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Applying TRIZ Method and PID Control for Problem Solving in the TFT-LCD Manufacturing Process

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Abstract

The advent of monitors changed people's lifestyles tremendously. The TFT-LCD has become the most widely used flat-panel display technology. A TFT-LCD consists of two polarization filters with a 90°difference in orientation and liquid crystal placed between them. The liquid crystal changes the light's direction and leads the light through both polarization filters. When voltage is applied to the liquid crystal, the light remains in a constant direction and is therefore blocked by the two filters. Continuous process improvement is essential and manufacturers employ traditional trial and error to search for quick solutions. However, the lack of comprehensive problem definition may cause the same or similar problems to occur repeatedly. This study aimed to identify and resolve issues in the TFT-LCD manufacturing process through a systematic approach. Function analysis is used to identify functional disadvantages: (1) liquid crystal overflows onto the PI and (2) the liquid crystal contains air. Cause–Effect Chains and Contradiction Analysis was then performed to identify engineering contradictions and corresponding parameters, such as (1) "Volume of moving object" and "Manufacturing precision" and (2) "Volume of moving object" and "Extent of automation". After applying the Contradiction matrix, inventive principle, "Partial or excessive action", is suggested. We propose applying the concept of PID control to vary the system output around the desired value and ultimately reach the desired value. Thus, the dispensing pressure accuracy can be enhanced, and the problems of liquid crystal overflow and air bubbles can be eliminated.

Keywords: TRIZ, flat-panel display, PID control

1.0 Background

The advent of monitors changed people's lifestyles tremendously. Dynamic diagrams can deliver complex information more easily than text or static images can. The cathode ray tube, the first monitor revolution, broke the barrier of information exchange. Now that flat-panel displays are available, consumers demand digital products, such as smartphones, laptop computers, and televisions, featuring lighter and thinner monitors. With their higher quality and lower price, flat-panel displays are quickly replacing cathode ray tube monitors and the "second monitor revolution" has begun.

The three most common flat-panel display manufacturing technologies are the plasma display panel (PDP), organic light-emitting diode (OLED), and thin film transistor liquid crystal display (TFT-LCD). A PDP operates similarly to a fluorescent lamp: small cells containing ionized gases are charged and release ultraviolet light to illuminate the screen. An OLED uses as an illuminating film to emit light through indium tin oxide (ITO) and a glass substrate. A TFT-LCD consists of two polarization filters with a 90°difference in orientation and liquid crystal placed between them. The liquid crystal changes the light's direction and leads the light through both polarization filters. When voltage is applied to the liquid crystal, the light remains in a constant direction and is therefore blocked by the two filters. By controlling the voltage, the transmission intensity of each RGB light can be determined. The TFT-LCD is fabricated using mature manufacturing technology and has a relatively low price and no screen burn-in problem; thus, the TFT-LCD has become the most widely used flat-panel display technology.

2.0 TFT-LCD Manufacturing Process

The TFT-LCD manufacturing process comprises an array process and a cell process. In the array process, a glass substrate is first washed to remove harmful particles; the substrate surface is coated with an ITO film through thin film deposition; the substrate is also coated with photoresist and then exposed to UV light under a photomask, which creates the desired shade shape; the area of photoresist exposed to UV light is removed using a developing process; ITO not protected by photoresist is etched away; the remaining photoresist is removed; and the ITO layer with the desired pattern forms. The aforementioned processes are iterated to generate multiple ITO layers. The final substrate array with functional circuits is called a TFT substrate array. The color filter (CF) substrate array consists of RGB color elements. The TFT substrate and the CF substrate are then subjected to the subsequent cell process.

The cell process starts when polyimide (PI) is placed on the substrate: PI is rolled and attached evenly onto the inner sides of both the TFT substrate and CF substrate. Then, the PI rubbing process ensures that the liquid crystal is aligned in the same direction; liquid crystal droplets are dispensed onto the substrate through the one drop filling process; sealant glue on the substrate encloses the liquid crystal; a spacer ensures a uniform gap between the TFT substrate and the CF substrate; and then the two substrates are hot pressed together to form a panel. After a functional inspection, panels are scribed and broken into pieces of the desired size. The final step is to attach polarization filters to both sides of the panel. The assembly drawing for an LCD panel is illustrated in Fig. 1.

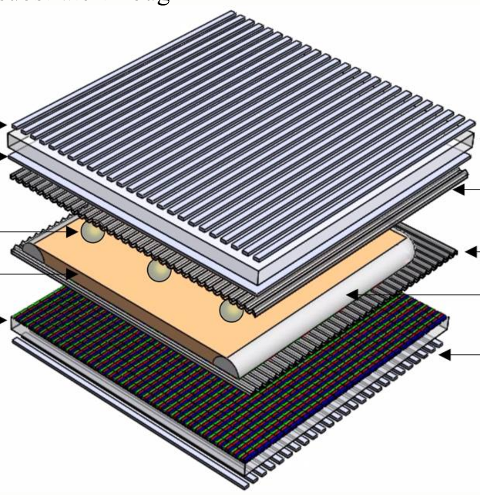


Fig. 1 Exploded View Diagram for LCD panel

3.0 Objective

Manufacturing defects may occur due to inappropriate material properties, improper process parameters, a lack of equipment precision, and an uncontrolled manufacturing environment. Inadequate process yield in TFT-LCD mass production may result in significant profit loss. Chen *et al*. (2016) proposed a real-time intelligent design method for parameter control that involves adding extra modules to a TFT-LCD, because of its high material cost. Continuous process improvement is essential to be competitive in the industry, and manufacturers employ traditional trial and error to search for quick solutions. However, the lack of comprehensive problem definition may cause the same or similar problems to occur repeatedly. This study aimed to identify and resolve issues in the TFT-LCD manufacturing process through a systematic approach.

4.0 Methodology

Many studies have addressed the use of TRIZ for product or process innovation in engineering fields. Sheu and Kuo (2012) integrated the contradiction matrix and inventive principles (CM/IP), the principle of separation, and the 76 standard solutions from substance field analysis to alleviate delamination issues in lead frame packaging of electronic components. Yeh *et al*. (2011) applied four-stage quality function deployment to investigate engineering contradictions and resolved these contradictions through TRIZ CM/IP. An environmentally friendly notebook was thus developed. Huang *et al*. (2015) integrated TRIZ and cluster analysis to develop effective rework processes for underfilled electronic components. Our study explored the TFT-LCD manufacturing process by using the TRIZ methodology to systematically analyze and resolve contradictory problems. The TRIZ tools and how they were applied are discussed in the following sections.

4.1 Function Analysis

Function analysis is used to clarify the functional relationships between components in an engineering system and identify functional disadvantages. The two primary functions of the TFT-LCD manufacturing system are as follows: (1) polarization filters polarize the white light and (2) the liquid crystal rotates the polarized light. First, we identified components of the engineering system and those of the super system. Components in the engineering system are material objects comprising the engineering system, whereas components in the super system are material objects outside of the engineering system but coexisting and/or interacting with its components. In the present case study, the components in the engineering system are polarization filters, the glass substrate, ITO, the CF, PIs, sealant glue, the liquid crystal, and spacers. The components in the super system are white light and air.

Second, an interaction matrix is used to exhibit the interactions (or physical contact) between all components of the engineering system and those of the super system (Table I). The matrix shows the specific functional relationship between components. The useful functions of the engineering system are as follows: (1) polarization filters polarize the white light; (2) ITO controls and aligns the liquid crystal; (3) the liquid crystal rotates the polarized light; (4) an RGB color module filter changes the white light into red, blue, and green light; (5) the spacers separate the PIs; and (6) the glue bonds the PIs. A review of the realistic manufacturing environment indicated two harmful functions as shown in bold: (1) liquid crystal overflows onto the PI and (2) the liquid crystal contains air (Table 1). A graph of function modeling is presented in Fig. 2.

Table 1 Interaction Matrix

From \ To	polarization filter	glass substrate	ITO	color filter	polyimide	sealant glue	liquid crystal	spacer	white light	air
polarization filter		-	-	-	-	-	-	-	polarize	-
glass substrate	support		support	-	-	-	-	-	-	-
ITO	-	-		-	support	-	control	-	-	-
color Filter	support	-	-		support	-	-	-	filter	-
polyimide	-	-	-	-		support	contain/twist	-	-	-
sealant glue	-	-	-	-	bond		contain	-	-	-
liquid crystal	-	-	-	-	**overflow**	-		-	rotate	**contain**
spacer	-	-	-	-	separate	-	-		-	-
white light	-	-	-	-	-	-	-	-		-
air	-	-	-	-	-	-	-	-	-	

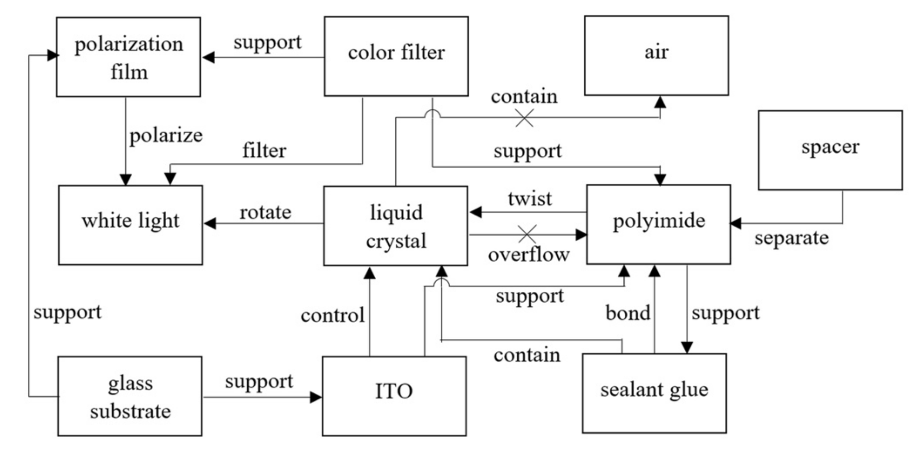


Fig. 2 Function Modeling

4.2 Cause–Effect Chains and Contradiction Analysis

The algorithm for creating a Cause–Effect Chains Analysis model involves first recording the target disadvantage and then determining the cause of the upcoming disadvantage. The step is repeated until the fundamental cause (key disadvantage) is identified. The Boolean values "and", "or," and "combine" are used to indicate the logical relationships between causes and effects. In Cause–Effect Chains and Contradiction Analysis (CECCA), the benefit (or what prevents improvement) of the key disadvantage is identified as the engineering contradiction to the target disadvantage. The target disadvantages and the benefit are then related to one (or several) of 39 engineering parameters (Mann 2002), as shown in Fig. 3. The target disadvantages (specific problems) are represented by engineering parameters (generalized problems); for example, the cause of liquid crystal overflow is either excessive liquid crystal injection or insufficient sealant glue—both causes are attributed to inaccurate dispensing. In CECCA, the engineering contradictions "liquid crystal overflow" and "easy manufacturing" relate to engineering parameters #7 [Volume of moving object] and #29 [Manufacturing precision] (and #38 [Extent of automation]), respectively. The presence of air bubbles is another target disadvantage, caused by insufficient liquid crystal injection. This cause is also attributed to inaccurate dispensing. "Presence of air bubbles" and "easy manufacturing" relate to engineering parameters #30 [Object-affected harmful factors] and #29 [Manufacturing precision] (and #38 [Extent of automation]), respectively.

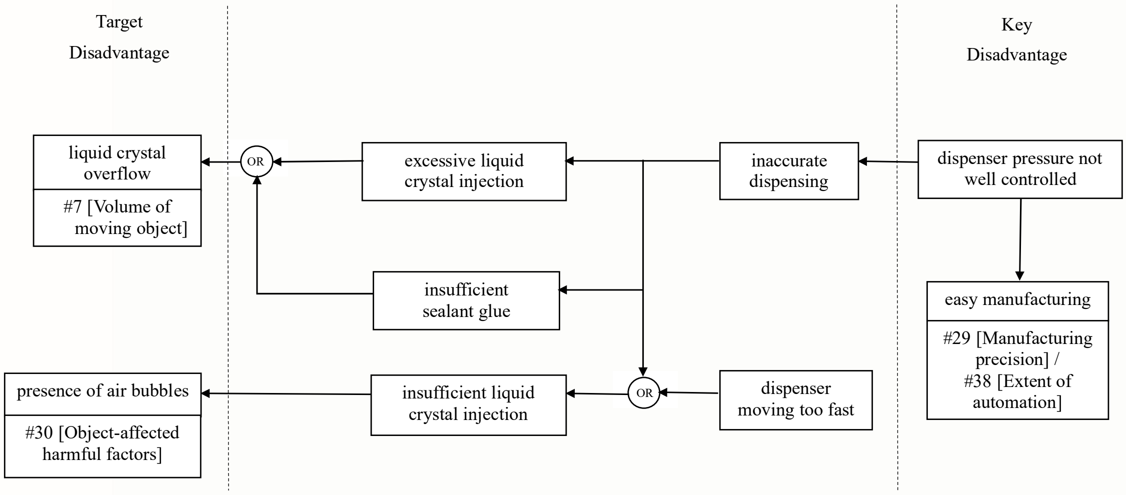


Fig. 3 CECCA

4.3 Contradiction Matrix and Inventive Principles

Altshuller, the inventor of TRIZ, studied engineering problems and their resolution by analyzing thousands of patent documents. He created the contradiction matrix (CM), which recommends inventive principles (generalized solutions) for engineering parameter contradictions. Inventive principles trigger ideas for specific solutions. The engineering parameter contradictions in our case study are shown in Table 2. After applying the CM, inventive principle #16 {Partial or excessive action} is suggested to resolve the engineering contradictions. This inventive principle states that when it is not possible to achieve the desired target, actions that yield values less than or even greater than the desired target can be considered. We propose applying the concept of proportional, integral, and derivative control (PID control) to vary the system output around the desired value (alternately more than and less than the desired value) and ultimately reach the desired value. Thus, the dispensing pressure accuracy can be enhanced, and the problems of liquid crystal overflow and air bubbles can be eliminated.

Table 2 CM and Inventive Principles

Worsen / Improve	#29 [Manufacturing precision]	#38 [Extent of automation]
#7 [Volume of moving object]	2, 16, 25, 28	16, 24, 34, 35
#30 [Object-affected harmful factors]	10, 18, 26, 28	3, 33, 34

5.0 Specific Solution – PID Control

In control theory, system output signal $y(t)$ is desired to follow reference input signal $r(t)$. To address uncertainties in either system identification or disturbances, a feedback controller is used to determine system input $u(t)$ with measured error $e(t)$, as shown in Fig. 4 (Franklin 2014). PID control theory suggests using a controller to calculate real-time $u(t)$ with Eq. (1), as shown in Fig. 5, where positive values K_P, K_I, and K_D represent proportional, integral, and derivative coefficients, respectively.

$$u(t) = K_P e(t) + K_I \int_0^t e(\tau)d\tau + K_D \frac{de(t)}{dt} \quad (1)$$

In our example system, $r(t)$ equals 1. Proportional control (P control) acts as a spring in a mechanical system. As P control is applied, $y(t)$ approaches $r(t)$, as shown in Fig. 6a. Although K_P can be increased so that $y(t)$ reaches $r(t)$ faster, $y(t)$ might overshoot or oscillate at a higher frequency. Therefore, P control combined with derivative control (PD control) is employed as a damping mechanism to smoothen $y(t)$. The example system output with PD control exhibits less oscillation, as shown in Fig. 6b. PID control accounts for past information and ensures that $y(t)$ reaches $r(t)$ eventually. The example system output with PID control reaches 1, as shown in

Fig. 6c. Li *et al*. (2012) maintained a constant temperature in the dispensing process by using a PID control algorithm and an AT89S51 single-chip microcomputer. In our case study, *r(t)* represents a desired constant pressure value in the liquid crystal dispenser. The pressure value should ensure steady liquid crystal dispensing; system input *u(t)* represents the pistol displacement of the liquid crystal dispenser; and *y(t)* represents the sensors value measuring the pressure in the liquid crystal dispenser. With a properly chosen K_P, K_I, and K_D, the controller stabilizes the pressure and therefore provides accurate dispensing.

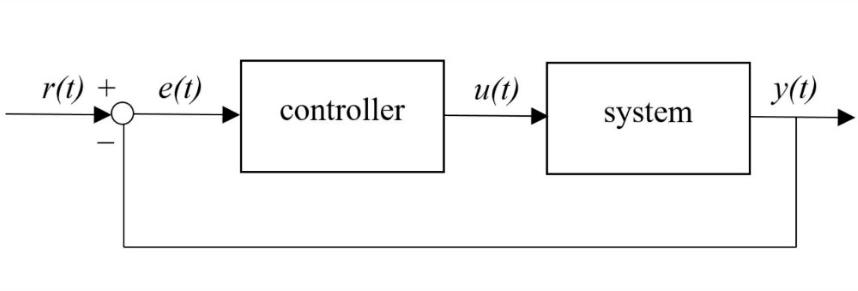


Fig. 4 Block diagram of feedback control theory

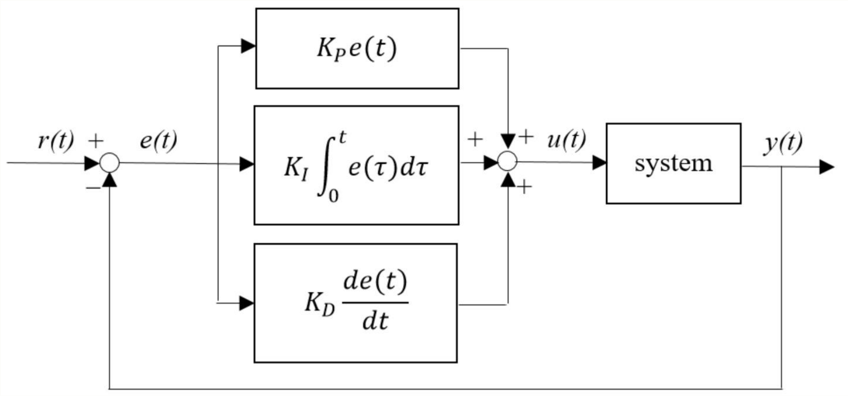
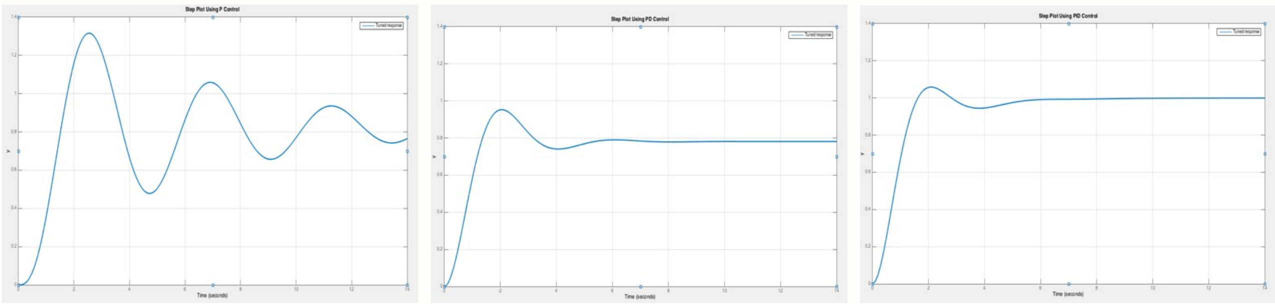


Fig. 5 Block diagram of PID control theory



(a) P control (b) PD control (c) PID control

Fig. 6 Example system outputs

Conclusion

This research improved the TFT-LCD manufacturing process by using the TRIZ systematic innovation process. Functional analysis was first used to identify two harmful functions: (1) the liquid crystal overflows onto the PI and (2) the liquid crystal contains air. CECCA was then performed to identify four engineering contradictions and corresponding parameters: (1) #7 [Volume of moving object] and #29 [Manufacturing precision], (2) #7 [Volume of moving object] and #38 [Extent of automation], (3) #30 [Object-affected harmful factors] and #29 [Manufacturing precision], and (4) #30 [Object-affected harmful factors] and #38 [Extent of automation]. Finally, considering inventive principle #16 {Partial or excessive action} suggested by the CM as a trigger solution, we employed PID control theory as a specific solution. PID control was applied to a liquid crystal dispenser to improve pressure control and thus achieve an accurate volume of liquid crystal. For future research, constant values of K_P, K_I, and K_D can be studied to enhance liquid crystal dispenser performance; for example, stability can be improved with a minimum lead time.

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Eric Huang receives the M.S. degree from the Department of Mechanical and Aerospace Engineering at University of California, Los Angeles (UCLA) in 2017. He is interested in Control of Linear Dynamic System, Stochastic Dynamic System, Digital Control, Optimal Control, Robotics, Optimization, Applied Mechanics, and Mechanical Design.

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