Development of an Automated Pre-Sensitized Printed Circuit Board Etching Machine

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Abstract: **This research automates the etching process which includes light exposition, developing, and etching processes for a pre-sensitized PCB for board sizes ranging from 2" by 4" to 6" by 4". It integrates a CNC Laser with the developing and etching processes to provide fast, accurate, and reliable etching. Applied-Quantitative type of research was used, which aims to ease the complexity of manual etching while providing better etching experience by comparing data acquired for both type of process. To assure the effectiveness and efficiency of the machine, Speed, Accuracy, and Reliability tests were conducted. The machine was proven accurate and reliable after 8 out of 9 boards passed the continuity test. This paper also contains tables that compares the time consumed using the automated PCB machine and the manual etching.**

Keywords: **Automation, Etching, Laser, Pre-Sensitized.**

I. INTRODUCTION

Prototyping a Printed Circuit Board (PCB) is one major task in the creation of electronic projects. Focusing on a pre-sensitized PCB, prototyping process includes designing and exposing the layout to the PCB with light, developing, etching, drilling, and soldering. The output of which is ready for the latter processes such as soldering and testing. However, the whole picture of the process may not be fully understood by an amateur student or project maker who had no previous experience on the etching process. In addition, lack of safety precautions may induce harmful effects of acids used during the process to the student. As one of the commonly used chemical compound for etching, exposure to ferric chloride, a non-oxidizing mineral acid can irritate eyes, nose, respiratory tract, and throat, and may cause severe skin burns and eye damage which when inhaled can cause coughing or breathing difficulty. Furthermore, according to New Jersey Department of Health and Senior Services (2004), repeated exposure may lead to excessive iron build-up in the body causing nausea, stomach pain, vomiting, constipation, and black bowel movements. As for the developer used, potassium carbonate may also cause irritability to skin, eyes, respiratory tract, and mucous membrane of eyes.

In terms of time, the etching process (inclusive of layout printing to the pre-sensitized PCB, developing, and etching proper) can last from an approximate time of 30 to 90 minutes. As for students and hobbyist who are doing their own projects, this might take a span of time where they could be doing other tasks. Lastly, manual etching process is prone to error. For example, underexposed board will have an output with failed continuity. Prolonged exposure, on the other hand may cause the acetate paper to bend, thus producing an output with misalignments. With these findings, the researchers will incorporate the said processes into a single machine, while incorporating a CNC Laser for the photoengraving process, in order to utilize time efficiently (time management), reduce safety hazards, produce quality output and provide faster etching process.

This study entitled "Automated Pre-sensitized Printed Circuit Board Etching Machine" aims to integrate different processes of manual etching (Layout printing, Developing, and Etching) into a single machine that will simplify work of the students. Specifically, the study aims to interface the PCB etching machine and the computer; to construct a Computer Numeric Controlled (CNC) Laser that can engrave the layout drawing from the computer into the Printed Circuit Board (PCB); to develop a program that can control the machine and utilize Benbox to upload circuit design from the computer into the CNC Laser; to create a single machine for the automation of the etching process; and to test and evaluate the machine in terms of Efficiency, Accuracy, and Reliability.

The benefactors of this project are the professors, students, hobbyists, and future researchers. This study can facilitate a faster etching for the experiments and projects that are needed. Also, the etching process can be taught with live demonstration. The students can easily etch a PCB in the school's Engineering Laboratory without exposing themselves much in hazardous materials which were used in etching. The device and its processes are easier to understand and utilize for the students. If the project will be developed for mass production in the future, this project can simplify the task of hobbyist in terms of etching a PCB. With this, they can do other activities while waiting for the automated etching process to be done. Lastly, It can be a basis or reference of future researchers for their innovations.

This study focuses on the automation of the etching process, namely photoengraving, developing, and etching. This does not cover other processes of prototyping a project which are drilling and soldering. For the layout printing process, the researchers utilized a Computer Numeric Control (CNC) to convert the layout from the computer in G-Codes and control the movement of the laser. This CNC assemblage is responsible for removing the mask or shielding the parts as bounded by the layout from the photoresist PCB area. However, the laser beam's diameter and wattage is fixed which means that the proponents did not cater circuits with very thin (0.010" and 0.020") nor considerably wide tracks and spaces. The application of this study concentrates on a single-sided pre-sensitized (photoresist) PCB with dimensions of 6" by 4", 4" by 4", and 2" by 4" inches, with the board having a border line of at least 0.5 cm, and negates the application and any comparison to copper type PCBs. Moreover, the machine processes one PCB at time which means that another PCB cannot be processed unless whole etching process for the first board is completely done. The machine is plug-and-play, considering that the necessary software used in the study is installed on the computer. The machine will have to be connected to an AC power source and cannot function unless enough power is supplied. It incorporates an alarm to notify the user when the whole process is finished. Finally, the study does not include the methodologies for disposing the acids used in the project for its focus is to build an automated machine for the etching process of PCB alone.

II. METHODOLOGY

This project was conducted to classify the ordered system on how the prototype must be set up. This chapter also covers various ways on verifying the validity and accuracy of the project as well as the materials needed in the system.

Research Design:

Since the goal of this research is prove that the automated etching machine can provide a faster, more accurate and reliable etching experience, the proponents used an Applied-Quantitative type of research. This research aims to solve a practical problem in manual etching while comparing data gathered from manual etching versus the automated process. A research was conducted to assist the idea of the proposed project especially on the software and hardware system needed for stabilization. This project was set to determine the effectiveness and efficiency of the project versus manual etching process. It also determines the accuracy of the output of the proposed project.

As for the Engineering students and some hobbyist who manually etch a design into the PCB who experience various difficulties within the process. The manual PCB etching takes much of a time for the users to finish the entire PCB, and sometimes tend to repeat the whole process due to failure of the proper etching.

The proponents showcased a background study to fully understand the problems that the users usually encounter during etching. An error occurred in layout printing via light exposure since the layout was not visible until it underwent the development process. To support the study, the proponents surveyed the ECE and CPE students regarding the typical time they consume conducting the entire etching process, disregarding the time spent printing the layout on an acetate paper.

The objectives were the basis of different types of solutions that the proponents have devised in response to the problems mentioned. These formulations were evaluated to find the most appropriate solutions for the problems.

Looking for the most appropriate alternative to traditional etching methodology in prototyping a PCB, the proponents integrated the CNC laser with the development and etching processes. This CNC laser imprinted the design to the photoresist PCB, which according to research is faster than manual transfer of a design printed on an acetate paper with the aid of non-coherent light. Considering the harmful effects of direct exposure to liquid chemicals such as the developer and the ferric chloride. The proponents designed a machine where these chemicals were placed in safe container, concealed on both sides, whereas reducing the exposure. The important materials used in the hardware are Computer Numeric Control (CNC) Laser, Pre-sensitized PCB, motor drivers, microcontroller, IR sensor, and mini airpump. The software includes utilization of Benbox and Visual Basic.

Project Construction Procedure:

In order to aid the reader in understanding how the researchers created the project, a design flow chart was shown in Figure 1 presenting the process of the creation of the project.

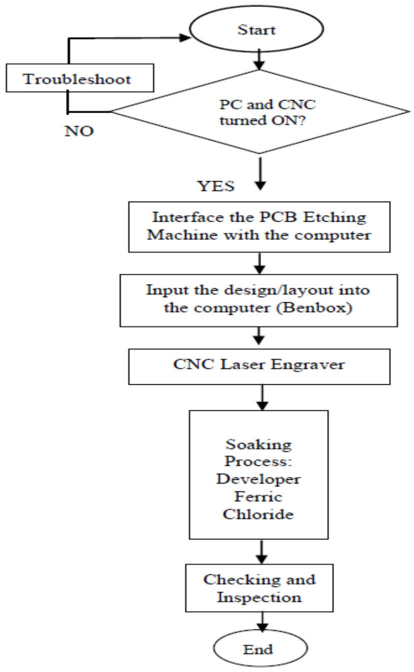

Fig 1: Flow Chart System Design

In correspondence to the system design, the PCB Etching Machine was interfaced to a computer with the installed software dedicated to control the machine.

System Model:

To understands how the device works, the researchers created a design flow chart. Figure 2 shows the flow chart with the proper process of PCB etching.

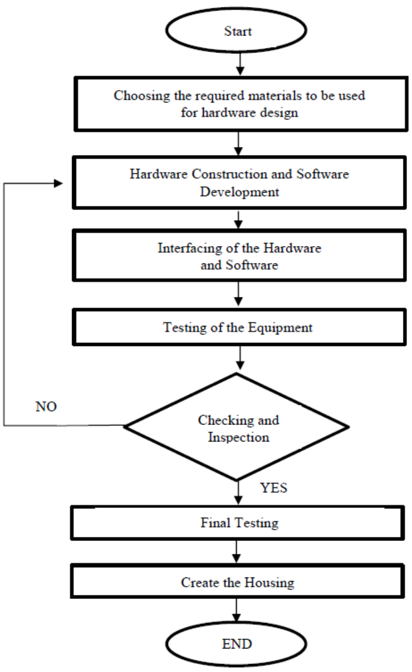

Fig 2: Flow Diagram of the System

The PCB Etching Machine will be interfaced to a computer with the installed software dedicated to control the machine. The user will have to open the GUI to choose the board size he desire and then the design/layout for etching. Then a pre-sensitized PCB must be placed under the laser to start the design transfer process. Once the engraving is done, a will vertical pulley will then move the board to the soaking processes. The machine will soak the PCB into the developing solution, then the pulley will rinse it. Next, after rinsing, it will soak the PCB into the ferric chloride, then rinse again. Lastly, inspection of the output has to be conducted.

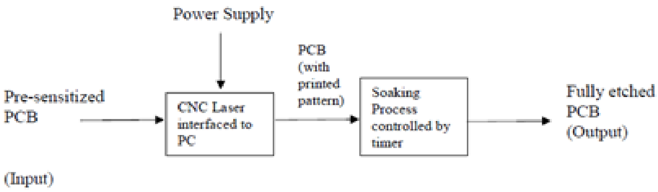

Fig 3: Open Loop Control System

The pre-sensitized PCB will be inserted in the CNC laser given that the design was uploaded in the computer. After the CNC transferred the design to the PCB, it will undergo to the soaking process. Soaking process includes developer solution and ferric chloride solution. We have a dedicated timer for each solution depending on the size of the PCB. The timer will be included in our user interface making it easy for the user to use. Once soaking is done, we can now get and inspect the fully etched PCB.

To present different perspective views of the proposed design for the Automated Pre-Sensitized Printed Circuit Board Etching Machine, several figures are drawn. Illustrated in figure 4 is a perspective view of the machine design. The blue ones indicate non-metal materials such as acrylic glass and plastic containers.

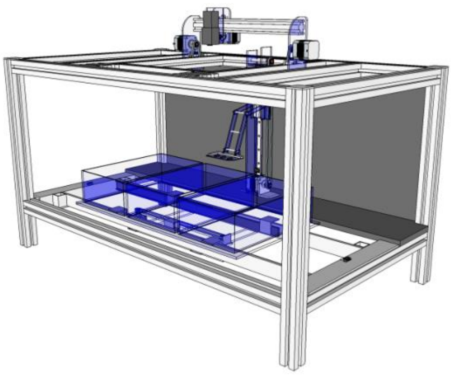

Fig 4: Machine design: Perspective view

The Graphical User Interface (GUI) was created using Visual Studio to form a direct communication between the codes written in C language via Arduino and Benbox, the dedicated software for the CNC laser. The main menu of the GUI, shown in Figure 5, contains the *Start Process* and *Hardware Test.* Noticeably, the *Start Process* button will lead the user to the actual operation of the machine. Conversely, the *Hardware Test* is dedicated for calibrating the machine and for checking if the functionalities of the motors intended for horizontal and vertical operations are working.

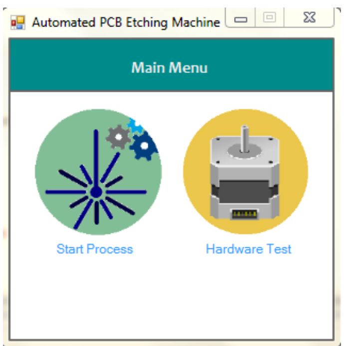

Fig 5: GUI Main Menu

Project Testing and Evaluation:

The system was tested for functionality at each of the features stated. If the system does not perform as expected, troubleshooting will be performed and corrections will be made. Each of the system was tested for consistency with its intended function.

Three main tests will be performed to determine the consistency of the machine: accuracy, reliability and speed. The Accuracy Test will determine if the machine can replicate the design by conducting a continuity test. On the other hand, the Reliability test will determine whether the machine will be able to etch the PCB consistently or not. It will be computed based on the equation below:

$$\text{Reliability (\%)} = \frac{Successful\ Attempts}{No.of\ Attempts} \text{ X } 100 \quad \text{eq. [1]}$$

The speed test will determine the estimated time of finish for a specific board size. The result will be the basis of time which will be put into codes. The time consumed producing an output, for each station and the total time, will be compared to that of the manual process by examining the same PCB design for a specific board size. The goal of this test is to have an overall time of producing an output faster than manually etching the same design. The board size will be 6”by4”, 4”by4”, and 2”by4”.

III. RESULTS AND DISCUSSIONS

The results in terms of light exposure in manual etching have a significant difference compared to the automatic machine’s laser engraving. It can also be observed that laser engraving significantly makes the developing faster than the manual exposition to fluorescent lamp. The etching process, however, has a minimal deviation which can be neglected out of the equation.

With the results acquired in this section, the 2” by 4”, 4” by 4”, and 6” by 4” boards was programmed to an approximate etching time values of 15 min, 19 min, and 19 min, respectively. For uniformity, all board sizes was soaked in the developer for 1 min 35 sec and in water for a total time of 32 sec. The CNC Laser engraving time varies depending on the complexity of the circuit but as observed it does not last for more than 10 min using the configuration of the Benbox done by the researchers.

A. Speed Test:

Table 1: Layout 1 (2” by 4”) Manual Etching and Automated Comparison

PROCESS	MANUAL	AUTOMATED
Light Exposure/ CNC Laser	8 min	2 min
Developer	2 min 29 sec	1 min 35 sec
Water	-	16 sec
Wet Etching	14 min 53 sec	15 min
Water	-	16 sec
Machine Transitions	NA	1 min
Total	25 min 22 sec	20 min 7 sec

Table 2: Layout 2 (4” by 4”) Manual Etching and Automated Comparison

PROCESS	MANUAL	AUTOMATED
Light Exposure/ CNC Laser	16 min	3 min
Developer	2 min 08 sec	1 min 15 sec
Water	-	16 sec
Wet Etching	19 min 58 sec	19 min
Water	-	16 sec
Machine Transitions	NA	1 min
Total	38 min 06 sec	24 min 47 sec

Table 3: Layout 3 (6" by 4") Manual Etching and Automated Comparison

PROCESS	MANUAL	AUTOMATED
Light Exposure/ CNC Laser	32 min	7 min 9 sec
Developer	2 min 03 sec	1 min 47 sec
Water	-	16 sec
Wet Etching	19 min 16 sec	19 min
Water	-	16 sec
Machine Transitions	NA	1 min
Total	53 min 19 sec	29 min 28 sec

As indicated in Table 1 -3, the automated machine speedily finished the process compared to the manual etching.

B. Accuracy Test:

After getting the proper timing for each board size, the machine is now ready for the accuracy testing. To obtain 100% accuracy, the output of the automated PCB machine must pass the continuity test for all test nodes. Since continuity testing will be done to assure that two nodes are indeed connected according to the layout design, one failed continuity result will mean a failure of the trial.

The accuracy will be calculated using this formula:

$$\% \text{ Accuracy} = \frac{No.of\ successful\ continuity}{No.of\ continuity\ to\ test} \text{x } 100\% \qquad \text{equation [2]}$$

1. Layout 1 (2" by 4")

For the 2" by 4" PCB, the test nodes A to X are shown in figure 6. Several pair of nodes were chosen based on the computer circuit design (Table 4) to undergo continuity evaluation.

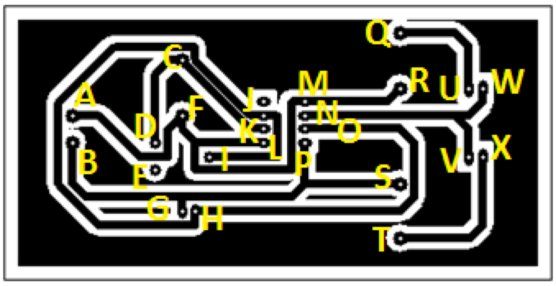

Fig 6: 2" by 4" Test Nodes

Table 4: Layout 1 list of nodes to check

NODES	Connected (Ideal)
A-L	NO
A-K	YES
K-D	YES
K-L	NO
L-H	YES
L-O	YES
N –O	NO
A-R	YES
R-N	NO
U-W	NO
V-X	NO
Q-W	YES

T-X	YES
N-W	YES
N-V	YES
B-S	YES

Table 5: Layout 1 Accuracy Result

TRIAL	Accuracy
1	100%
2	100%
3	100%

Table 5 shows that the continuity testing was successful for all trials conducted. Therefore, the test conducted for the 2" by 4" board was 100 % accurate.

2. Layout 2

For the 4" by 4" PCB, the test nodes A to X are shown in figure 77. Several pair of nodes were evaluated to assure continuity (Table 6).

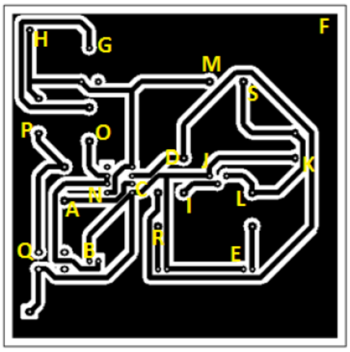

Fig 7: 4" by 4" Test Nodes

Table 6: Layout 2 List of Nodes to Check

NODE	Connected (Ideal)
P-Q	YES
G-H	NO
B-C	NO
A-N	NO
R-D	NO
O-B	NO
L-K	NO
I-J	NO
M-N	YES
M-F	NO
D-F	NO
B-F	NO
B-J	YES
E-R	NO
S-K	NO
D-B	NO

No test nodes failed the continuity test among the three 4" by 4" boards tested as shown in Table 6. Averaging the result, Layout 2 has acquired 100 % Accuracy.

Table 7: Layout 2 Accuracy Result

TRIAL	Accuracy
1	100%
2	100%
3	100%

3. Layout 3 (6" by 4")

For the 6" by 4" PCB, the test nodes A to X are shown in figure 8. Several pair of nodes were undergone continuity testing in comparison with the computer circuit design as shown in Table 8.

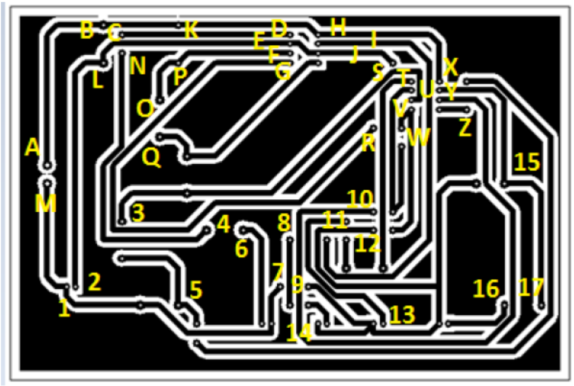

Fig 8: 6" by 4" Test Nodes

Table 8: Layout 3 List of Nodes to Check

NODE	Connected (Ideal)
A-X	YES
2-J	YES
M-7	YES
Q-G	YES
X-14	NO
14-13	NO
W-U	NO
3-4	NO
D-E	NO
E-F	NO
H-I	NO
I-J	NO
10-11	NO
11-12	NO
R-U	NO
6-7	NO

Table 9: Layout 3 Accuracy Result

TRIAL	Accuracy
1	100%
2	100%
3	87.5%

One of the test nodes failed the continuity test on the third trial of Layout 3 as shown in Table 15. Averaging the result, Layout 3 has acquired 95.83 % Accuracy. The mean of the test results for layouts one to three resulted to 98.61% accuracy.

IV. SUMMARY AND CONCLUSION

Summary:

In a nutshell, the idea of this study started with a scrutiny about the manual etching process. The proponents realized several problems encountered in etching a PCB manually. First, underexposure to light results to circuit continuity error. Second, there are misalignments and coupled lines due to unexpected light exposure. In the midst of light exposure, there exists a tendency that the acetate, printed with circuit design, to bend, allowing light to pass through portions unintended to get an exposure. Third, the time it takes submerging a board into the ferric chloride solution may takes much time for a person to manually agitate it. With this, the researchers integrated the etching processes while utilizing a CNC Laser as a substitute to the traditional light exposure. With this, the problem involving underexposure and mismatched lines was solved. In addition, the constant agitation of liquid by the mini-airpump solved the hassle of shaking the container manually in etching process, thus reducing the exposure to the acid since it was discussed that too much ferric chloride exposure leads to negative effects to human health.

The proponents have highlighted three testing parameters to compare the automated process with the manual etching. In speed test, as a basis of time for each board size, each sample processes was timed manually in order to acquire the estimated time of finish. For layout 1, a 555 Timer Circuit, 2" by 4" board, took a total time of 20 min 7 sec vs 25 min 22 sec of manual etching. Layout 2, an egg timer, consumed 24 min 47 sec of time doing the etching processes. And Layout 3, finished in 29 min 28 sec. With this, the time it takes etching a PCB using the automated machine was proven to be faster than the manual etching. The proponents conducted three trials for the accuracy and reliability testing. The result of accuracy testing concluded with 100% accuracy for layout 1 and layout 2. Meanwhile the accuracy test for layout three resulted to an accuracy of 95.83% due to two failures in continuity testing. The primary reason behind this is that the solutions were already used for several trials. With eight of nine (8/9) failures the proponents were able to acquire 88.89% reliability.

One hundred forty (140) evaluated the machine and the system UI. It was a success as the researchers obtained an excellent mean of 4.63 for the machine and 4.62 for the system UI.

Conclusion:

The Automated Pre-Sensitized PCB Etching Machine was proven to be fast, less error, accurate, reliable, and user friendly. The time acquired in speed test of each machine station were satisfactory as the three board sizes have provided a data not greater than nor equal with the time consumed doing the process manually. It was also observed that the developing process was significantly faster (about 30 seconds faster) when laser was used to engrave the design than when a typical fluorescent lamp was used and the researchers conclude, in correspondence to the study stated in Chapter 2, that this is merely because the laser can remove the mask more effectively than the normal light exposure. With laser engraving, broken lines, and misalignments are reduced. Acquiring eight out of nine boards with satisfactory continuity results, the study was proven to be accurate and reliable. The evaluation, for both user interface (UI) and machine, was successful. While all mean for machine falls within the excellent range, the physical appearance acquired the highest mean (4. 69) among other indicators while the time efficiency the lowest (4.49). This does not indicate that the machine cannot save the time etching a PCB manually but rather, other respondents could have agreed to etch manually than learning a new technology. Despite this conclusion, the overall assessment for the machine still falls flat in excellent range with a mean of 4.63. The System UI obtained an excellent result of 4.62 which leads to the conclusion that the respondents agreed that the UI can be used without the guidance of the creators (Usability), that the functions performs each commands effectively (Accuracy) overtime (Reliability).

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