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Automated LCD Masked-Based Lithography PCB Layout Etching System

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Abstract – *The manual pre-sensitizing method usually takes about 30 minutes to an hour, which is very time-consuming and difficult since finding services that print on acetate film is challenging. Implementing manual procedures is also prone to inaccurate results and even exposes the user to various health and safety hazards. Instead of utilizing an acetate film, a transparent monitor was used as the layout mask by displaying the layout on it and letting the UV light pass through to the transparent areas. Exposing, developing, and etching were automated, which reduced potential risks and hazards. With automation and LCD-Masked Based Lithography, the process of printing layouts on acetate film for layout masking can be eliminated, and printing layouts can be done safely and conveniently. The system could etch layouts on pre-sensitized PCBs within 16 minutes, faster than the manual method. Etched PCBs have 100% accuracy and 84% precision. Essentially, the system has obtained a weighted mean of 3.69 from the student respondents and 3.57 from the professional respondents, which, based on its equivalent descriptive rating, implies an excellent performance for achieving its objectives.*

Keywords – *Etching, Layout Masking, Printed Circuit Board, and Pre-sensitized*

INTRODUCTION

In the modern time, almost every industry makes use of electronic devices for different purposes, such as to improve work convenience, efficiency, and safety. Since before, printed circuit boards have been used as the physical platform where the components needed to build an electronic device can be connected and soldered to hold them in place. According to Silvestre, Salazar, and Marzo (2019), almost all electronic applications are supported by printed circuit boards (PCBs), including mobile phones, aircraft, medical equipment, and industrial machinery (Silvestre, et.al. , 2019). It is a copper clad board that is mainly used to mechanically support and connect electrical circuit components where the circuit connection has been designed, etched, and soldered (Buhnia and Tehranipoor, 2019).

It is no doubt that manufacturing PCBs is difficult because it usually takes a lot of time, involves several procedures to be performed, and necessitates both the addition and removal of materials by mechanical, electrical, or chemical means (Obe, et. Al, 2020). However, when cost and time are vital in constructing circuits, engineers use alternative methods of fabricating their PCBs. Among these alternatives is using ultraviolet (UV)-sensitive copper clads (Gduru and Eswaran, 2016).

Unfortunately, according to the majority of the student respondents surveyed, with 29% who agreed and 31% who strongly agreed, looking for services that print on acetate film is challenging, and the manual pre-sensitizing method takes about 30 to an hour to successfully etch PCBs, as emphasized by the 3 professional respondents interviewed. Meanwhile, the pre-sensitized method employs UV lights and chemicals that may cause detrimental effects on the human body if exposed for a prolonged time. Exposure to ferric chloride, a non-oxidizing mineral acid often used for etching, can irritate the eyes, nose, respiratory tract, and throat and cause significant skin irritation, burns, and eye damage.

Despite that, emerging technologies like automation have made the PCB fabrication process easier, faster, and safer. It offers a practical alternative to manual labor with a higher error probability. Automated machines ensure safe working conditions because they can house various components and materials, including

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hazardous ones, reducing the risk that humans are exposed to.

One of the automation applications is the study conducted by Santos et al. (2018) entitled "Automated Pre-sensitized Printed Circuit Board Etching Machine." It aims to lessen the complexity of manual etching regarding speed, accuracy, and reliability. To achieve their objectives, they have used photoresist PCBs and lasers with the application of CNC technology (Santos, et. Al, 2018). Apparently, the use of laser has limited the line width that can be engraved onto the PCB, and its utilization is quite risky and expensive.

Meanwhile, the lack of capable methods for producing complicated PCB layouts with small and smooth profiles requires expensive machines and tools. It is inherently dangerous due to laser beam utilization, which has motivated Suwandi et al. to conduct their research project in 2019 entitled "Dry Film Photoresist Application to a Printed Circuit Board (PCB) using a Maskless Photolithography Method." They have developed a system that utilizes visible light maskless lithography using a DLP projector-beam to replace the negative tone photoresist with a negative dry film photoresist (Suwandi, et. Al, 2018). However, both the external lens adjustment and the etching process are made manually, which adds to the uncertainties in accuracy and distance. Given this, the quality of their output is mainly dependent on the operator's eye focus, hand stabilization, and expertise.

Based on previous studies, it is evident that the manual pre-sensitizing method is time-consuming and poses a significant threat to the user's health and safety. Furthermore, there will be higher uncertainties when manually fabricating PCBs since the overall quality will depend on the user's capabilities. Although automating it and employing a laser beam is slow-processed, costly, and dangerous. For these reasons, the need for innovation in terms of manual pre-sensitized PCB etching methods has become more apparent

OBJECTIVES OF THE STUDY

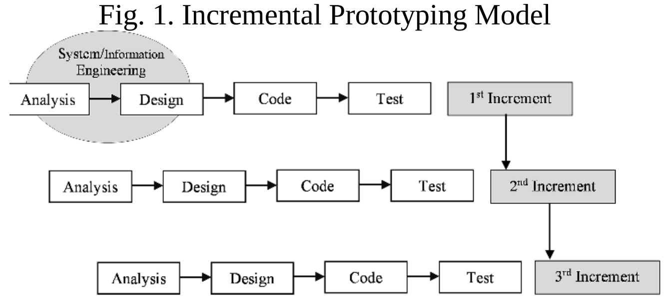
The primary objective of this research project is to develop an automated PCB layout etching system using LCD Masked-Based Lithography that can conveniently etch PCBs in less than 30 minutes. It also aims to eliminate the process of printing PCB layouts on acetate film, which serves as the mask to transfer the layout to the PCB's photosensitive surface. Specifically, it involves automating the procedures of exposure, development, and etching processes with the following sub-objectives: a) To transfer the PCB layout onto the pre-sensitized PCB by exposing it to UV light; b) To dissolve the photoresist film on the UV-exposed area of the PCB using a developer solution; c) To dissolve the copper surface that was not protected by the photoresist film with the help of an etchant solution; and d) To stop the system's operations automatically when an overflow happens.

MATERIALS AND METHODS

This section covers the methodology utilized to carry out the research project "Automated LCD Masked-Based Lithography PCB Layout Etching System." It discusses the tools that were used to describe the operation of the proposed system. This section contains information on the research method, analysis tools, system process, and system development methods.

This study used Developmental Research, specifically the Type I - Formative Research System-Based Evaluation, which emphasizes the program design, development, and evaluation of the developed project. The said method assisted in obtaining the objectives of this research, which is to develop a prototype model of the automated PCB layout etching system and evaluate its work performance (Cruz and Dizon, 2021)

Fig. 1. Incremental Prototyping Model



The incremental prototyping model, shown in Fig. 1, served as the framework for the prototyping model because the development can continue to progress even though other requirements are still being collected and prepared, and proceeding with gradual modifications is possible.

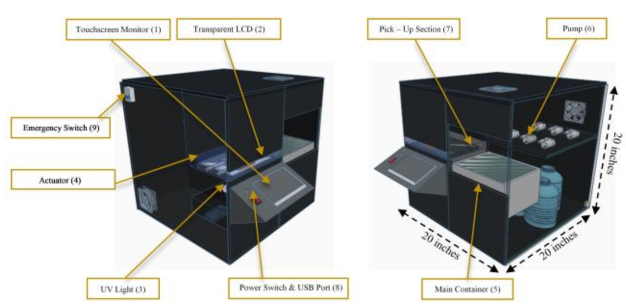


Fig. 2. Machine Design

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Machine design was presented in Fig. 2, highlighting the important components that will be incorporated into the system to etch PCBs using the pre-sensitizing method. (1) The user will provide the PCB layout and input it through the touchscreen monitor. (2) The system will display the PCB layout through a transparent LCD for layout masking, and then (3) the board will be exposed to ultraviolet (UV) light, and (4) will be pushed into the main container using an actuator. Then, (5) the board will be submerged in the main container containing a solution, (6) which can be replaced after one process to another using a pump. This is also where the developing, etching, and rinsing processes occur. When the board is finally etched and cleaned, (7) it is now ready to be picked up by the user. (8) The power switch will enable the system to start, and the USB port is where the user will insert the flash drive. (9) Emergency switch will allow the stop of the system's operation manually.

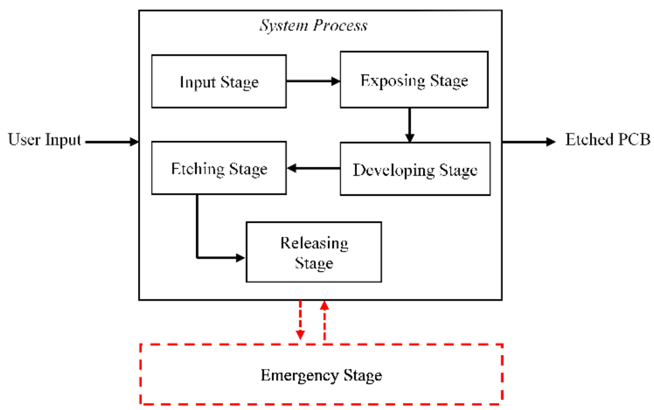

Fig. 3. System Process

Fig. 3 shows the relationship between the different stages of the automated PCB layout etching system. The input stage is where the whole system process will commence since the system user will supply the initial input requirements in this stage. Raspberry Pi 3 Model B will be used as the main controller of the system, which has a quad-core CPU running at 1.2GHz, 1 GB of RAM, 40-pin extended GPIO, USB ports, a Micro SD port, a DSI display interface, and built-in wireless connectivity. A 64 GB Micro SD will be used to load the operating system and store data. Meanwhile, the output of the Raspberry Pi will be interfaced on a 7-inch touchscreen monitor with 1024 x 600 resolution.

The exposing stage is where the blank PCB will be subjected to light to transfer the PCB layout in a mask to the photoresist film that covers the surface of the PCB. A 7-inch IPS screen with 1024 x 600 resolution will be used to act as the mask, which will be removed from its housing and backlight. The UV light with 6 watts of power and a light wavelength of 405 nanometers will be utilized to curate the photosensitive coating on the PCB. Stepper motor with stainless-lead screw, which have a 1.5-amp current per phase, will be employed to transfer the PCB from the tray to the main container. L298N motor driver module will be utilized to control the speed and direction of the motor.

The developing stage is in charge of dissolving the exposed photoresist of the PCB, while the etching stage is in charge of dissolving the copper. Water pump diaphragm will be used to draw the liquids, namely developer, etchant, and water, inside the silicon tubes and pump them to the other end of the tube. Meanwhile, an air pump with air stones will be used to agitate the solution by creating bubbles in the container.

The releasing stage is where the etched PCB will be available for retrieval.

In case of emergency, particularly when the motor pump fails, the system process will be stopped either by using the emergency switch or when the non-contact liquid sensor detects it.

A circuit power analysis will be conducted to determine the power consumed by each component and the overall power consumption of the circuit.

The researchers will conduct multiple experiments to determine the system's appropriate developing and etching solutions. The effectivity of the solutions will be analyzed based on the time it takes to dissolve their targeted material.

The developing solution must dissolve the photoresist film on the PCB within 1 to 3 minutes, while the etching solution must dissolve the copper in less than 10 minutes.

White–box and black–box testing will be conducted on the system. White – box testing is an in-circuit testing where the researchers observe the connections between each component and stages while the system is working and ensure that each internal connection is functioning properly to uncover any errors in the system. While black – box testing is also a type of testing that observing whether the system was able to generate its intended output without opening it.

The system will be assessed using general testing and endurance testing. In general testing, the system will be observed to determine whether it is functional each time it is powered on and is operating correctly. While endurance testing will be conducted to determine how well the system can perform over an extended period.

Speed testing will be conducted on the system, wherein the automated process, from the exposing stage up to the etching stage, will be timed to determine whether the system can etch pre-sensitized PCBs in less than 30 minutes.

Reliability testing will be done on the system, which involves the use of a range of PCB layouts and sizes to test whether the system generates the intended output. Reliability testing involves PCB sizes with variations ranging from 1 square inch to 15 square inches.

The system's output will be evaluated in terms of its accuracy and precision. In the accuracy test, the expected PCB layout will be compared to the expected output to check whether the system generates the desired results. The PCB layout will be printed on paper with a grid of 10 rows and 10 columns for the precision test, as shown in Fig. 4, and the layout tracks' positions will be compared to the grid to make sure they were etched correctly.

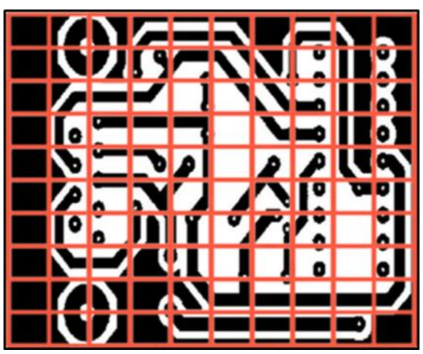

Fig. 4. Grid Test

The developed system will undergo a post-evaluation assessment among computer and electronics engineering students and professionals (Students=36, Professionals=7) to determine whether it effectively achieved the desired objectives of the study. As stated in the ISO/IEC 25010 (2011), different product quality characteristics must be met to ensure a good quality system model, and some of these are functionality, usability, reliability, and performance. The evaluation was based on ISO (International Organization for Standardization) and IEC (International Electrotechnical Commission) 25010 to assess the system's quality properly.

Weighted Mean will be used to statistically treat the data gathered by calculating the average set of values by multiplying the weights with their respective mean and taking its sum, as indicated in the formula below.

$$\textbf{Weighted Mean} = \frac{\sum_{i=1}^{n}(x_i * w_i)}{\sum_{i=1}^{n} w_i}$$

Where

∑ = denotes the sum

w = weights

x = value or number of occurrences

The qualitative description was presented in Table I to interpret the weighted mean to quantify the respondent's answers to each questionnaire item. The interval in the aforementioned scales was computed as:

$$\textbf{Interval} = \frac{(h-l)}{h}$$

Where

h = highest number in scale

l = lowest number in scale

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$$\textbf{Interval} = \frac{(h-l)}{h}$$

Where

h = highest number in scale

l = lowest number in scale

Table 1. Descriptive Rating for the Post-evaluation Results

Weighted Mean	Descriptive Rating
3.26 – 4.00	Excellent
2.51 – 3.25	Good
1.76 – 2.50	Fair
1.00 – 1.75	Poor

RESULTS AND DISCUSSION

This section presents the statistical analyses and interpretation of the study on developing an automated PCB layout etching system using LCD-masked based lithography. It includes the testing and experimental data, system functionalities, survey responses and statistical findings, conclusion, as well as the recommendations.

Unit testing was conducted among the gathered components to verify their functionality and capabilities in terms of their intended purpose in the system. Modular testing was also performed, wherein components were tested to ensure that they performed their intended function correctly with the other modules or components. Integrated testing was conducted among the

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groups of components assigned to the exposing, developing, and etching stages to determine if the objectives of each stage were accomplished.

The researchers conducted multiple experiments to determine the appropriate parameters and components that will be used in the exposing, developing, and etching stages. Based on the result of the experiments, the ideal system guidelines were identified and was shown in Table 2.

Table 2. System Guidelines

GUIDELINES	
Exposure time	120 seconds
Developing time	200 seconds
Etching time	240 seconds
Rinsing time	10 seconds
Solution Fill-up time	30 seconds
Draining time	40 seconds

The UV exposure distance for the system is 8.5 cm and the UV exposure time is 120 seconds (2 minutes), wherein the UV light with an 8.5 cm reflector will pass through the glass and transparent monitor with screen protector to the PCB, respectively. The PCBs were developed excellently using a concentration of 600 ml/ 2 tsps, in 200 seconds, and cleanly etched in 240 seconds (4 minutes).

The researchers were able to develop the automated PCB layout etching system through a thorough planning and systemic development process.

(A)

(B)

Fig. 5. Automated LCD Masked-Based Lithography PCB Layout Etching System

Fig. 5 shows the actual image of the developed system, wherein the proposed machine design was completely followed and implemented. The system frame has a dimension of 20x20x20 inches and was created using Lawanit wood, a high-density fiberboard with a 15-mm thickness.

Proper ventilation and exhaust were also administered. A portable fan was positioned near the Raspberry P is to reduce the heat generated when used for prolonged periods, and another one was placed above the main container to shorten the time it takes to dry the rinsed PCB. A single portable fan is mounted behind the peristaltic pumps to divert the harmful fumes produced by the chemical solutions.

The developed system was able to achieve positive results in white-box, black-box, general, and endurance testing. It was determined that the system was functioning properly, and was able to generate the desired output, which is the etched PCBs.

Speed testing was performed on the system, wherein the time it takes to accomplish the automated process, starting from the exposing stage up to the etching stage was recorded. It was determined that the system was capable of etching pre-sensitized PCBs in approximately 16 minutes.

Reliability testing was performed on the system, wherein the output PCBs were checked to see whether the system could etch the same PCB layout on different PCB sizes. Table III present the results of the reliability testing, wherein the same PCB layout was etched in different PCB sizes on the first set (Table 3 – A), and

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various PCB layouts were also etched in different PCB sizes on the second set (Table 3 – B).

Table 3– a. Reliability Testing Results

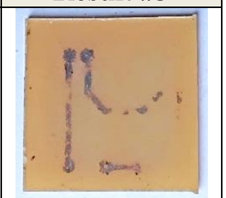
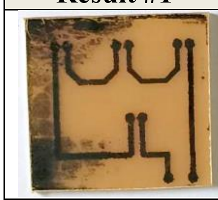
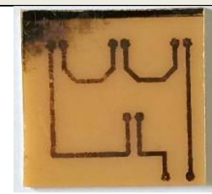
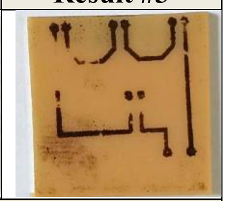
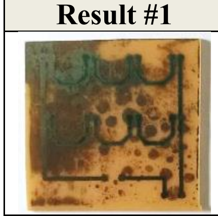
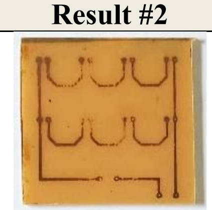
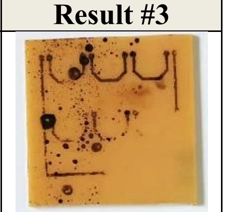
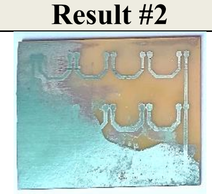
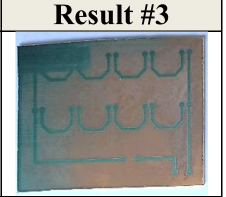
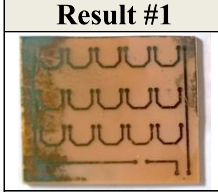
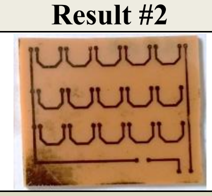
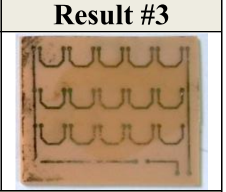
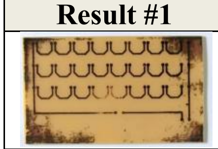
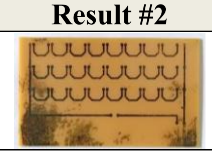
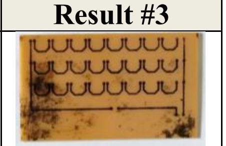
PCB SIZE: 1 x 1 inches		
Result #1	**Result #2**	**Result #3**
		
PCB SIZE: 1.5 x 1.5 inches		
Result #1	**Result #2**	**Result #3**
		
PCB SIZE: 2 x 2 inches		
Result #1	**Result #2**	**Result #3**
		
PCB SIZE: 2 x 2.5 inches		
Result #1	**Result #2**	**Result #3**
		
PCB SIZE: 2.5 x 3 inches		
Result #1	**Result #2**	**Result #3**
		
PCB SIZE: 5 x 3 inches		
Result #1	**Result #2**	**Result #3**
		

Table 3 – b. Reliability Testing Results

PCB SIZE: 1 x 1 inches		
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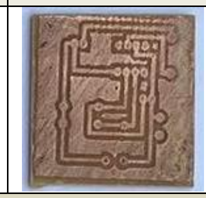
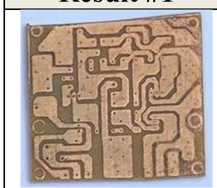
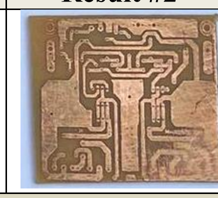
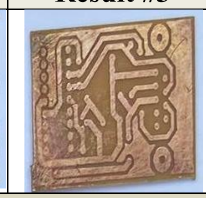
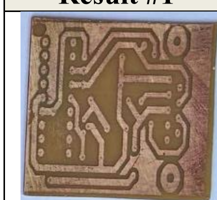
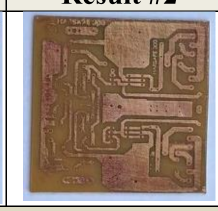
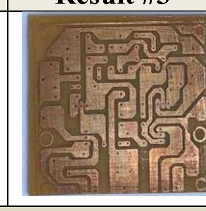
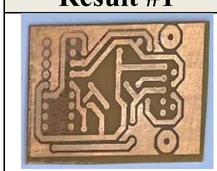
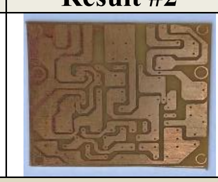
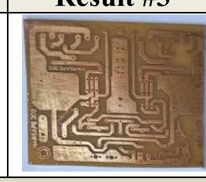
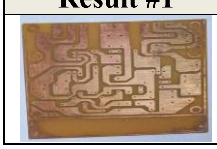
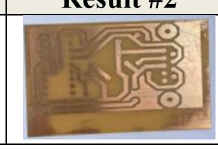
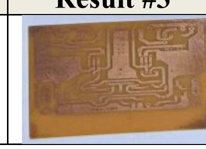
		
PCB SIZE: 1.5 x 1.5 inches		
Result #1	**Result #2**	**Result #3**
		
PCB SIZE: 2 x 2 inches		
Result #1	**Result #2**	**Result #3**
		
PCB SIZE: 2 x 2.5 inches		
Result #1	**Result #2**	**Result #3**
		
PCB SIZE: 5 x 3 inches		
Result #1	**Result #2**	**Result #3**
		

Table 4 presents the results of the precision and accuracy testing of the system. During these tests, the researchers etched 10 PCBs with the same layout to effectively analyze the precision and accuracy of the system. In the precision testing, a 10x10 grid was used to analyze the result, in which the system garnered 84%. Moreover, in accuracy testing, the system has been able to etch the same layout on 10 out of the 10 PCB layouts.

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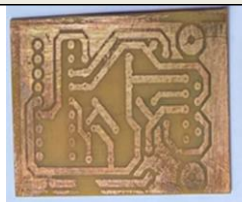
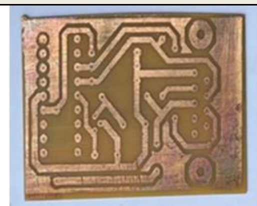
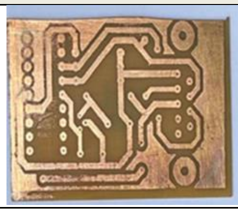
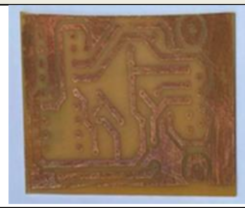
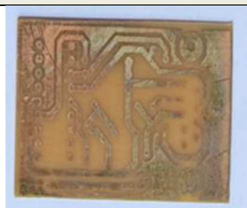
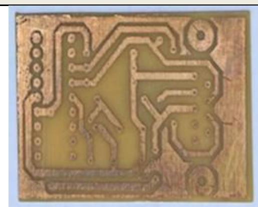
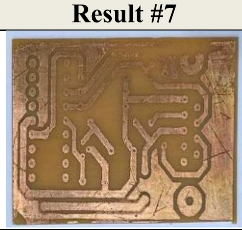
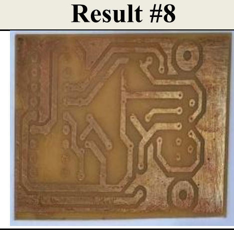
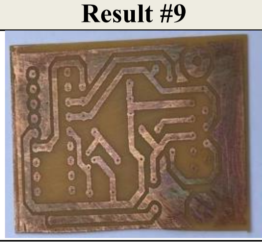
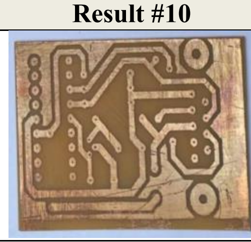
Table 4. Precision and Accuracy Testing Results

Result #1	Result #2
	
Result #3	**Result #4**
	
Result #5	**Result #6**
	
Result #7	**Result #8**
	
Result #9	**Result #10**
	

Post – evaluation assessment was conducted among electronics and computer engineering students and professionals. It was determined that the system was able to achieve its objectives with a weighted mean of 3.57 from the professionals and 3.69 from the students, wherein both indicate an excellent descriptive rating.

With the developed system, imprinting layouts on PCBs can be conveniently done on a safer setup and is less time-consuming. Moreover, the overall quality of the output PCB will not be compromised since it will not depend on the user's capabilities but rather on the automated system.

CONCLUSION AND RECOMMENDATION

Conclusively, the researchers developed the system, Automated LCD-Masked Based Lithography PCB Layout Etching System, after thorough planning, development, calibration, and testing. This study proved that implementing a transparent monitor as an alternative way of masking the PCB prior to exposure was possible and cost-effective. In addition to that, in the developing stage, it shows the importance of the right type and concentration of the solution to develop the exposed PCB effectively. In the etching stage, cupric chloride has been proven to be a good alternative for ferric chloride as an etchant solution, as it can also etch the PCB layout efficiently. Agitation also plays an important role to speed-up the process of developing and etching the pre-sensitized PCB. With a series of testing and the conducted post-evaluation, the system could operate as intended and achieve its desired objectives.

The generalization of this study was of significant benefit to the existing processes of PCB printing that utilize the pre-sensitizing approach, as users will be able to have their layouts printed more promptly and accurately than with the manual method. The development of the said system lessens the processes involved by eliminating the need for printing the PCB layout on acrylic or acetate film. The health problems associated with using UV lights and chemicals will be prevented because there will be minimal interaction between these hazardous materials and the user. Generally, there will be a convenient way of etching complicated PCB layouts using the developed system while maintaining easy and safe procedures.

The following recommendations for system development are made for researchers who wish to continue and enhance the study in the future: Use a bigger screen for both the touchscreen and transparent monitor so that larger PCBs can be accommodated and batch printing can be implemented; a more appropriate container that is intended for highly corrosive chemical solutions is advised; a suitable agitating method with controllable intensity movement is highly suggested; a stopper can be added to hold the PCB in place during the exposing stage; and a customizable time limit for the exposing, developing, etching, and rinsing stages can also be included.

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