paper describes an Ideal Solution Mitigating Content Disadvantages based on Three Phases called $ISMCD_{3P}$. Experiments show that the algorithm can propose an appropriate solution to solve all the problems of content-based filtering. Experimentations operating on real datasets are used to estimate the efficacy of our strategy.

Keywords: Content-based filtering drawbacks, Over-specialization, Limited content, Serendipity, Sparsity.

1. Introduction

Recommender systems are strategies and application solutions that offer consumers tailored recommendations concerning a selection of objects, such as goods, videos, music, or other resources (Oumaima et al., 2020). Recommender systems are beneficial when there is an information overload or when the user finds it difficult to navigate and make selections from the catalog due to the overwhelming number of options (Kumar & Thakur, 2018). Numerous online stores and multimedia services, such as Spotify, Netflix, YouTube, and Amazon, as well as social networking sites like Facebook and Twitter, have succeeded in increasing user satisfaction and revenue through the personalized assistance that recommender systems provide in the exploration and discovery of content. The last 10 years have seen an increase in interest in recommender systems, which is still an active area of study.

Recommender systems are computer programs that may examine a user's past actions and make recommendations for present problems. Consequently, to process data that might be quite vast in volume effectively. We frequently consult others while making decisions in life, whether it be choosing which shampoo or book to buy, music to listen to, a movie to watch (Saraswat et al., 2020), or an article to read (Stitini et al., 2021) on the Internet, among others. We may consult friends, family members, or more frequently these days online product reviewers. This has made the recommender's path more accessible.

Consumers have embraced e-commerce quickly thanks to the rise in the number of products available for purchase online and the accessibility of information on the features and functionality of these products. Online purchasing environments have become crowded due to the availability of information and options. Due to the overwhelming amount of options available to them and the abundance of information available for each, consumers are less motivated to filter and assess items (Papneja, 2018) as mentioned in Table 1. Numerous internet retailers provide thousands of unique items, including music, movies, books, and services. A store with a large selection of products is likely to have a product that suits customer preferences. Although more options are accessible, this does not always result in satisfied customers since it can occasionally be challenging to choose a product from the vast selection (Saraswat, 2022). Online vendors are using recommender systems more frequently to deal with the problem of information overload. These systems can be categorized into two types: non-personalized and personalized as mentioned in Fig. 1. Non-personalized algorithms offer the same recommendations to all users, based on factors such as item popularity. Conversely, personalized algorithms generate customized suggestions based on the individual user,

resulting in different recommendations for different users.

Fig. 1. Main Recommender System Types.

We concentrate on personalized recommendations in this study. Personalized recommender systems often offer recommendations based on user profiles. Any information about a person, such as an ID, age, gender, and historical activities the user has taken with objects, may be included in a user profile. In this essay, "user profile" refers to a collection of things the user has rated. This opened the door for recommender systems, which are now well-liked platforms for e-commerce. Systems that recommend user items based on their interests and preferences have been created. These solutions simplify things for customers to make decisions by managing information overload, cutting the cost of searches, and enabling users to make wiser, more informed decisions. Recommender systems frequently serve as a user's sales assistant by assisting them. At the same time, they browse, putting the finishing touches on the list of items they have selected and, most importantly, providing personalization.

The key contributions of this paper are as follows: Section 2 contains our literature assessment and theoretical basis. We outline our research contribution in Section 3. We describe our suggested recommender system model in Section 4. Then, in Section 5, we will elaborate on experimental results. In Sections 6 and 7, we discuss our proposed approach $ISMCD_{3P}$ with other related works. Section 6 compares our proposed approach with existing ones. At the end of the work, we discuss and conclude all the work in Section 8.

2. Literature Review and Theoretical Background

Content-based filtering systems create a model by analyzing items and user preferences. This model considers a user's specific interests and tries to find content items that match the user's profile (Javed, 2021). In other words, the system examines the properties of the recommended content items and matches them with the user's preferences. This information is used to personalize the recommendations and suggest items that are likely to be of interest to the user. They also suffer from the drawback of needing sufficient data to create a solid classifier. Wrapper approaches break the characteristics down into smaller groups, analyze these groups, and then determine which of these groups appears to be the most promising. Heuristic techniques are employed by filtering algorithms to assess the content of features, which can be used regardless of the methods utilized. On the other hand, feature extraction is performed during the training stage of embedding techniques, which are integrated into the algorithm. As mentioned earlier, content-based filtering scrutinizes users' previous behavior and proposes items similar to their preferences, based on the characteristics considered. This purpose is to suggest movies to users based on related genres. Content-based filtering techniques use several attributes of an item to suggest other things with related qualities (Pérez-Almaguer et al., 2021). In terms of content-based filtering techniques, it aims to suggest to the active user products comparable to those rated favorably in the past (Sunandana et al., 2021). It is predicated on the idea that things with comparable features would receive comparable ratings. Text documents are the primary information source utilized by content-based filtering algorithms. The main emphasis of content-based recommendation is on modeling both person and item profiles using a single extracted feature strongly connected to item attributes. This section is divided into four parts the first 2.1 represents the procedure used during content-based filtering, the second 2.2 presents how content-based filtering is built, the third 2.3 describes the architecture of content-based filtering, and the last 2.4 shows the objectives and challenges of content-based filtering.

2.1 Recommendation Process

Content-based recommendation can be divided into four steps as mentioned in Fig.2:

- Analyze: Content-based recommender systems examine the item descriptions and a collection of papers that have already received user ratings to determine which things are of interest to the user.
- Develop: Based on the characteristics of the things that users have assessed, they construct a model or sketch out users' interests.
- Build: Then, using a machine learning model, recommendations are made based on user profiles.

- Recommend: The user profiles are compared to the content profiles, and the users are suggested material with comparable feature values.

Fig. 2. The main steps for the content-based recommendation process.

2.2 Content-based recommendation techniques representation.

The item is recommended by content-based recommender systems depending on how well the article's contents fit the user's profile. Content-based recommendation systems typically involve the following steps as mentioned in Fig. 3:

1. Item representation: This involves representing each item (e.g., movie, book, product) in the system using features such as textual data (e.g., title, description), metadata (e.g., genre, director), or other characteristics (e.g., price, release date).
2. User profile creation: This involves creating a profile for each user based on their past interactions with the system (e.g., items they have rated, viewed, or purchased) and their explicit feedback (e.g., ratings, likes, dislikes).
3. Content-based filtering: This involves using the item representations and the user profiles to recommend items that are similar to the items the user has already interacted with or expressed interest in. This can be done using various techniques such as cosine similarity, Euclidean distance, or clustering.

Content-based recommender systems use a user's preferences and interests to recommend items that match their profile. The system generates item recommendations based on the similarity between the content of the items and the user's interests. To do this, the system creates a representation of the item's content and the user's preferences. There are several techniques to represent the content of an item, including:

- Bag-of-words (BoW): This technique represents the content of an item as a set of words or terms that occur in the text. BoW does not take into account the order or context in which the words appear.
- TF-IDF: This technique is similar to BoW but assigns a weight to each word based on how often it appears in the document and how rare it is in the collection of documents. This helps to prioritize important words in the representation.
- Word embeddings: This technique represents words as dense vectors in a high-dimensional space, where words that have similar meanings are closer together. This allows the system to capture semantic relationships between words and to represent the content of an item as a combination of the embeddings of the words that appear in the text.

Once the item is represented in a suitable way, the system can compare it to the user's profile and recommend most similar items. This is typically done using a similarity measure such as cosine similarity, which calculates the cosine of the angle between the two vectors representing the item and the user's profile. The higher the cosine similarity score, the more similar the item is to the user's profile and the more likely it is to be recommended.

Fig. 3. Content-based recommendation representation.

2.3 Architecture of content-based filtering

Content-based techniques build user profiles based on the features and descriptions of the products the user evaluates rather than drawing on the preferences of other users when generating suggestions (Kunde et al., 2022). Content-based have several benefits; on the one hand, strategies over collaborative filtering algorithms are their capacity to address the issue of new products or the potential for encouraging new things for which there is no user input (Stitini et al., 2022). On the other hand, Contrary to collaborative filtering approaches, which may be used everywhere, content-based algorithms

heavily rely on the recommendation domain. They also rely on the availability of trustworthy information about the characteristics of the items, which might be difficult to get at times. Additionally, content-based strategies could though not usually be prone to over-specialization, which is the tendency for them to propose goods that are excessively similar to ones the customer has already assessed. Algorithms from several domains, including Information Retrieval, Semantic Web, and Machine Learning, are included in proposals for content-based recommendation systems. For instance, early concepts for Web recommendations, news recommendations, and, more recently, social tagging systems incorporated term-weighting models from information retrieval. For content-based recommendations, such as news recommendations or movie and music recommendations utilizing Linked Open Data, methods utilizing Semantic Web technologies have also been proposed. The architecture of a content-based filtering system typically involves the following steps as mentioned in Fig. 4:

1. **Data Collection:** Collect data on items to be recommended, which can include textual descriptions, tags, or metadata.
2. **Content Analyzer:** Use a Content Analyzer component to extract features from the item data. The Content Analyzer analyzes the text and metadata to identify important features of the item, such as keywords, topics, and categories.
3. **Profile Learner:** Create user profiles based on their historical behavior, such as items they have viewed, rated, or purchased. The Profile Learner builds a profile for each user based on their preferences and behavior.
4. **Filter Component:** The Filter Component then takes the user profiles and the features of the items and calculates the similarity between the user profiles and the items. The Filter Component recommends items that are most similar to the user profile, based on the features of the items.
5. **Evaluation:** It is important to evaluate the performance of the recommendation system to ensure its effectiveness. Common evaluation metrics include accuracy, precision, recall, and F1-score.

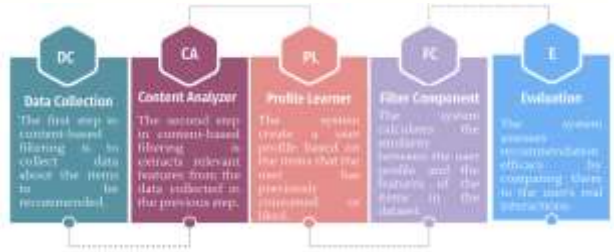

Fig. 4. Global architecture of content-based recommendation system.

2.3.1 Content Analyzer

Examining texts to find pertinent ideas that best describe the content enables the introduction of semantics into the recommendation process. With this method, the appropriate meaning or senses for each ambiguous word are chosen based on the context in which they are used (Stitini et al., 2022). To combat the issues caused by ambiguity in natural language, ideas rather than keywords are used to express texts in this fashion. A repository of disambiguated documents is the end product of the preprocessing procedure. This semantic indexing primarily draws on the linguistic information in the WordNet lexical ontology and is based on natural language processing techniques (Felfernig et al., 2014).

2.3.2 Profile Learner

The system learns the user's preferences and creates a user profile based on the content they have interacted with in the past. To create a user profile, the system typically uses machine learning algorithms to analyze the user's historical behavior such as what items they clicked on, how long they spent on each item, and what items they purchased or rated positively. These behaviors are used to identify patterns and characteristics that can be used to make recommendations in the future. The user profile created in this step typically contains information such as the user's preferred genres, authors, actors, and other attributes that are relevant to the type of content being recommended. This information is then used in the next step of the recommendation process, which is content filtering. Overall, the profile learner is an essential component of a content-based recommendation system as it helps the system to personalize recommendations based on a user's individual preferences and behavior.

2.3.3 Filter Component

The Filter Component is responsible for selecting and filtering the items that will be recommended to the user based on their preferences and interests. This component uses a set of filtering techniques to identify the items that are most relevant to the user. The filtering techniques can include content-based filtering, collaborative filtering, or a hybrid of both. Content-based filtering involves recommending items that are similar to items the user has interacted with in the past. Collaborative filtering involves recommending items that other users with similar interests and preferences have interacted with. The Filter Component takes into account the user's profile, which includes their past interactions, demographic information, and explicit feedback. The user's profile is compared to the item profiles, which include attributes such as genre, artist, director, and rating. The Filter Component uses algorithms to match the user profile with the item profiles to determine the relevance of each item to the user. Once the Filter Component has identified the most relevant items, they are passed onto the next component, which is the Recommender Component. The Recommender Component is responsible for generating a ranked list of items that will be recommended to the user. The ranked list takes into account the relevance of each item and the user's preferences and interests.

2.4 Objectives and Challenges of content-based filtering

Recently, recommender systems have become more prevalent in several commercial applications to assist customers in finding their favorite goods. The accuracy of predictions and the relevance of suggestions have typically been the emphasis of recommender system research. Other suggestion quality criteria, on the other hand, may significantly influence a recommender systems overall performance and user satisfaction (Sharma et al., 2011). As a result, the focus of researchers on this subject has lately expanded to incorporate other recommender system goals. Fig. 5 shows the challenges of content-based filtering.

Fig. 5. Content-based filtering drawbacks.

When the Recommender system RS is implemented, the quantity of digital products that a user will search for is reduced to the user's most likely favored set of objects. To put it another way, the RS aims to assist online users in finding content that is relevant to their preferences rather than sifting through a mass of undifferentiated data.

Recommender systems have recently gained popularity on several online platforms that offer many things, resulting in information overload for consumers. The primary purpose of an RS is to give customers a list of possibly desired things to assist them in shopping online, which benefits both the company and the client. The goal of recommender systems is to make product suggestions relevant to the user's interests. In the recent decade, the objective of RS research has been to give suggestions that are relevant to the user's preferences. However, in real-world circumstances, this is insufficient to captivate customers and persuade them to check out and buy different things. Research on RS has recently switched its focus to integrating relevance with other goals diversity, novelty, coverage, and serendipity.

A recommender system helps users find tailored items, documents, friends, places, and services while saving time. Furthermore, the recommender system addresses the problem of information overload that has plagued the internet in the twenty-first century. Simultaneously, various settings or technologies cloud, mobile, and social networks have grown popular in recent years and are confronted with the challenge of massive amounts of data. As a result, the researchers believe the recommender system is an appropriate answer to this problem in specific settings.

A million digital goods like documents, merchandise, music, and books are uploaded to the internet every day. This enhances the information available on the Internet and gives consumers more options. Users will find looking for and locating the target documents, items, music, and books difficult and time consuming.

2.4.1 Problem 1: over-specialization issue

A crucial method for assessing anything unusual is absent from a content-based recommendation system. The algorithm may offer ideas with a higher score when analogized to the user profile (Jain et al., 2015). It stands

likewise called the serendipity problem since it highlights the limitations of content-based recommendations. The amount of fresh content produced by the ”ideal” content-based method would be small, which would limit its potential uses.

Because they only propose goods similar to those that consumers have already assessed, the content-based approach suffers from the over-specialization challenge. One solution to this problem might be incorporating any randomness. Not all content-based algorithms that cannot suggest things that are unrelated to what the consumer has already viewed fall under the category of over-specialization (Mohamed et al., 2019). Items that are highly similar to what the user has previously seen, such as many news stories documenting the same occurrence, should not be made available in some cases.

The inability of the program to suggest to the user objects that are distinct from those he has already observed is only one aspect of the over-specialization problem but also that it must not recommend items that are too close to those he has enjoyed in the past. As a result, certain recommendation algorithms exclude not just things that differ from the user profile, but also those that are highly similar to those already followed by the present user. The diversity of the recommendations is a criterion for evaluating the quality of the recommendations. The user must receive diversified and not homogeneous relevant recommendations. For example, it is not wise to recommend all of Henri Garetta’s books to a user who has enjoyed one of his books.

2.4.2 Problem 2: serendipity issue

Serendipity refers to the potential for obtaining an unanticipated and lucky article (Iaquinta et al., 2008). It is a technique for increasing the variety of suggestions. Due to over-specialization, content-based algorithms lack a crucial method of providing spontaneous ideas, even though people rely on happenstance and experimentation to uncover new items they did not realize they wanted (Shrivastava et al., 2022). Operational serendipity tactics significantly increase the functionality of content-based recommender systems and lessen the problem of over-specialization. Table 2 summarizes contributions regarding the serendipity problem.

Serendipitous recommendations are suggestions that may interest users, even if they aren't directly related to their previous behavior or preferences. By introducing unexpected recommendations, users are exposed to diverse content that they might not have discovered otherwise. This can lead to a more enjoyable user experience and increased engagement. In their work, (De Gemmis et al., 2015) explore how serendipitous recommendations can engage users in unique ways. They discuss various methods for generating such recommendations, including using contextual information or machine learning algorithms that consider diverse factors beyond just user behavior. Recommender systems have become widespread in various domains, but users are increasingly concerned about the privacy and security of their data, as well as the transparency and accountability of the algorithms used. (Rodríguez-García et al., 2019) review existing research on trustworthy recommender systems, including privacy-preserving recommendation algorithms, explainable AI techniques, and the design of transparent and accountable recommender systems.

A crucial mechanism for finding anything unexpected is absent from a content-based recommendation system. The user offers products comparable to previously rated things since products are suggested as reasons for the high score and compatibility with the user’s profile (Ziarani & Ravanmehr, 2021). The over-specialization problem, which describes the propensity of content-based systems to offer unoriginal ideas, is another name for this issue (Kotkov et al., 2020). An excellent content-based strategy is essential to discover some inventive and unbelievable recommendations.

Item-based recommendation systems face the serendipity issue because they only suggest things to users who have already previously loved them. For instance, a movie recommendation engine could only suggest films to a user if the genre or performers are comparable to ones they previously adored. On the other hand, a user-based suggestion can provide surprising advice by examining the users' close friends who have rated the same item as them and by examining their ratings of different products that they have not yet evaluated (Kotkov et al., 2017).

Due to the restricted content analysis, overspecialization results, with CB filtering selecting previously seen items over brand-new ones. By using evolutionary algorithms that offer diversity to suggestions, we may promote unique and coincidental items alongside well-known goods by adding additional hacks and noting unpredictability. There is no necessary method to find something surprising in a recommendation system that uses content.

The user offers products comparable to previously evaluated entities since products are recommended based on a high score and also fit the user’s profile. The tendency of content-based algorithms to provide ideas with minimal originality is sometimes referred to as the over-specialization problem.

2.4.3 Problem 3: limited content issue

Content-based approaches restrict the number and type of common qualities they may offer manually or automatically with objects. Expertise in the domain and taxonomies relevant to the field are also essential. The content-based recommender system could not provide appropriate suggestions if the examined content lacks sufficient information. According to restricted content analysis, the system can only give a tiny quantity of information about its consumers or the range of its products. On the other hand, the way content-based strategies advertise new items results in over-specialization (Adamopoulos & Tuzhilin, 2014). For instance, in a recommendation system for movies, the framework can suggest to a user a film with the same genre or cast as one they have already seen. As a result, the algorithm could overlook some items that the user finds intriguing. A natural limitation of content-based filtering is the need to have a varied and rich representation of item content, which is not always the case. The quantity of data the algorithm needs to distinguish between products the user likes and doesn't like affects how accurate the suggestions are. Table 3 summarizes the contribution regarding the limited content problem.

2.4.4 Problem 4: Scalability issue

For a recommendation machine to understand user preferences, a lot of ratings must be gathered. Because no past data is available, the algorithm cannot give reliable recommendations to new users. With little or limited information, accurate suggestions cannot be generated for new users/items. This is known as the "cold start" issue. Before the algorithm can understand the user's tastes and offer pertinent recommendations, the user must rate some goods (Su et al., 2022). The user-cold start problem is the name given to this issue in the literature. Lack of consideration of the evolution of the user's interests. Table 4 summarizes the contribution regarding the limited scalability problem.

2.4.5 Problem 5: Synonym issue

Synonyms are two or more words expressing the same thing or concept. However, recommendation algorithms are unable to distinguish between these terms. A memory-based CF method, for example, determines between "comedy movie" and "comedy film". Synonym overuse degrades the quality of a recommender system (Isinkaye et al., 2015). Table 5 summarizes contributions regarding the synonym problem

Table 1. Summarization of contribution regarding the over-specialization problem.

Contribution	Dataset	Proposed approach	Solution proposed	Metric
(Stitini et al., 2022b)	MovieLens	Genetic algorithm	Genetic algorithm & We made an effort to investigate a fresh strategy to address the issue of over-specialization in content-based recommender systems and develop novel things for the user. The genetic algorithmRRS_{GA} was employed in this work to carry out content-based filtering. RRS_{GA} employs a genetic algorithm approach to provide suggestions to the user. The main goal of this system is to find a list of fresh goods with a strong correlation to user preferences and a high likelihood of being selected (the proposed fitness function)	Novelty and diversity
(Adamopoulos & Tuzhilin, 2014)	MovieLens and MovieTweetings	Probabilistic neighborhood selection (PNS) algorithm	The authors argue that collaborative filtering systems can suffer from over-specialization, where users are recommended items that are too similar to the ones they have already consumed. This can limit user exploration and prevent them from discovering new items that they might enjoy. Additionally, CF systems can also exhibit concentration bias, where popular items receive a disproportionate amount of recommendations, while niche items are overlooked. To address these issues, the authors propose a probabilistic neighborhood selection (PNS) algorithm that selects neighbors based on the probability of their ratings being similar to the user's ratings. This helps to increase diversity in recommendations and reduce concentration bias.	Novelty and diversity

Table 2. Summarization of contribution regarding the serendipity problem.

Contribution	Definitions	Metrics	Solution proposed
(De Gemmis et al., 2015)	Serendipity is a representation of anything valuable, difficult to recognize, unexpected, and happening just once.	They define serendipity in the context of content-based recommender systems as: • Relevant: Items that still connect to or resemble the user profile in some way. • An enthusiastic response from users was unexpected. • novel: describing to users as new things.	No solution
(Grange et al., 2019)	Serendipity is the unanticipated occurrence of fortuitous circumstances, such as finding necessary knowledge.	Unexpectedness and informational value.	No solution
(Saat et al., 2018)	The term serendipity is a symbol of value, difficult to identify, unexpected, and only happens at first sight.	Relevant, unexpected, and novel	Linked Open Data.

Table 3. Summarization of contribution regarding the limited content problem.

Contribution	Definitions	Metrics	Solution proposed
(Beleveslis & Tjortjis, 2020)	They provide a feature-weighted heuristic technique for content-based filtering to foster suggestion diversity and streamline similarity computations.	Diversity	The hashing technique in the suggested method accelerates and streamlines the computation of product similarity compared to conventional methods
(Stitini et al., 2023)	A content-based recommendation system recommends items to users based on their preferences and past behavior. One of the limitations of these systems is that they can suffer from a limited content issue, where they only recommend items that are very similar to each other. This can result in a lack of diversity in the recommendations and lower overall user satisfaction.	Novelty and Diversity	They suggest novel, unpredictable, and startling objects that may be loved by consumers and may help make up for the lack of content.

Table 4. Summarization of contribution regarding the scalability problem.

Contribution	Definitions	Metrics	Solution proposed
(Ishtiaq et al., 2016)	Cold start users and insufficient data definition.	Accuracy	This introduces a novel method for generating recommendations that is both accurate and scalable. The algorithm employs various techniques for scalability to minimize processing demands and produce recommendations based on a vast quantity of data.
(Su et al., 2022b)	The authors evaluate their approach on several real-world datasets and show that it can significantly reduce the computational cost of distance-based link prediction algorithms while maintaining high prediction accuracy. They also compare their approach to other similarity selection methods and demonstrate its superiority in terms of both efficiency and effectiveness.	Accuracy	The authors propose a new method for similarity selection called Cluster-based Similarity Selection (CSS), which partitions the items into clusters and selects a representative item from each cluster. The similarities are then calculated only between the representative items, rather than between all pairs of items.

Table 5. Summarization of contribution regarding the scalability problem.

Contribution	Definitions	Metrics	Solution proposed
(Kim et al., 2017)	The authors aim to improve recommendation systems by analyzing the correlation between data collected from different types of content, specifically movies and music, which were gathered simultaneously.	Novelty and diversity	Despite their differences in content, folksonomy tags for music are considered by them to be associated data with movie genres.
(Rodríguez-García et al., 2019)	The article presents a novel approach to the problem of providing personalized dating recommendations using ontology-based modeling and context-aware techniques. The BlindDate Recommender platform has the potential to improve the online dating experience for users by providing them with more relevant and personalized recommendations.	-	The platform is designed to provide users with personalized dating recommendations based on their preferences and interests. The platform uses an ontology-based approach to model the domain of dating and to represent user preferences and interests. The article describes the architecture of the BlindDate Recommender platform and the various components that make up the platform. The article also discusses the evaluation of the platform using a dataset of real user profiles. The evaluation results show that the BlindDate Recommender platform provides accurate and effective dating recommendations to users.

3. Research Contribution

3.1 Motivation

Relying solely on accuracy for evaluating a recommendation system may result in the system suggesting redundant options to the user. The reason is that a system solely focused on accuracy would give priority to recommending items similar to those the user has already consumed, instead of offering novel and varied options.

Integrating metrics like novelty, diversity, unexpectedness, utility, usefulness, relevance, and popularity into recommendation systems can potentially improve user satisfaction and involvement.

- Novelty: Recommending new and unique items to users can enhance their experience by exposing them to a wider range of content.
- Diversity: Recommending a diverse set of items can broaden users' horizons and prevent them from being trapped in a filter bubble, where they only see content that reinforces their existing beliefs or preferences.
- Unexpectedness: Recommending items that are unexpected but still relevant to users' interests can provide a pleasant surprise and increase their engagement with the system.
- Utility and usefulness: Recommending items that are relevant to users' needs and preferences can increase the likelihood that they will find the recommendations useful and continue to use the system.
- Relevance: Recommending items that are closely related to users' interests can improve the relevance of the recommendations and increase their satisfaction with the system.
- Popularity: Recommending popular items can increase users' trust in the system and provide a social validation effect, where users are more likely to engage with items that others have enjoyed.

Serendipity has a significant role in improving recommendation systems by preventing redundancy and enhancing user experience. If a recommendation system relies solely on accuracy, it may suggest items that the user has already encountered, resulting in a monotonous and tedious experience. Conversely, the inclusion of serendipity into a recommendation system can stimulate the exploration of new and surprising options, maintaining the user's interest in the system's recommendations. Consequently, this can elevate user satisfaction and involvement in the recommendation system. To summarize, although accuracy is crucial for recommendation systems, integrating serendipity into the assessment process can offer users a more varied and captivating experience while mitigating the issue of recommendation redundancy.

3.2 Demonstration of the Choice of One Solution

Recommendation systems play a crucial role in helping users navigate the vast amounts of content available online, but striking a balance between personalized recommendations and unexpected discoveries can be tricky. Serendipity is an important aspect of recommendation systems, as it allows users to encounter content that lies beyond their typical preferences but is still enjoyable and relevant to them. The idea is to introduce users to new and captivating items while keeping recommendations fresh and engaging.

A serendipitous recommendation can broaden a user's horizon and expose them to new interests. However, implementing serendipitous recommendations while maintaining personalized recommendations that cater to the user's interests can be challenging for recommendation system designers. Despite the challenge, achieving a balance between these two types of recommendations can lead to a more engaging and enriching user experience.

Content-based filtering has some limitations, such as synonym sparsity, which refers to the situation where the system fails to find similar items due to a lack of synonyms or similar terms in the features or attributes used for recommendation. An ideal solution to mitigate this disadvantage would be to use a combination of techniques that overcome the limitations of content-based filtering.

3.3 Contribution

To sum up, the article describes the following key contributions:

- A precise explanation of all content-based filtering drawbacks.
- A new solution that combines different approaches to generate unexpected recommendations is designed and tested.
- We named our proposed approach an **I**deal **S**olution **M**itigating **C**ontent-based filtering **D**rawbacks$ISMCD_{3P}$, which uses three phases that best evaluate the recommender systems rather than precision and diminish the monotony.

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● We conducted a comparison between our proposed model and other advanced serendipity recommender systems and exhibited the practicality, technical accuracy, and consistent performance of our model.

● We assessed the effectiveness of our recommender system in movie Lens application scenarios and displayed that using the established criteria, the recommendation process can significantly enhance the recommendation quality, not just limited to precision.

4. The proposed recommender system model

Our proposed model describes an Ideal Solution Mitigating Content Disadvantages based on Three Phases called$ISMCD_{3P}$. This section is divided into two sections the first 3.1 represents the aim of the study, and the second 3.2 produces detailed steps in our suggested methodology.

4.1 Aim of the study

Our interest is to find a general solution for dealing with all content-based filtering drawbacks. Our goal is to provide a general model to follow by categorizing by phase each solution that can contain. Fig. 6 describes the suitable solution for each issue.

Fig. 6. Content-based filtering drawbacks.

4.2 The Proposed Architecture

Instead of selecting individual products to create a list of recommendations, $\boldsymbol{ISMCD_{3P}}$ prioritizes the overall composition of the recommendation list. Its primary principle involves systematically evaluating the entire set of suggestions and presenting customers with new products that align with their interests. Algorithm 1 outlines the key steps of $\boldsymbol{ISMCD_{3P}}$ main procedure.

Algorithm 1 The main procedure of $ISMCD_{3P}$

Input: User preferences.
Output: Recommendation List.

1: Phase 1 NLP Techniques
1.a: Generate the initial population that contains cleaned text with Punctuation removal.
1.b: Convert all text to lowercase.
1.c: Remove common words (stop-words).
1.d: Deal with emojis by either removing them or converting them to textual representations.
1.e: Eliminate words that are not relevant to the context or topic.
1.f: Correct misspelled words to their appropriate spelling.
1.g: Reduce words to their base or root form by removing suffixes or prefixes.
2: Popularity
2.a: New user
2.b: Address the ability of our proposed solution to handle increasing amounts of data, users, or resources without compromising performance or functionality.
2.c: Deal with situations where data is sparse, meaning there are a large number of missing or empty values, which can pose challenges for analysis or modeling.
3: Metrics Applications
3.a: Measures the degree of novelty of the recommended list by assessing how different it is from user preferences given in the input.
3.b: Evaluate the variety or range of different elements, options, or perspectives within a set or system.
3.c: Assess the level of surprise or deviation from expectations that are in particular results.
3.d: Determine the degree of significance, applicability, or pertinence of a particular item, in relation to a specific context given in the input.

4.3 Methodology and overall approach

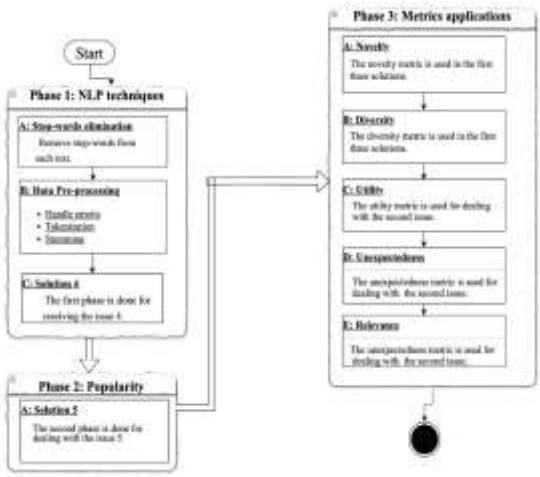

Fig. 7. Architecture of the proposed approach.

We started with the first phase which deals with the synonym drawback by applying NLP techniques, moving to the second phase which concentrates on resolving the problem of scalability or data sparsity, for example when we have a new user. The last phase solves the first three issues which converge in the same direction. Fig. 7 presents the architecture of our proposed architecture.

For that, our proposed technique $ISMCD_{3P}$ contains a three-phase process to deal with all content-based filtering challenges starting with NLP techniques, moving to the popularity-based recommendation, and finishing by applying new metrics.

1. Phase 1: NLP techniques

We utilized data preparation methods on our existing data to reduce its size. Texts of raw feelings are unstructured data sources containing noisy information. Before disabling the template's functionality, the raw text must first undergo pre-processing. The text may be transformed in various ways to make it modeling-ready. We then left off the punctuation.

The capital letter information was then converted into the text's lowercase. We have deleted the pointless stop words in a language and created noise when employed as text classification characteristics. The sentences are then returned to their original forms. We used the data preprocessing techniques on the news Twitter articles to reduce the amount of accurate data. Unstructured sources of information like raw news texts may include distracting material. The basic text must be preprocessed until the functionality of the model is eliminated.

There are several ways to modify the text so it can be modeled. Fig. 7 shows a general outline of our first phase in the proposed model which contains eight steps: Punctuation removal, lower Casing, stop-words removal, handling emojis, removing irrelevant words, spelling correction, stemming, and tokenization. By using this step we can deal with the synonym issue, exactly the problem number 4 as it is mentioned in Fig. 5.

Fig. 8. The main steps in phase 1.

2. Phase 2: Popularity

The cold start problem, which complicates the system by not possessing any past rating history and covers three cases—recommending a new user, recommending a new product, and recommending a new product to a new user—is the most concerning of these difficulties. Content-based systems make an effort to provide suggestions based on the target user's ratings and the features connected to the specific item. Only things with a past rating history, or those that have been rated before, are eligible for this suggestion strategy. This method is impossible to produce an effective result without a prior rating history. By integrating the popularity which means the use of demographic information we can mitigate the new user issue, exactly the problem number 5 as it is mentioned in Fig. 5.

3. Phase 3: Metrics applications

Over-specialization, limited content, and serendipity all these issues converge to the same problem meaning. The accuracy of predictions and the applicability of suggestions have always been the main topics of research in recommender systems. However, the effectiveness of a recommender system as a whole and user happiness may be significantly impacted by other suggestion quality indicators. As a result, current research in this area has focused more on other recommender system goals. For that, we propose these three issues, especially problems 1,2, and 3 as it is mentioned in Fig. 5 in one solution summarized in Fig. 9.

Fig. 9. Proposed solution for the first third issues mentioned in Fig. 5.

5. Experimental results

Evaluating feedback systems includes addressing an issue and utilizing an assessment technique to determine how the problem has been resolved. For recommender systems to be useful, a problem must have a solution. The problem must be precisely explained to establish if the issue has been resolved. This section shows how the proposed strategy was tested. To compare the proposed recommender system to other recommendation methods, many experiments were run:

- Content-based filtering: Based on the cosine similarity, this recommendation method produced the suggestions.
- The use of clustering: To improve the suggestion, they employ clustering, particularly the k-means method.

Table 6. Comparison of our proposed approach with the recommender system approach.

Properties	**Content-Based Filtering**	**Clustering**	**Our approach**
Effect of over-specialization	High	Medium	Less
Effect of serendipity	High	Medium	Less
Effect of limited content	High	Medium	Less
Synonym	High	Medium	Less
Cold start	High	Medium	Less

Table 6 describes the comparison between our proposed method and other recommender system approaches in terms of over-specialization, serendipity, limited content, synonym, and cold start, which is high if we use the classic content-based filtering and becomes higher when using our proposed approach.

5.1 Phase 1: NLP techniques

5.1.1 Solution 4 Interpretation

Table 7 above shows the transformation of the raw dataset into an understandable format using the eight steps mentioned in Fig. 7.

Table 7. The transition steps in data pre-processing.

Before pre-processing	**After pre-processing**
A conseiller +++	a conseil
Excellent	excel
Excellent rapport qualité prix	excel rapport qualité prix

5.2 Phase 2: Popularity

5.2.1 Solution 5 interpretation

Table 8. Popular recommendation example.

Domain	**New user**	**Top-N popular recommendations**
Movie recommendation	New user 1	["The Godfather", "The Dark Knight", "Fig. . ht Club"]
Book recommendation	New user 2	["The Hunger Games", "Harry Potter", "A Fairy Story"]
Hotel recommendation	New user 3	["Hotel Ekta", "Le Domaine de La Reserve","Château de Roncourt"]

Table 8 shows an example of the second phase in our proposed approach.

5.3 Phase 3: metrics applications

5.3.1 Interpretation of Solutions 1,2, and 3

Table 9. Novelty results of the recommendation methods.

Method Recommendation	K=1	K=3	K=5	K=7	K=9	K=11
Content-based filtering	0.285	0.289	0.297	0.316	0.328	0.410
Our third phase proposition	**0.845**	**0.740**	**0.726**	**0.6329**	**0.602**	**0.533**

Table 9 demonstrates the obtained novelty findings. The reader may see that, when compared to previous recommendation systems, our third phase proposal methodology exhibits notable improvements. The term "K" represents the range of recommendations, starting from one recommendation (k=1) and extending up to eleven recommendations (k=11). In Top 1 and 3, the uniqueness of the third phase's recommended method reaches its peak, which starts to decline. The outcomes show how practical the suggested approach is. Otherwise, the third phase recommended technique outperformed the content-based recommendation method in terms of originality by an average of 56%.

Table 10. Comparison of precision results of both methods.

Method Recommendation	K=1	K=3	K=5	K=7	K=9	K=11
Using CB filtering	0.641	0.640	0.643	0.636	0.615	0.643
Our third phase proposition	0.740	0.740	0.739	0.738	0.736	0.735

Table 11. Comparison of Recall results of both methods.

Method Recommendation	K=1	K=3	K=5	K=7	K=9	K=11
Using CB filtering	0.238	0.235	0.245	0.236	0.231	0.239
Our third phase proposition	0.673	0.671	0.670	0.670	0.698	0.698

7. Discussion

This study's primary goal is to evaluate content-based filtering problems and provide a single fix that eliminates all of their downsides. Therefore, our suggested method looks for a recommendation list that matches three essential criteria:

Tables 10 and 11 show the outcomes of the recommendation techniques recall and accuracy. The authors conclude from these data that all recommendation algorithms performed better as the number of Top-N recommendations increased. This is because recall shows the proportion of the collection's favorite suggested things out of all choices. As a result, the likelihood of proposing goods to users that they will find exciting rises as the number of recommended items increases.

6. Distinctions

Table 12 shows a comparative study between the novel proposed approach and other existing ones.

Table 12. Works Comparison.

Works	Over-specialization	Limited content	Serendipity	Synonym	Scalability
(Stitini et al., 2022i)	✓				
(De Gemmis et al., 2015e)			✓		
(Saat et al., 2018b)			✓		
(Kotkov et al., 2020b)			✓		
(Adamopoulos & Tuzhilin, 2014b)		✓			
(Su et al., 2022c)					✓
(Ishtiaq et al., 2016)					✓
(Isinkaye et al., 2015)				✓	
(Kim et al., 2017)				✓	
$ISMCD_{3P}$	✓	✓	✓	✓	✓

- Lack of synonymous words in a recommendation list.
- The suggestions list contains novel and serendipitous items.

Lack of data sparsity by integrating popularity into the recommendation list.

Our proposed method for generating a list that satisfies those criteria involves a combination of various techniques and algorithms, including natural language processing and cutting-edge algorithms, to ensure diversity in the recommendation list. The authors suggest that the performance of the method is influenced by the size of the dataset and the number of items suggested (i.e., the size of the individual). To achieve optimal results, the Top N should be selected carefully and based on empirical evidence, using a substantial dataset.

The key obstacle affecting content-based filtering is over-specialization or the limited content, or in other words serendipity issues. As a result, our proposed methodology $ISMCD3P$ intends to address all content-based filtering issues to increase suggestion quality and recommendation accuracy. The suggested methodology was tested on the MovieLens dataset.

8.Conclusion and future work

The rise of information overload has emphasized the importance of recommender systems, leading to an investigation into a new strategy for addressing the limitations of content-based recommenders. The goal of this research study was to develop a solution that would overcome these drawbacks by proposing a multi-task model for content-based filtering. This model utilizes a range of techniques to provide recommendations to users based on their interests. The main idea behind this approach is to create a list of highly connected items that are semantically related, while also introducing new and diverse content, taking into account potential new user and synonym words.

Although this research study presents a promising solution, it is important to note that it is limited by its use of only one dataset (MovieLens). However, future studies could address this limitation by incorporating additional datasets to expand the scope of the proposed multi-task model. Overall, this research provides a significant contribution to the development of recommender systems and paves the way for further advancements in this field.

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