# "Develop a new manufacturing approaches for production of microcircuitry by 3D laser patterning"

**By**

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# I. Synopsis

With the continuous upgrading of technology, electronic devices are becoming smaller and more precise. For different electronic equipment, personalized electronic devices and circuit layout are particularly important. In the research the professor has done, a method for selective plating of 2D microcircuity on polyetherimide[1] is proposed. By reproducing the existing technology, it is possible to develop a new method in selecting plating. The core task of the project is to use high-power lasers to replace the LEDs in the existing technology in the exposure process.

The whole project is divided into two parts. Firstly, use existing equipment to design a system that can basically reproduce the process in the paper given by the professor, following the method provided on the thesis, carved the desired mark on the polyetherimide film, which simulate the process of engraving microcircuitry on a 2D surface. Because the wavelength of the laser can influence the result of exposure, it is also useful to design a system to change the wavelength of the laser. However, limited by the lack of equipment, the aim of changing the wavelength is cancelled in the second semester.

In the second part, to achieve 3D laser irradiation, a feasible method is to transform the CNC machine tool, replace the drill with the laser. For the modification of the CNC machine, the underlying code needs to be modified and the laser needs to be connected to the appropriate pins of the board. Then the user can use the G code to control the move of the CNC machine to achieve the 3D laser printing on the sample.

## II. Acknowledgement

I want to express my heartfelt thanks to all the people who helped me in the project

Firstly, I would like to thank my supervisor, Dr Jose Marques Hueso. He gave me lots of useful suggestions and gave me the opportunity to study more advanced technologies. Even when I accidentally broke the machine, he continued to comfort and encourage me. And I am also very grateful to Abdulrhman Mansour, my mentor's postgraduate research student, who showed me the chemical process of the patterning on polyetherimide and gave me a lot of valuable opinions when I modified the CNC machine.

Then I want to say thanks to the staff of Pocket CNC Ltd, when I have problems on using the machine, they can always give me the correct solution.

Also, my teammate, Yuze Sun, we work and solve the problems together. He is always full of energy, which also keeps me moving forward.

Finally, many thanks to Prof. Jiasheng Hong for giving a lot of guidance for project planning and the final report.

## III. Statement of Authorship

I, Yibing Liu

State that this work submitted for assessment is my own and expressed in my own words. Any uses made within it of works of other authors in any form (eg. Ideas, figures, text, tables) are properly acknowledged at their point of use. A list of the references employed is included.

Date…………14/04/2020……………

## IV. Nomenclature

**PEI------------------- Polyetherimide**

**CAD----------------- Computer Aided Design software**

**DI water------------ Deionized water**

**CNC----------------- Computer numerical control**

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## 1. Introduction

Micro-patterning is a very important part in the production of the microelectronic components for instance printed antennas and encoders[1]. But in the ready-made process, we use the grating to expose the sample directly under the LED light to get the pattern we want. The disadvantages of this method are obvious, the user can only get the pattern according to the grating. After subsequent processing, we can only get the circuit which is just corresponding to the grating. In order to get personalized circuit patterns, we introduced the laser printing, the pattern is selectively irradiated by laser.

Which means we can get personalized microcircuit patterns on the polyetherimide by controlling the laser path[2]. In the previous experiment, the relevant design has been basically completed. But the system still has some shortcomings, the laser can only provide a single color of light. We want to use different wavelengths of the laser, because the color changes the properties of the patterned area.

Based on the previous research, we have a structure of the optical part[3]. The way to change the color of the laser is to add a shutter in front of the laser. Modifications to this system also include replacing LEDs with lasers[3].

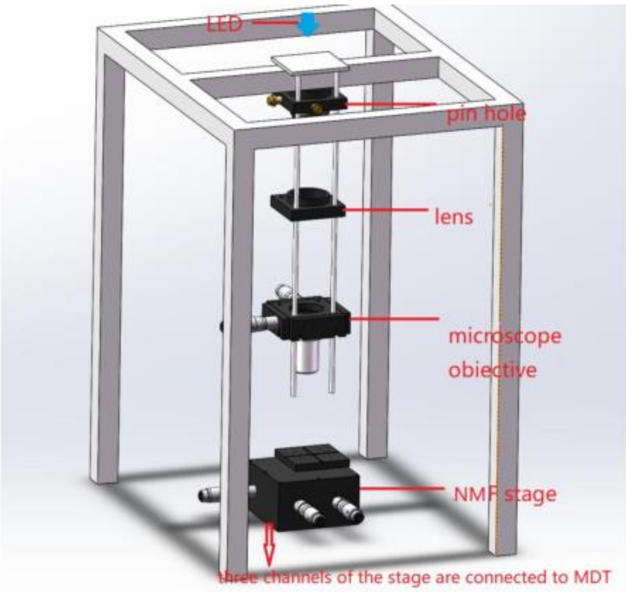


*Figure 1 structure of the optical part [3]*

The LabVIEW, a program development environment is used to control the stepper motor to control the position of the shutter. G language, a graphical programming language is used in the LabVIEW,


*Figure 2 LabVIEW*

The whole above system is patterning in a plane, to achieve pattern in 3D, the CNC machine must be used. The sample is put on the holder, the drill is replaced by the laser. As the figure4 shows, when the user moves the axis, the laser can directly illuminate the inner ring of the sample, which realizes 3D patterning. The core problem is that how the replace the drill with a laser.

*Figure 3 Pocket 5-axis CNC*

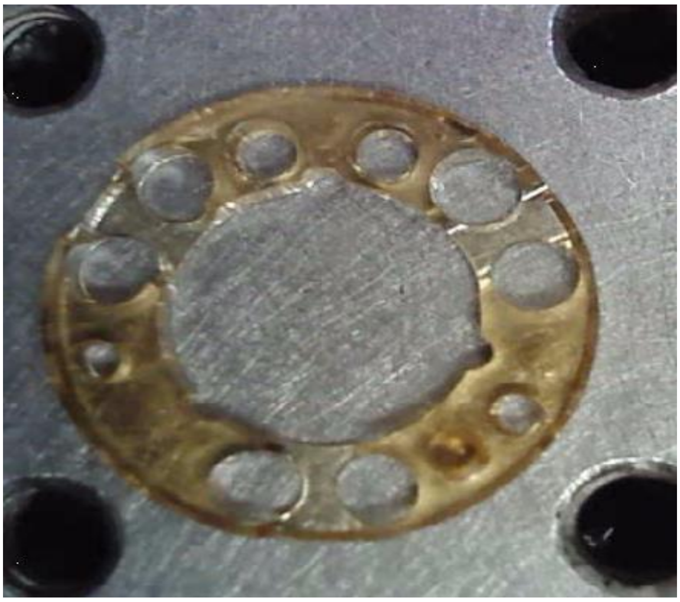

*Figure 4 the sample*

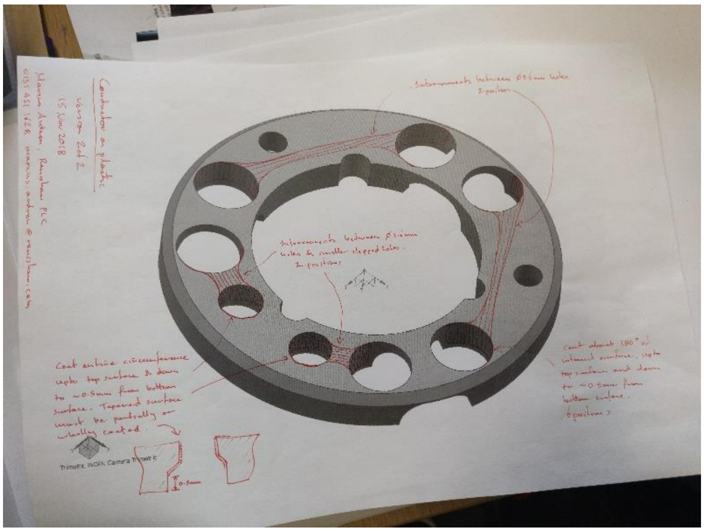

*Figure 5 Sample drawings*

In the first semester, my main focus was on studying how to change the laser color. But in the second semester, As the task of the project changed, my main focus was on how to modify the CNC machine and how to use the machine.

The ultimate goal of the project is to use the designed system to pattern on the samples of polyetherimide, after subsequent chemical treatment, the metallic microtracks is presented.

# 2. Background

This part mainly introduces the core content of some thesis materials related to the project and the software and equipment needed in the project, such as the LabVIEW and the Pocket CNC.

## *2.1 Thesis Materials*

The materials are mainly the thesis provided by the supervisor. In previous experiments, the researchers have designed a complete process to produce the microcircuitry on PEI.

Micropatterning of conductive tracks on flexible substrates and contoured surfaces enables a lot of novel packaging solutions[4]. The metallization of polyimides(PI) has received much attention due to their mechanical biocompatibility, strength, resistance, chemical, and the ability to withstand high temperatures. However, using PI also has been held back because the photopatterning stage and the exposure energy should be controlled strictly. In the meanwhile, the polyetherimide (PEI) has the same excellent properties as the polyimides[1].

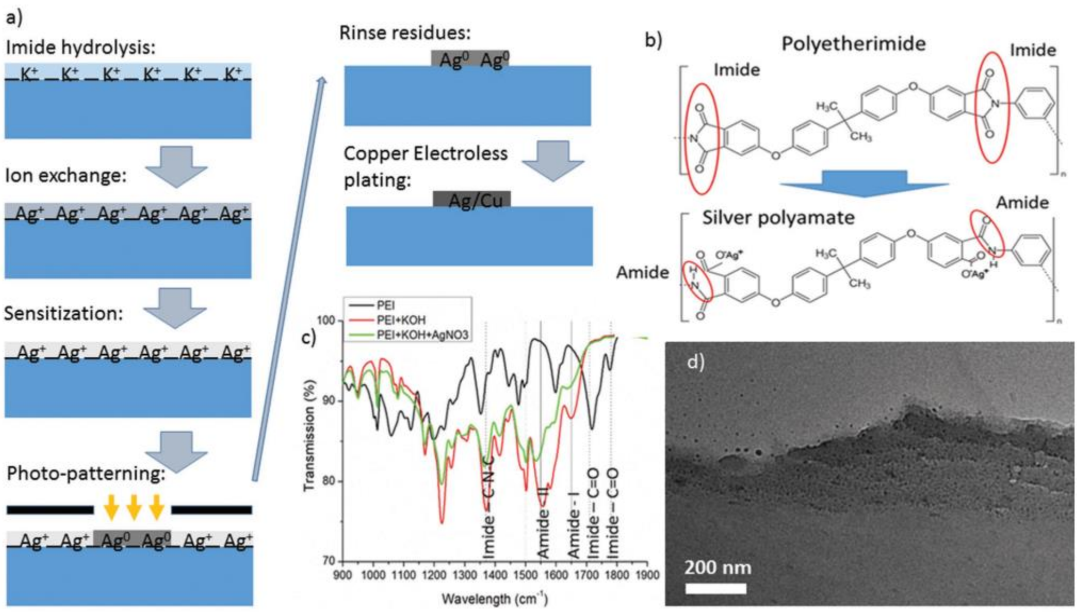


*Figure 6 The general process to form the silver patterns on the polyetherimide surface[1]*

The specific experimental process is as follows. For different materials, some steps take different time, take filament ULTEM 9085 as example:

| | | |
|---|---|---|
| a | Degrease | Use the isopropanol or ethanol to clean the sample |
| b | Clean | Use DI water rinse the sample |
| c | Hydrolysis | Immerse the sample in a heated Potassium Hydroxide(KOH, 15M) solution bath at 50℃ for 15 minutes and ultrasound agitation. |
| d | Clean | Rinse it under the DI water for 2 minutes. |
| e | Ion Exchange | Place the sample in a Silver Nitrate(AgNO3, 0.1M) solution for 15 minutes. |
| f | Clean | Rinse it under the DI water for 5 second. |
| g | Optical Sensitization | Submerge the sample in Potassium Chloride(KCl, 0.01M) for 30 second. |
| h | Photoreduction | For flood exposure: Photolithography mask aligner(11mW*cm$^{-2}$ at 365nm)<br>For local exposure: high-power LED (1W at 460nm) |
| i | Etch | Immerse the sample in ammonia(17%)to remove the metallic residues for 15 second. |
| j | Clean | Rinse it under the DI water for 2 minutes. |
| k | Etch | Etch the sample in sulfuric acid(5%) for 20 second. |
| l | Copper Plating | Electroless Copper plating |

*Table 1 Process Stage*

Some chemical reagents need to be prepared on site in the chemical laboratory:

<u>15M KOH solution recipe:</u>

Add 84g in small quantities of 100ml of DI water with stirring.

<u>KCl recipe:</u>

| **Concentration** | **Ethanol/DI water** | **For 80 mL stock solution** |
|---|---|---|
| 0.01M | 3:1 | 0.06g of KCl mixed into 20ml of DI water then topped up with 60ml ethanol |
| 0.1M | 1:1 | 0.6g KCl mixed into 40ml of DI water then topped up with 40ml ethanol |

*Table 2 KCl makeup*

<u>Ammonia solution:</u>

The ammonia is in a 2.5L bottle in the solvent storage opposite the fume cupboard. It is at 35% concentration and the user can dilute it 1:1 into DI to get a 17.5% concentration.

<u>Sulfuric acid</u>

The user can dilute 5% sulphuric acid solution found in the acid store under the fume cupboard. 5.3 ml sulphuric acid to 94.7ml DI water.

Electroless copper bath:

8g of hydroxide, 6g of copper sulfate and 28g of potassium tartrate into 200ml of DI water.

Following the process shown in Table 1 Process Stage, the user can get the processed sample:

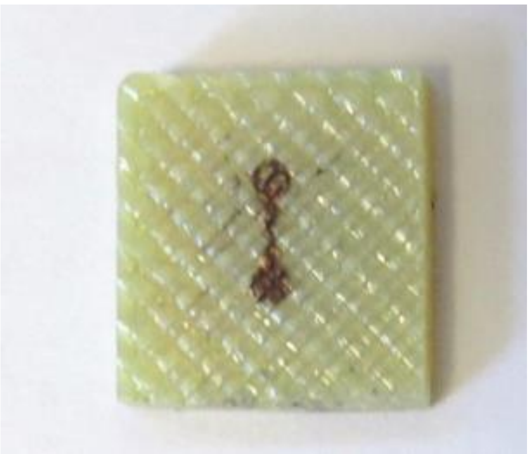

*Figure 7 Processed samples*

## *2.2 Project Documentation*

This part mainly contains the preparation work required for projects other than the thesis, including the introduction of the software and experiment equipment.

### *2.2.1 LabVIEW*

LabVIEW is a program development environment, developed by National Instruments (NI), using BASIC and C development environments. However, the significant difference between LabVIEW and other computer languages is that other computer languages use text to generate code LabVIEW uses the graphical editing language G to write programs, and the generated programs are in the form of etching[6].

The LabVIEW development environment includes all the different tools that scientists and engineers need to design a variety of applications quickly, which enhance scientists and engineers' ability to solve problems and innovate[6].

The LabVIEW program is called VI (Virtual Instrument), and has the extension of .vi, so we are accustomed to use VI to represent the LabVIEW program. After the user start LabVIEW (my version is version 2018), create a blank VI, you can get two windows, one is the block diagram, and the other is the front panel, as shown below:

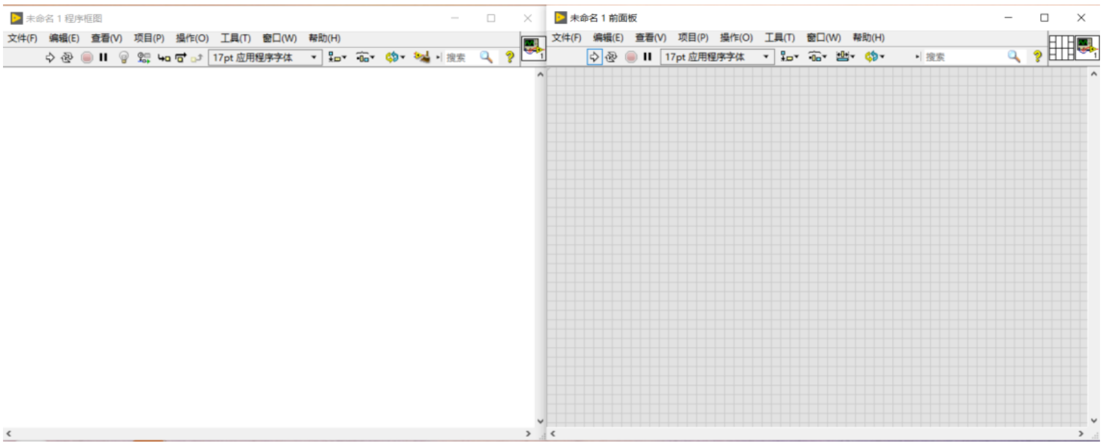

*Figure 8 Blank VI in LabVIEW*

LabVIEW provides lots of widgets that look like the traditional instruments (for instance the multimeters and oscilloscopes) , which makes it easier to produce user interfaces. The front panel, the user interface in LabVIEW uses the wiring and icons, we can control the objects on the user interface by programming, which is a kind of graphical code, called G (graphics) code. The graphical source code of LabVIEW is kind of like the data flow flowchart, so we often called it block diagram code[14]. Each widget on the user interface is corresponded to an item in the block diagram. Each time the data "flows" to the widget, the widget will display the data in some ways based on their own characteristics, such as graphics, numbers, or switches[6].

In order to design the system we want, firstly add widgets in the user interface. The widgets in the VI front panel are split into control widgets and display widgets. The display widget is used to display data or information to user, and the control widget is used to control signals or input data to the program. Lots of widgets in LabVIEW imitate real-world instrument interfaces, such as knobs, switches, and sliders. As an example, here we put two knobs on the user interface of the VI to control the frequency and amplitude of the simulated signal[14]. When the user adds widgets on the front panel, the back panel automatically generates a block diagram[14]. As shown below:

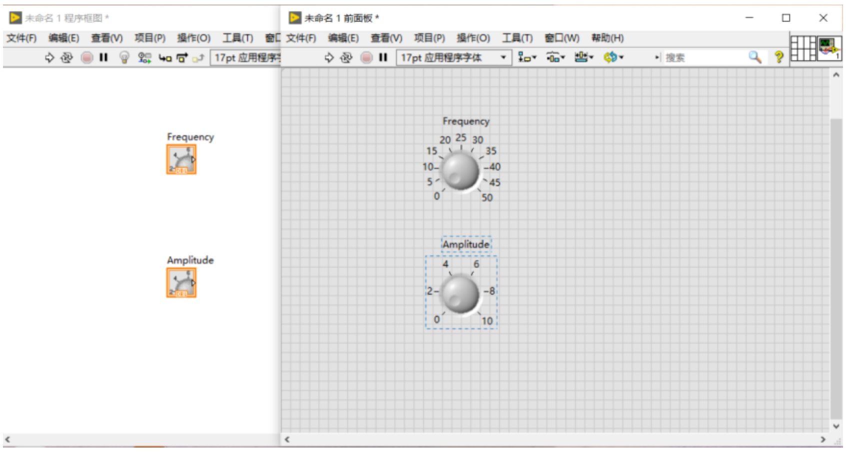


*Figure 9 Two knobs are set in LabVIEW(Frequency and Amplitude)*

Next step is adding a signal generation module on the block diagram window. And the connected signal is set as a sinusoidal signal. Enter the VI block diagram, double-click the icon of the simulation signal generation function or right-click the icon to select the Properties option. The "Configure simulation signal" dialog box shown below will pop up and set the properties:

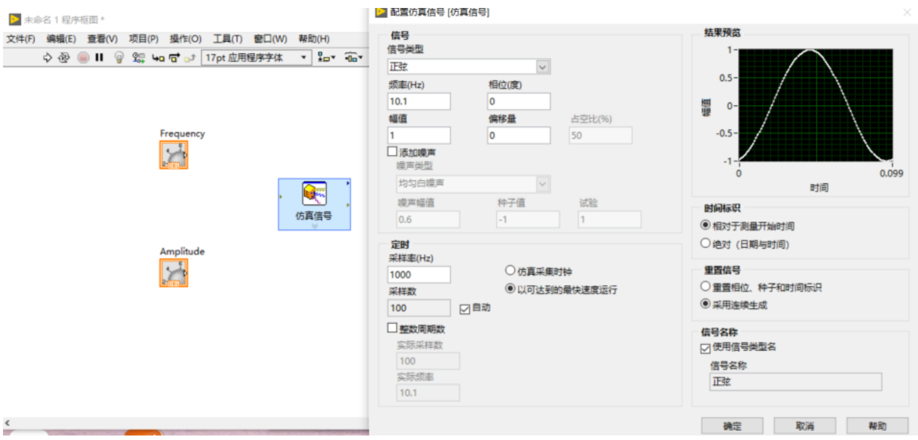


*Figure 10 Set sinusoidal Signal*

After that, add the module of oscilloscope on the user interface, Finally, add a while loop to the block diagram. The physical architecture is similar to the subsystem, Frame all the modules in the block diagram. as shown below:

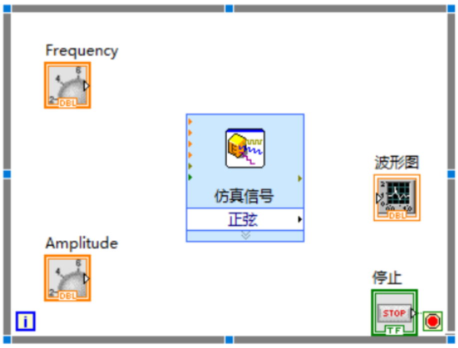


*Figure 11 Block Diagram for this small system*

Having all the module icons placed correctly and the properties set successfully, we can connect them, when the program is edited correctly, the run button on the VI toolbar will be a white arrow, which indicates that the program can be executed, otherwise it will be a broken gray arrow, which means that there are errors in the program and it cannot be executed[14]:

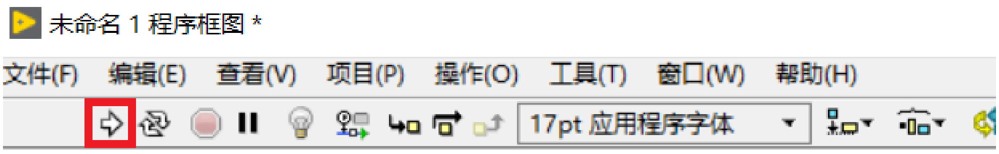


*Figure 12 The correct program*

Run the program, we can change the frequency and amplitude in the front panel:

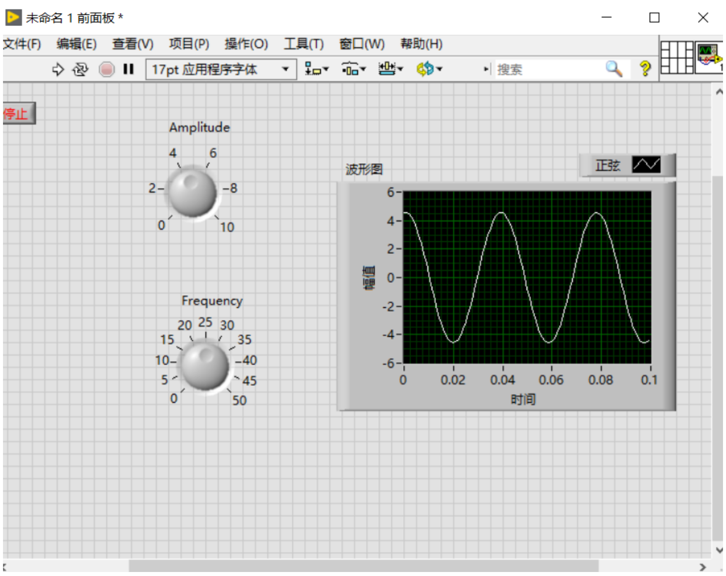


*Figure 13 Run the program*

### 2.2.2 CNC machine

The CNC machine used in the project is Pocket NC V2-10. The user can control CNC through G code. Users can study the G code and the working principle of the machine through the CNC machine simulator on the network.


*Figure 14 The picture of CNC machine*

| Code | Meaning |
|---|---|
| A | Rotation about X-axis. |
| B | Rotation about Y-axis. |
| C | Rotation about Z-axis. |
| D | Cutter diameter compensation (CDC) offset address. |
| F | Feed rate. |
| G | G-Code (preparatory code). |
| H | Tool length offset (TLO). |
| I | Arc center X-vector, also used in drill cycles. |
| J | Arc center Y-vector, also used in drill cycles. |
| K | Arc center Z-vector, also used in drill cycles. |
| M | M-Code (miscellaneous code). |
| N | Block Number. |
| O | Program Number. |
| P | Dwell time. |
| Q | Used in drill cycles. |
| R | Arc radius, also used in drill cycles. |
| S | Spindle speed in RPM. |
| T | Tool number. |
| X | X-coordinate. |
| Y | Y-coordinate. |
| Z | Z-coordinate. |

*Table 3 CNC programming language[9]*

G-Code is the language that be used to control the CNC machines. It is just one kind of CNC programming method that the CNC programmers use, the other kind is the CAM programming. Normally, the CNC controller probably executes g-code, in the meanwhile there are some other possibilities such as the Heidenhain. And others have proprietary formats. Some machines with proprietary format can also run g-code, which is the Lingua Franca (a kind of working language) for CNC[7].

Here are some common codes:

| G-Code words | | | |
|---|---|---|---|
| **G0** | Rapid Linear Motion | **G59.2** | Select Coordinate System 8 |
| **G1** | Linear Motion at Feed Rate | **G59.3** | Select Coordinate System 9 |
| **G2** | Arc at Feed Rate | **G80** | Cancel Modal Motion |
| **G3** | Arc at Feed Rate | **G81** | Canned Cycles – drilling |
| **G4** | Dwell | **G82** | Canned Cycles – drilling with dwell |
| **G10** | Set Coordinate System Data | **G83** | Canned Cycles – peck drilling |
| **G17** | X-Y Plane Selection | **G85** | Canned Cycles – boring,no dwell, feed out |
| **G18** | Z-X Plane Selection | **G86** | Canned Cycles – boring, spindle stop, rapid out |
| **G19** | Y-Z Plane Selection | **G88** | Canned Cycles – boring, spindle stop, manual out |
| **G20** | Length Unit inches | **G89** | Canned Cycles – boring, dwell, feed out |
| **G21** | Length Unit milimeters | **G90** | Set Distance Mode Absolute |
| **G28** | Return to Home | **G91** | Set Distance Mode Incremental |
| **G30** | Return to Home | **G92** | Coordinate System Offsets |
| **G53** | Move in Absolut Coordinates | **G92.1** | Coordinate System Offsets |
| **G54** | Select Coordinate System 1 | **G92.2** | Coordinate System Offsets |
| **G55** | Select Coordinate System 2 | **G92.3** | Coordinate System Offsets |
| **G56** | Select Coordinate System 3 | **G93** | Set Feed Rate Mode units/minutes |
| **G57** | Select Coordinate System 4 | **G94** | Set Feed Rate Mode inverse time |
| **G58** | Select Coordinate System 5 | **G98** | Set Canned Cycle Return Level |
| **G59** | Select Coordinate System 6 | **G99** | Set Canned Cycle Return Level |
| **G59.1** | Select Coordinate System 7 | | |

*Table 4 List of common G codes[9]*

This is the demo code provided by the manufacturer, On the stage surface, the position of the drill bit can be controlled by x / y ± number:

```
%
G20
G90 G94 G40 G17
G53 G0 Z0
G0 A0 B0
G0 X0
M5
M0
T4 M6
G43
S8500 M3
F20

G0 A90
G0 X1 Y1
G1 Z0
G1 X-1
G1 y-1
G1 X1
G1 Y1

G49
G53 G0 Z0

M5
M30
%
```

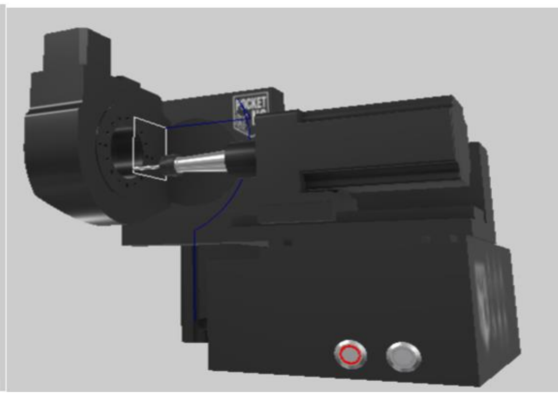

*Figure 15 Demo code and Corresponding motion state of the CNC*

### *2.2.3 5-axis kinematics*

Only understanding G code is not enough, the 5-axis kinematics is also very important when controlling CNC machine tools.

The processing objects of 5-axis CNC machine tools are often some parts with complex surfaces. The processing of such parts requires the direction of the tool vector to be consistent with the direction of the processing surface. In this way, the CNC machine tool should have rotational motion coordinate axes in addition to the translation coordinate axes[10].

As shown in Figure 16, the spatial motion of the CNC machine tool is composed of three translation coordinates X, Y, Z and three rotation coordinates A, B, C that rotate around the XYZ axis, respectively. According to the specific structure of the 5-axis linkage CNC machine, the motion coordinates X (A), Y (B), Z (C) can be realized by the translation (rotation) of the tool or the worktable that fixes the workpiece, respectively

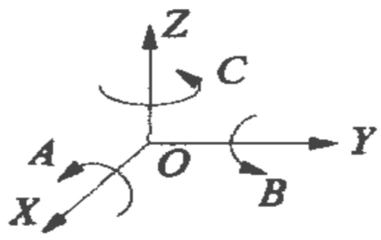


*Figure 16 Machine coordinate*

5-axis linkage motion coordinates of CNC machine tools are usually composed of three translation coordinates X, Y, Z and three rotation coordinates A, B, and C. There are three situations: XYZAB, XYZBC, and XYZAC. It should be noted that the machine tool movement coordinates here are the coordinates of the tool relative to the machine tool movement coordinate system (MCS system), not the tool's coordinates relative to the workpiece coordinate system (WCS system)[11].

According to ISO's regulations on the coordinate axes of 5-axis CNC machine tools and their movement directions: the Z axis of the MCS system is defined as the coordinate axis parallel to the machine tool spindle, and the positive direction is defined as the direction from the worktable to the tool clamping, that is, the tool is away from the work The direction of the table; the X axis is defined as parallel to the workpiece clamping plane and parallel to the main cutting direction, and the positive direction is the pointing direction; the Y axis movement direction is determined according to the right-hand rule according to the Z axis and the X axis; the rotation coordinate axis A, The corresponding direction of B, C in the positive direction of X, Y, Z axis is determined by the direction of the right-hand thread, shown as Figure 16.

Before processing, the CNC machine must first return each coordinate axis to zero and initialize the control system and store the offset value between the machine tool reference coordinate system (hereinafter referred to as RCS system) and the MCS system in the machine tool constant. After initialization, the machine motion coordinate XYZABC is displayed as zero, and the motion of the tool or workpiece relative to the MCS system is converted to the motion relative to the RCS system. After the workpiece is fixed on the machine table, the relative positional relationship between RCS and WCS is determined by measurement, and the measurement result is stored in the CNC system.

CAM/CAD systems are usually used to generate the CAM data as an input for the CNC 5-axis machine as well as the CAD models of the workpiece in 3D. The tool or cutter location data, which consists of the tip position and the tool direction relative to the workpiece coordinate system [12]. Two vectors, as created by most of the CAM systems and shown in Figure 17, includes the following information:

$$\mathrm{K} = \begin{bmatrix} K_x \\ K_y \\ K_z \\ 0 \end{bmatrix} \text{ Orientation vector;} \qquad \mathrm{Q} = \begin{bmatrix} Q_x \\ Q_y \\ Q_z \\ 1 \end{bmatrix} \text{ Position vector}$$

The K vector is equal to the third vector from the pose matrix E6 which was usually used in the kinematics of a 6-axis robot [13] and the Q vector is equal to the fourth vector of E6. In MASTERCAM, as an example, the information is included in the middle output of the ".nci" file[12].

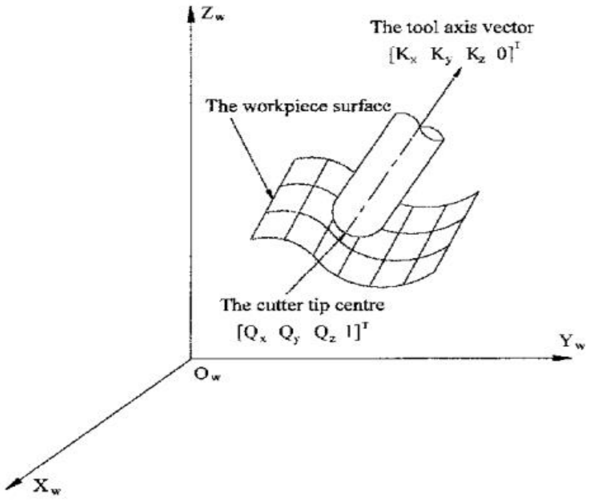


*Figure 17 Cutter location data*

Homogeneous transformation is a simple method to describe the kinematics of multi axis machine tools. A transformation of the space H is a 4x4 matrix, which is representative the rotation and translation transformations. Had a point x, y, x described by a vector u = $\{x,y,z,1\}^T$, then its transformation v is expressed by the matrix product[12]:

$$v = H \cdot v$$

There are four basic transformation matrices available for 5-axis kinematics:

$$T(a,b,c) = \begin{bmatrix} 1 & 0 & 0 & a \\ 0 & 1 & 0 & b \\ 0 & 0 & 1 & c \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad R(X,\theta) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & Cos\theta & -Sin\theta & 0 \\ 0 & Sin\theta & Cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$R(Y,\theta) = \begin{bmatrix} Cos\theta & 0 & Sin\theta & 0 \\ 0 & 1 & 0 & 0 \\ -Sin\theta & 0 & Cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad R(Z,\theta) = \begin{bmatrix} Cos\theta & -Sin\theta & 0 & 0 \\ Sin\theta & Cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The matrix *T(a, b, c)* means a translation in the X, Y, Z coordinate directions by the amounts a, b, c respectively. The R matrices indicates rotations of the angle theta around the X, Y and Z coordinate axes[12].

Generally speaking, for CNC machine tools, there are two different ways of rotation:

- A rotary table rotates around the vertical Z axis (C rotation, secondary) and is mounted on a tilt table that rotates around the X axis or Y axis (A- or B-rotation, primary). Workpiece is installed on the rotating table [12].
- The tilt table that rotates around the X axis or Y axis (A or B rotation, secondary) is installed on the rotary table, and the rotary table rotates around the Z axis (C rotation, primary), and the workpiece tilts the table[12].

# 3. Lab work

## *3.1 Brief Introduction*

For the lab work, following the supervisor's arrangement, at first in the first semester ,the project is aimed to design a color selecting system. Combining with the project of the teammate, we can design a complete system that can use different wavelength lasers for 2D patterning on the PEI. In the second semester, it can be sure that the lab will have a CNC machine for 3D patterning. Therefore, the main direction of research becomes how to modify CNC machine tools. In addition, in the second semester, we also conducted some chemical experiments, as shown in Table 5.

## *3.2 Color selecting system*

The simple DC laser is used in the laboratory, the current and voltage through the laser are basically fixed. Therefore, the wavelength of the laser is basically fixed. The wavelength of the laser cannot be changed by changing the current.

*Figure 18 DC laser*

Advised by the supervisor, we can try to add a filter before the laser to change the wavelength of the laser. Based on this research direction, the next job is study how to control the rotation of the filter. As the background show, the LabVIEW has huge advantages, and with the deepening of the project, we can add more complex functions.

What's more, the position of the filter is relatively fixed, so the stepper motor more meets the experimental requirements.

The core task is to control the movement of the stepper motor. In the stepper motor control system, the most common method is to use PLC or single-chip microcomputer to achieve stepper motor control, But the disadvantage of this technology is that the circuit is complicated and unstable, and the programming is more complicated.

Hence, we try to use LabVIEW to control the stepper motor to change the position of the filter.

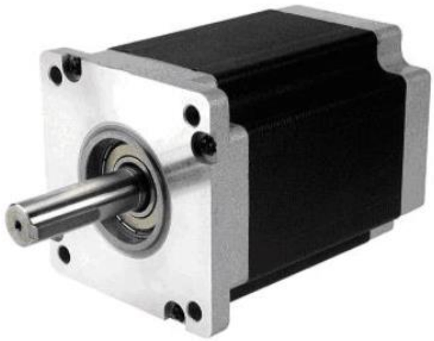

*Figure 19 Stepper motor*

Stepper motors are electromechanical devices that convert electrical pulse signals into angular displacement[15]. By changing the pulse frequency, the actuator can be quickly started, braked, and reversed. Therefore, the general stepper motor control system refers to single-chip microcomputer or PLC to produce the pulses, the circuit then generates a stepping pulse corresponding to the speed and distributes it to each phase winding of the stepper motor to realize the control of the stepper motor. Generally speaking, the pulse is generally generated by a microcomputer or some auxiliary circuits to generate the start signal of the stepper motor [错误!未找到引用源。].

The initial idea is to use LabVIEW to complete the process of generating pulse signals and Boolean signals with adjustable frequency. After the hardware connection, the pulse signals are sent to the driver through the DAQ board and connected to each input terminal of the stepper motor, respectively. Then realize the control of the stepper motor. As shown in figure 20(In the early stage of the project, I have not obtained the permission to enter the laboratory, so when designing the system, the most common equipment is used):

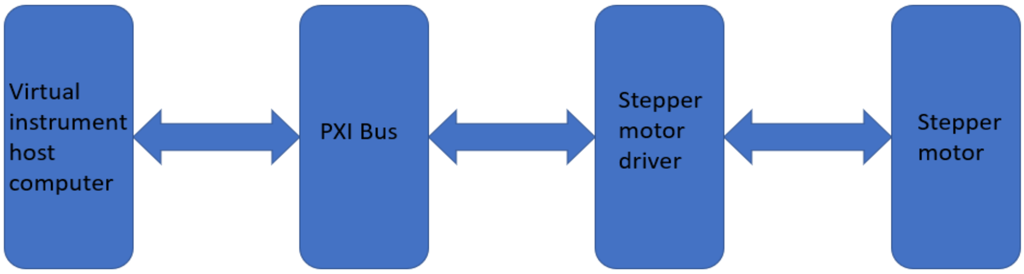


*Figure 20 The control of the stepper motor*

*Figure 21 Common DAQ board*

According to the working principle of the stepper motor, the control system should realize continuous operation and angle operation, so the program uses case structure to select different operating states. These two operating states are completed using the FPGA module of LabVIEW. Create a "Continuous Run" VI and a "Specified Angle Run" VI under the "FPGA Target" directory, as shown in Figure 22[16]


*Figure 22 Create sub VI in FPGA*

continuous operation of the motor

Use the built-in square wave generation function in the FPGA module to generate a pulse. This pulse signal is first output from the analog output channel 1 of the FPGA board, and then sent to the stepper motor driver, as shown in Figure 23.

Since the specified speed unit is r/s, and the control amount of the square wave generation function is frequency, the speed of the stepper motor can be controlled by frequency. Therefore, the speed needs to be converted into frequency calculation, according to the formula:

*Stepper motor speed = frequency * 60 / ((360 / inherent step angle) * Subdivision multiple)*

We can calculate the control frequency of the stepper motor, then you can directly control the pulse frequency to control the speed of the stepper motor. In addition, as shown in Figure 23, the square wave signal is added with an offset of 5V in order to ensure that the low level is 0. The waveform chart is used to display the pulse signal generated by the square wave generating function.

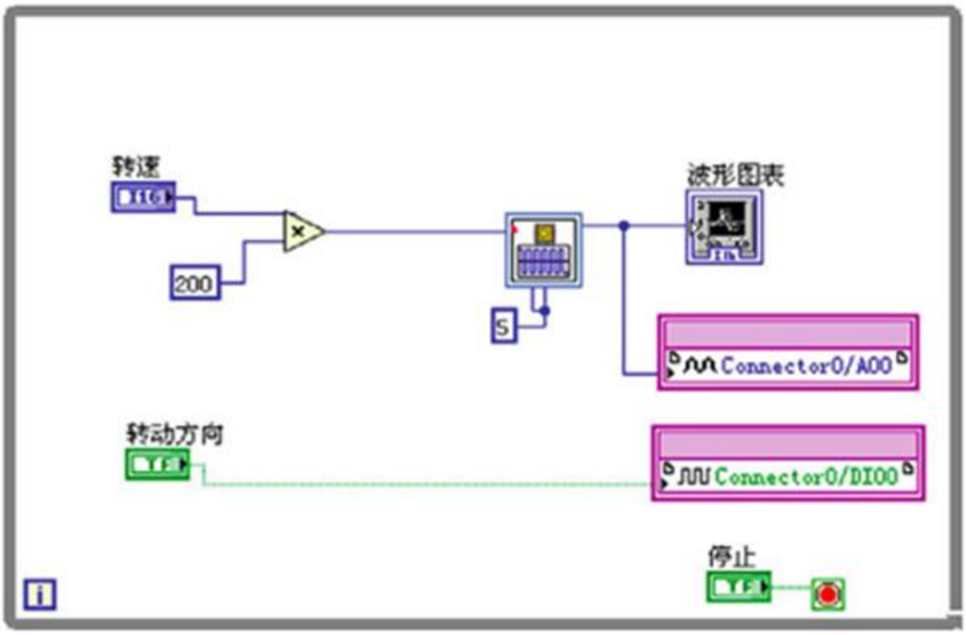


*Figure 23 Produce an impulse*

## *angle operation*

The rotation angle of the stepper motor is determined by the number of input pulses, so the programming of this VI can achieve a specified angle of operation. Therefore, we should calculate the number of input pulses. Generally, the timing method and the counting method are adopted. Compared with the two schemes, this design uses the method of counting pulses, because the stepping motor has a period of acceleration and deceleration when starting or stopping , Using the timing method there may be errors.

The solution is as follows: First, calculate the number of pulses required for the stepper motor to rotate to a specific angle. Secondly, the number of pulses required is equal to the number of pulses calculated by the counter, and the program must stop running[18]. Therefore, according to the programming idea, as shown in Figure 24, the Boolean value of the count should be operated by OR with the Boolean value of the "Stop" button. As long as the logical operation result shows 1, the motor should stop running., and finally connect the result to While The "cycle condition" end of the cycle

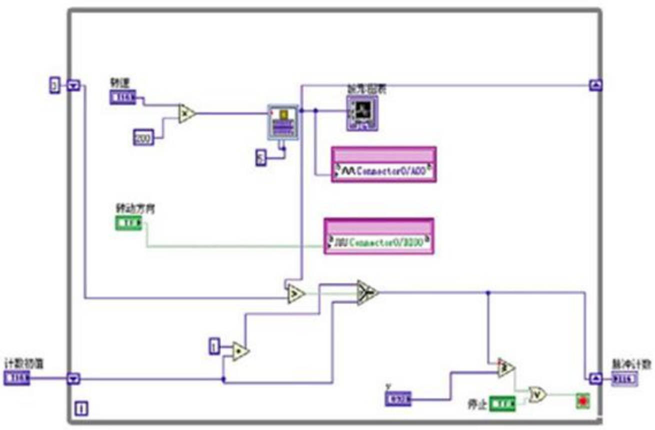

*Figure 24 Angle operation*

In the "continuous operation" state, only the pulse signal needs to be adjusted when the motor is started. Timing or counting can be ignored.

## *Problem*

Following the above design, we can succeed to control the stepper motor, but when try to assemble the whole system, we find that there are some serious problems:

- The accuracy of the stepper motor is not enough. When we control the motor to rotate through a small angle, it often cannot stop to the correct position.
- When the motor rotation speed is low, the motor will vibrate
- The filter driven by the motor is too large for the whole stage, as shown in Figure 1.

For the first and second problem, the solution is to try to use the servo motor[19][20]. For the third problem, we can design a bracket that meets the requirements to place the motor and filter, the staff in the workshop can produce it.

### *3.3 Chemical experiments*

In the second semester, under the guidance of professor and master, we conducted chemistry experiments in the chemical laboratory. Because the samples are precious, we have carried out many simulation experiments using PEI film.

The laser is very dangerous, so the entire laser processing table should be covered with an opaque box. When performing laser irradiation, which is just corresponding to the step h (Photoreduction) in the Table 1, the user needs to observe the change of sample by microscope. The microscope is controlled by A-MCB2 Zaber controller, whose debugging is the work of my teammate.

After many tests, the expected pattern did not appear on the PEI film. It's only a slight trace, as shown in Figure 25.

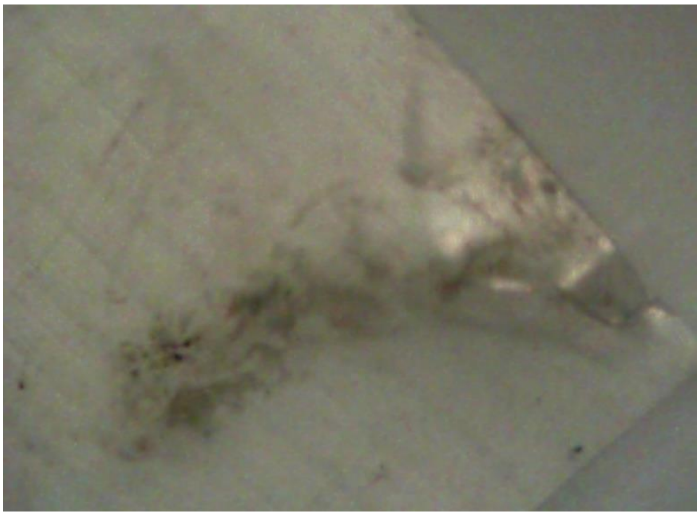

*Figure 25 The processed PEI film Observated through a microscope*

It is expected that there will be very obvious traces in the part directly irradiated by laser, which will become metal tracks through subsequent processing.

After discussing with the tutor, we think there are several reasons:

- The laser power in the laboratory is not enough. When using LED for pattern, the power of LED is 1W for local exposure[1]. But the power of the laser used in the lab is only a few hundred milliwatts.
- Insufficient purity or concentration of chemical reagent. In the chemical experiment, we directly used the reagent in the reagent bottle, but it is likely that the reagent used has been used too many times or polluted
- The film was left in the air for too long before laser patterning. It takes a long time to complete a whole set of processes, so we often stopped working before light reduction, and then continue to work after lunch.

Most of the above problems have been solved, and the final experimental results have been recorded by my teammate Yuze.

### *3.4 CNC machine*

The above work studied the patterning on 2D surface, in the second semester, the CNC arrived, hence the force of the project changed into modifying the CNC machine. Replacing the drill of the CNC machine by a laser is a topic that almost no one has ever studied.

#### *The use of CNC machine*

To use the CNC machine, follow the steps below for accessing the user interface[21]:

- With the machine's power switch is in the off position, plug the power cord into a wall outlet and then the machine.
- Plug the USB cord into a computer.
- Plug the usb cord into the machine and flip the power switch to the on (-) posi tion. Wait for the machine to boot up fully.
- Once the E-stop button is blinking red, open a new window in a supported browser(Google, Chrome, Firefox, Safari) and type *192.168.7.2* into the address bar and pass enter.

- When the user interface shows up, confirm that it says "Connected" in the bot tom left corner.

When succeed, we can come into the user interface, shown as Figure 25.

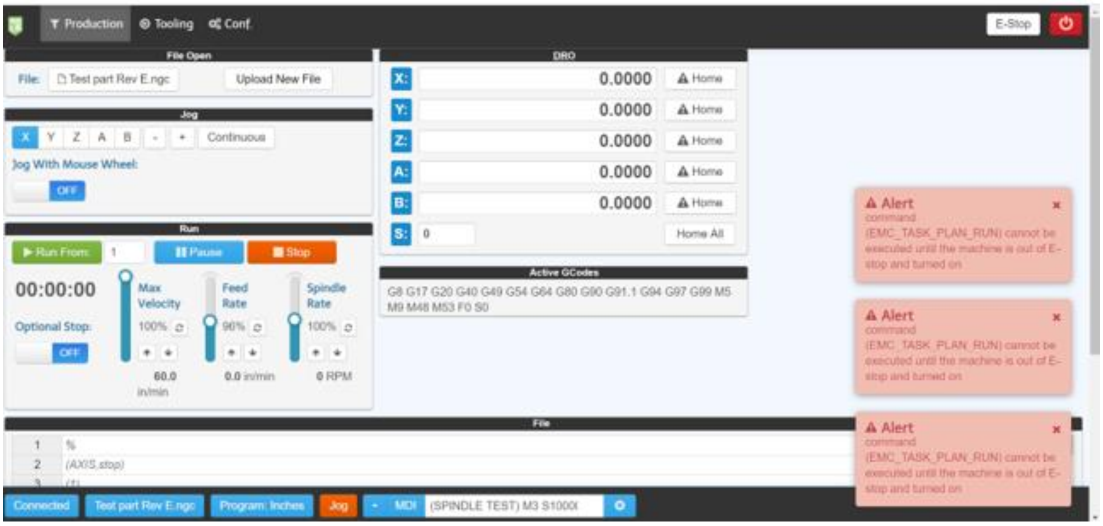


*Figure 26 User interface for CNC*

On the user interface, we can control each axis individually. Each axis has its own initial position, which is defined as 0. Before each use, all axes need to be initialized by "Home all". For the complete project, the user can upload the .ngc file in the upper left corner of the window. Then the CNC machine can work as directed.

For the .ngc file, it can be created in the software Fusion 360(the Fusion 360 cannot be open after I came back to China, hence there isn't enough picture to show how to use the Fusion 360). When use the Fusion 360, firstly the user should open or create model: open an existing model or use Fusion 360 modeling tools to create a model.

We can create the model in Autodesk CAD:

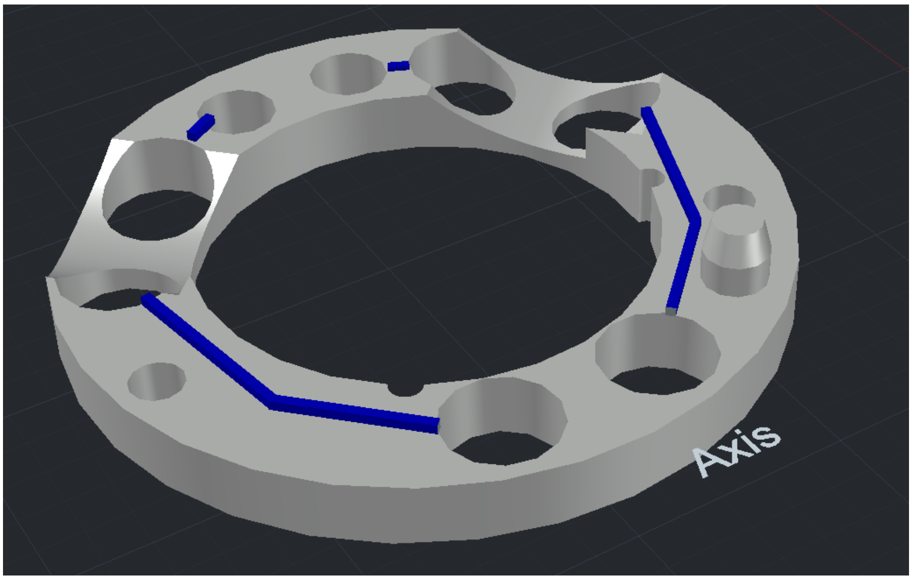


*Figure 27 Model for the sample*

Upload the CAD model of the sample into the Fusion 360. And in the work area 'CAM' set the tool path according to what we want. Then we can get the .ngc file.

## *Modify the CNC*

To add the laser to the CNC machine, we have communicated a lot with manufacturers.

Hello,

You will need to manually replace the spindle and replace it with a laser, but this is not an integration we will actively support. To modify code, the easiest option will be to connect to your machine with an SSH client (for Windows PC's PuTTY is the most common)  and then modify files directly. However you'll want to use software version control to ensure you can get back to a stable starting point if something goes wrong. With the open source documentation you should have what you need to modify the machine script, as our software developer indicated below.

Thanks,
Kerry

*Figure 28 E-mail from the company*

At first, we try to connect the laser to the machine directly, advised by the master, we open the cover panel:

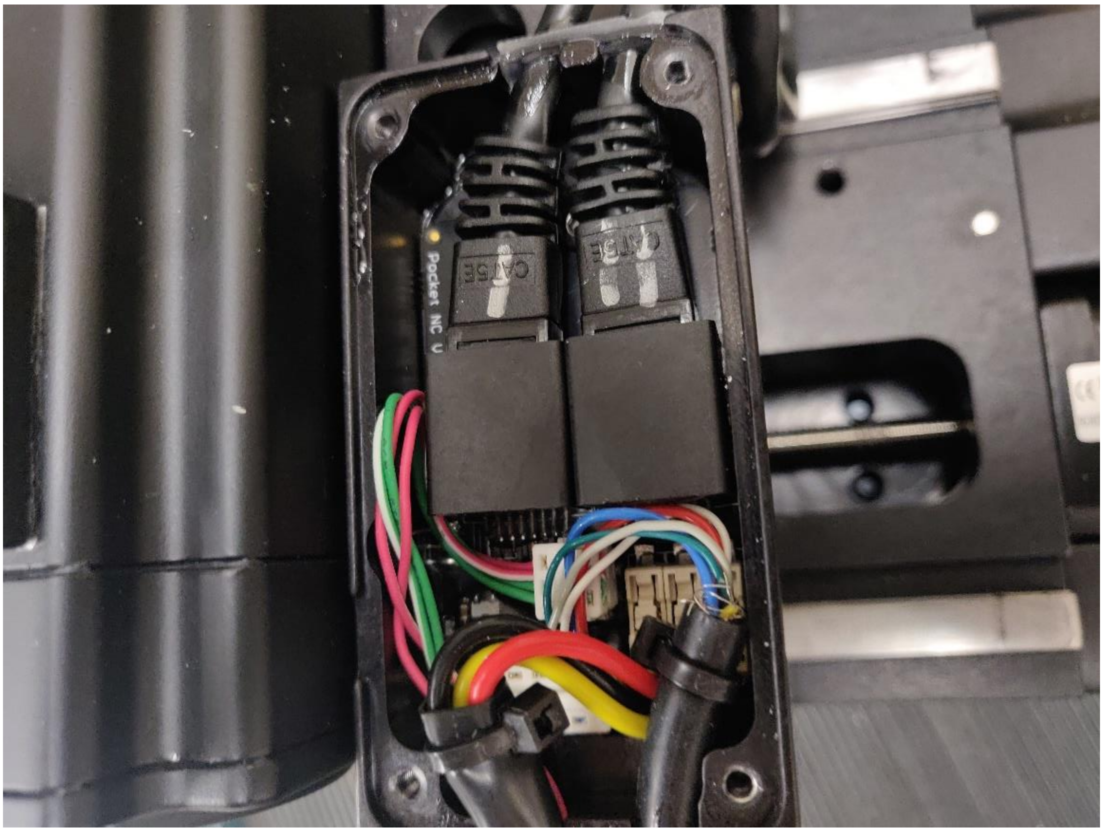


*Figure 29 Inside the cover panel*

But we can get the information from the mark on the wire: the CNC machine is powered by 3-phase 120 voltage AC. As a result, simply connecting the laser machine to the CNC by power will not work and be very dangerous, because the laser uses only 9 volts DC.

After continuing to ask, we got more information:

```
done <<- EOF
P8.8    in-     # Spindle Clock
P8.9    in+     # X Limit
P8.10   in+     # E-Stop Signal
P8.11   out-    # B Dir
P8.12   out-    # B Step
P8.13   out     # Spindle PWM
P8.14   in+     # Y Limit
P8.15   out-    # Z Dir
P8.16   out-    # Z Step
P8.17   out     # E-Stop LED
P8.18   in+     # Z Limit
P8.19   in+     # B Limit
P8.26   in+     # Start Signal
P9.11   out+    # Spindle Dir
P9.12   out+    # Enable
P9.14   out-    # Start LED
P9.15   out-    # Y Dir
P9.16   in+     # A Limit
P9.17   in+     # Unused
P9.19   i2c     # I2C SCL
P9.20   i2c     # I2C SDA
P9.21   in+     # Interlock Open
P9.22   in+     # Probe Signal
P9.23   out-    # Y Step
P9.24   out+    # Spindle On
P9.27   out-    # X Step
P9.28   out-    # A Dir
P9.29   out-    # X Dir
P9.30   out-    # A Step
EOF
```

*Figure 30 The define of the pin for the CNC machine*

To find out the location of each pin, I asked the master for help, we took out the small circuit board under the cover panel to observe:

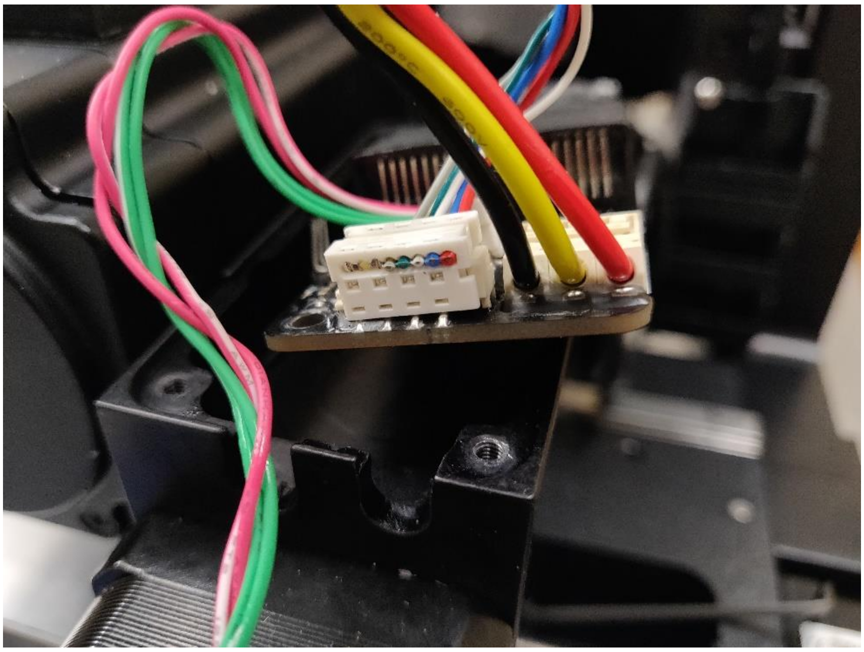

*Figure 31 Small circuit*

There is no doubt, we cannot change the circuit here. Finishing observing, we put it back intact.

With the help of the staff, we find the correct board:

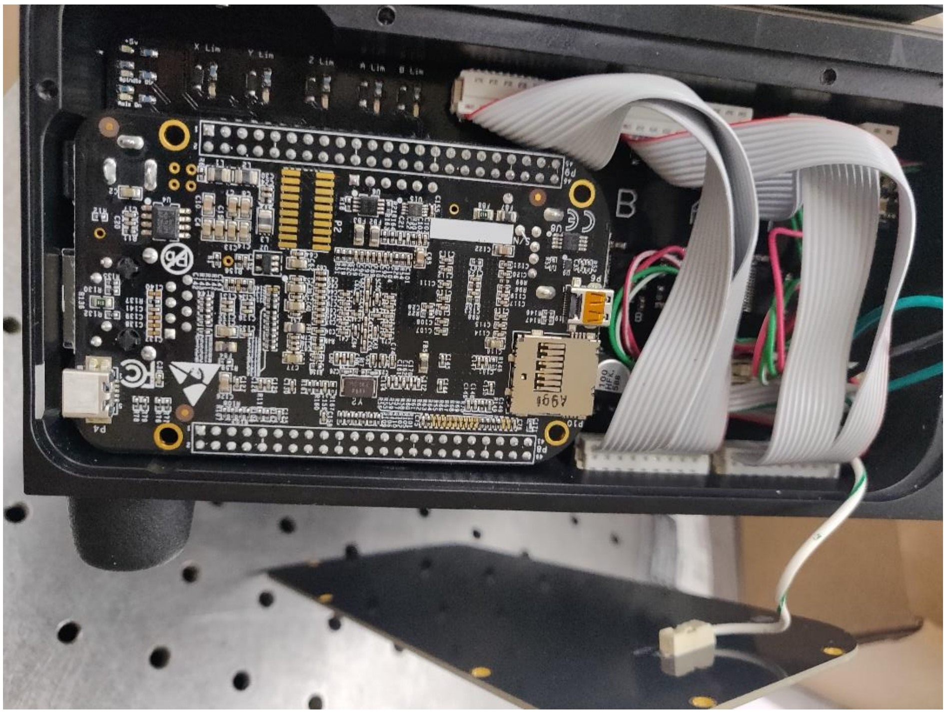

*Figure 32 Beaglebone Board*

As the Figure 27 shows, when we want to modify the underlying code, we need to use SSH client.

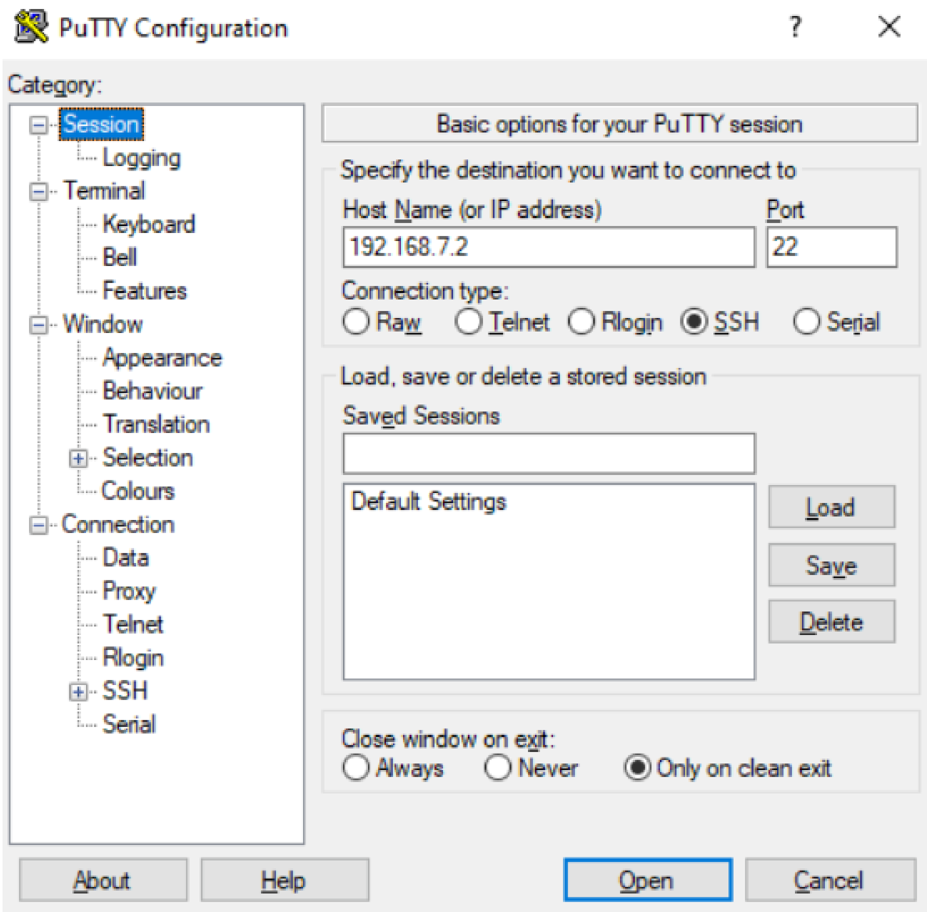


*Figure 33 SSH client*

However, before we can try to modify the code, we find that the machine no longer works. After investigation, we found that there was a problem with the Z axis.

After several repairs following the manufacturer's instructions, the situation was still not resolved, but we had to leave the laboratory

# 4. Fault analysis

Due to the impact of the coronavirus, the project had to be terminated early, and the cause of the failure of the CNC machine tool has not yet been fully determined. In this part, the cause of the failure was summarized and analyzed. Follow-up researchers can carry out the next research on this basis.

## *4.0 Fault summary*

Because of the influence of coronavirus, the project had to stop early. As a result, we can study the reason of fault and find the best solution for follow-up researchers

CNC machine is a typical equipment of modern industrial automation, which should be used in precision processing and production. It is widely used. However, because CNC machine tools use advanced control technology, the maintenance of the machine tools It is also relatively complicated. The fault categories of CNC machine tools can be divided into electrical faults and mechanical faults, At the same time, these two types of faults are also related to each other. The situation is diagnosed from electrical phenomena, so that the analysis of CNC electrical faults is particularly relevant key[25].

## *4.1 Classification of electrical failures of CNC machine tools*

There are many ways to classify the electrical faults of CNC machine tools, and they can be divided into the following categories according to the location, nature and structure of the fault[26].

### *4.1.1 Hardware failure and software failure*

Hardware failure refers to the failure of the electrical components, CNC hardware system, wires and cables, connectors, etc. to produce an abnormal state or even damage. Hardware failures can only be eliminated by repair or even replacement. Software faults generally refer to faults caused by improper setting or incorrect modification of PLC and NC programs or parameters. Such faults often require familiarity with the system and parameters of the device, and even require reloading of the entire system parameters to initialize the system.

### *4.1.2 Inevitable failure and probabilistic failure*

Inevitable faults are the phenomenon that a part of the index-controlled machine tool itself has changed, causing machine tool abnormalities. Such faults often have definite causes, and analysis and elimination are relatively easy. Probability failures are occasional failures of index-controlled machine tools. There are no certain rules to follow for failures, which are good and bad. The cause may be external influences such as electrical drift, loose grounding, or temperature changes. Abnormal, such faults are often difficult to diagnose[28].

### *4.1.3 System failure and peripheral failure*

The system failure is a failure of the index control system itself. Of course, it may be caused by an abnormal hardware of the CNC or servo system or a problem in the software. Solving this type of failure requires the maintenance personnel to have a deep understanding of the CNC system itself. Peripheral faults refer to faults caused by electrical components other than the CNC system. Of course, the most critical thing to deal with peripheral faults is to strictly analyze and find the problem according to the electrical schematic diagram of the device.

## *4.2 Thoughts before troubleshooting*

### *4.2.1 On-site understanding*

The first requirement for the troubleshooting of CNC machine tools is that the maintenance personnel go to the site to listen to the operator's talk and obtain the equipment failure information as much as possible, which can reduce the scope of the machine tool maintenance.

### *4.2.2 Judging the fault category*

Determine the nature of the fault by understanding with the operator, after fully understanding the possible range of the fault, the maintenance personnel can determine the nature and type of the fault, for example, it can be determined whether it is a software or hardware problem, whether it is the CNC system itself or a peripheral fault, inevitability or probability Faults, etc., the basic categories can be quickly judged by those who are often engaged in CNC machine tool maintenance.

### *4.2.3 According to the nature of the fault*

Develop maintenance methods from the most probable cause. When the general nature of the CNC machine tool is clear, the maintenance direction can be worked out. For example, peripheral faults need to refer to the electrical schematic diagram of the device. For system faults, you need to check the CNC system manual and parameter table. , Probability failure requires repeated observation and determination.

## *4.3 Fault finding method*

There are many ways to find the cause of the failure, here are some commonly used inspection methods, the check methods should be used in turn[29].

### *4.3.1 Check appearance*

(1) Look

Check the general situation from the appearance of the device, including checking the electrical cabinet of the device to see if there is a switch trip, whether there is a component burnout, etc.

(2) Listen

If it is a fault in the operation of the device, you can listen to whether there is abnormal noise in any part of the device, so as to lock the source of the fault.

(3) Smell

The components of the electrical cabinet can be quickly judged by smelling under certain short circuit conditions.

(4) Touching Touch the outside of these components when the CNC system unit, servo drive unit fails or the motor fails, and feel whether the temperature has increased significantly can also help the team to shorten the time to find the fault.

### *4.3.2 Multimeter testing*

In the case of peripheral faults, the most common way to find is to analyze the possible fault parts according to the electrical schematic diagram of the device, and then use the multimeter circuit, of course, you can use the power failure test or the point test to determine the fault.

#### *4.3.3 Search by alarm*

CNC machine tools have a set of diagnostic software. Once the equipment fails, there are prompts for the failure. When a failure occurs, it is convenient for the maintenance personnel to narrow the scope of investigation. However, the diagnosis of any CNC system has limitations in use, so maintenance personnel cannot rely too much on the diagnosis system at any time, and the alarm can only be a reference method for maintenance personnel.

#### *4.3.4 Parameter adjustment and initialization*

The CNC system is often stopped due to disordered parameters or the operator accidentally changed the CNC parameters when entering the processing program, or the equipment is running abnormally. Therefore, when a software failure occurs, the parameters that may cause failure should be carefully tested the maintenance personnel are required to be quite familiar with the software parameters, and if necessary, they can also initialize from the new device CNC and servo CNC.

#### *4.3.5 Try to replace new spare parts*

After using the instrument to find the fault according to the electrical schematic diagram, that is, after determining the damaged or malfunctioning component, you should replace the new spare parts in time. Of course, you can’t think that all problems can be solved by replacing the spare parts. There are also many problems in this regard. For example, many components such as servo drives, inverters, etc. need to be modified after replacement, and CNC replacement also requires parameter initialization. These are skills that maintenance personnel must master. However, when the researcher is not 100% sure that the CNC can be repaired by replacing , you can directly contact the manufacturer, the Pocket CNC Ltd: info@pocketnc.com

## 5. Future work

In the inspection that has been carried out, we have ruled out the problems of system power supply and software, the problem is most likely to appear on the hardware, which is where we changed the most.

After an in-depth study of the possible causes of failures of CNC machine tools，I think the most likely cause of the failure is that there is some problem on the network port. SMD network ports are used in our CNC machine, which are very unstable. In the meanwhile, influenced by the time, the inspection and maintenance methods summarized in Chapter 4 cannot be practiced one by one.

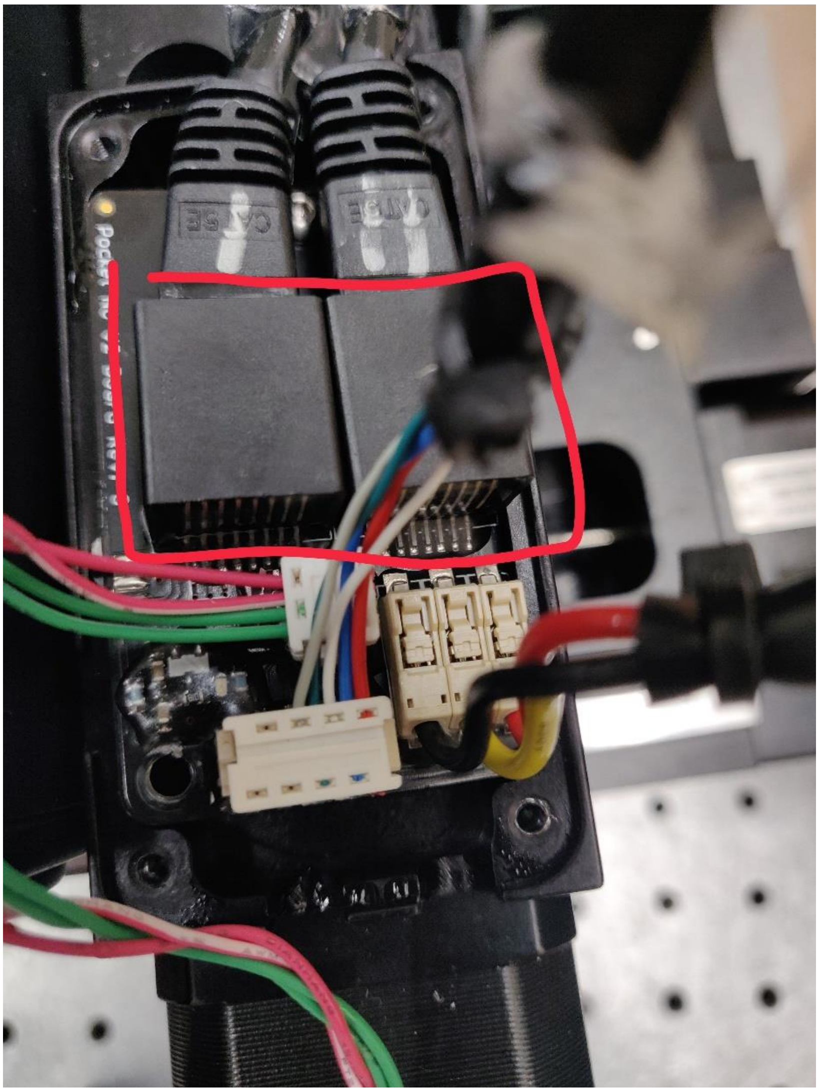

*Figure 34 The picture of network port*

It is very likely that the patch of the network port will be damaged when we take out the board. The follow-up researchers should focus on this part.

After the machine returns to normal, the follow-up research should use SSH client shown in Figure 32 to modify the files directly. The definition of the pin is as Figure 29. The Beaglebone Board is shown in the Figure 31.

The correct connection method is to define a brand new pin for the laser and use a separate battery as the power supply, the lasers in the laboratory usually use a 9 volt DC voltage[27].

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## Appendix

Here are my email records with the manufacturer. The follow-up researcher should study from the website: https://www.machinekit.io which is a platform for machine control applications. There is no doubt that this website has a lot of information useful for retrofitting machines.

**Kerry Neal** (Pocketnc)
Feb 25, 10:58 AM MST

Hello,

Here is what we sent to your professor a couple of weeks ago:
For input on attaching a laser, here is further feedback from our software developer:
There's not a single way to achieve this, so they'll have to do their own research. That said here are possible ways to go.
Anyway they decide to go I would recommend reading up on MachineKit:
http://www.machinekit.io/docs/index-user/
http://www.machinekit.io/docs/index-integrator/
http://www.machinekit.io/docs/index-HAL/
http://www.machinekit.io/docs/config/ini_config/

1) Leverage the output voltage of the spindle to control the laser. This is the script that outputs a specific voltage to control the spindle speed:
https://github.com/PocketNC/Settings/blob/master/spindle_voltage.py

In G code, the spindle can be turned on with M3 if the spindle speed is greater than 0, which can be set on the same line, so something like:
M3 S10000

To turn off the spindle you use M5.

The above script will look at the desired speed and output a voltage based on that. They could potentially tie into that voltage without needing any software changes. Changing the above script could also be an easy way to fine tune that voltage.

2) You could also write custom M codes (one to turn off the laser and one to turn it on) by placing properly named scripts in

**Kerry Neal** (Pocketnc)
Mar 5, 4:01 PM MST

Hello,

You will need to manually replace the spindle and replace it with a laser, but this is not an integration we will actively support. To modify code, the easiest option will be to connect to your machine with an SSH client (for Windows PC's PuTTY is the most common) and then modify files directly. However you'll want to use software version control to ensure you can get back to a stable starting point if something goes wrong. With the open source documentation you should have what you need to modify the machine script, as our software developer indicated below.

Thanks,
Kerry

**Liu, Yibing**
Mar 5, 4:16 AM MST

Dear Sir

I have read the most material. But I am still confused that how to add a laser on the NC V2-10, there is no external interface, so where does the laser link.
Another question is that the first way you give me to add laser need to change the script written in Python, if I change the script, how can I upload the script into the machine? Can I modify the underlying code of the machine?

And how is your software developer's research progressing?

Many thanks

**Kerry Neal** (Pocketnc)
Mar 13, 9:33 AM MDT

Hello Yibing,

The line that powers the spindle has a red arrow pointing to it in the attached photo. The spindle motor requires 3 phase power, so each line is one of the 3 phases. You can take off the four screws that hold on the cover plate where those two lines go in and out from (where the red arrow spans in the attached photo) and measure the voltages that are on each line.

To find out how the pins are allocated on the beaglebone board inside the side cover panel, please see this information. This would allow you to program the laser from the software interface. We were not thinking that you would be utilizing the power supply for the spindle, it may be better to power the laser separately. Making the modifications to the machine and powering the laser via the spindle power may damage the laser, but may also damage the electronics in the machine. Note that because this is a modification it would not be something that would be covered by warranty.

Thanks,
Kerry

Attachment(s)
spindle.jpg

---

**Liu, Yibing**
Mar 12, 4:26 PM MDT

Dear Sir

As I have asked many times, I want to equip a laser on the CNC machine.

My tutor and I want to try connect the laser directly to the wires of machine, hence could you please tell me the effects of the two wires on the picture? And which wire is used to supply the voltage?

Another question is that whether I can use the control the voltage supplied by the wires from the moment I turn on the power? As you have told me the I can change the script and use M3/M5 to control the laser's on and off, but I am afraid that at the moment the power turn on, the voltage will be so large to burn out the laser.

**Q Rothing** (Pocketnc)

Mar 17, 10:40 AM MDT

Hi Yibing,

Are you sure you put everything back into that compartment you opened first correctly? More than likely the Z axis can't home because something in that compartment has been disturbed. Z has to successfully home before any of the other axes will begin to move.

Other things to check are:
-Power cord plugged in
-Power switch on

Thanks,

Q Rothing
Applications Engineer, Pocket NC

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**Liu, Yibing**

Mar 17, 10:19 AM MDT

Dear Sir

What does it happen to make my machine can't 'home', every time I click 'home all' the machine doesn't move at all,

But the value of Z axis in the DRO increase.

The Alert is 'end of move in home state 7'

Looking forward to hearing from you.

**Q Rothing** (Pocketnc)
Mar 17, 12:11 PM MDT

Yibing,

Are you able to jog or home any of the axes individually? Could you send me a picture of that compartment the way it looks now?

Thanks,
Q

---

**Liu, Yibing**
Mar 17, 10:49 AM MDT

Dear Sir

I'm sure I have put everything back. And I have checked it.

What should I do to repair it?

Many thanks

Yibing

**Q Rothing** (Pocketnc)
Mar 17, 1:47 PM MDT

When you try to jog the Z axis does the motor make any noise or vibrate? Double check that the white connector with the red and green wires is pressed all the way down onto the circuit board as well.

**Liu, Yibing**
Mar 17, 12:22 PM MDT

Yes, I can jog or home any of the axes individually except Z axis, Z axis doesn't have any response.

**Q Rothing** (Pocketnc)

Mar 18, 11:11 AM MDT

Hi Yibing,

It is very likely that the Z axis is not moving due to something that happened when that cover plate was taken off and since that cover plate was taken off in an attempt to modify the machine, technically this problem is not under warranty. With that being said, we will do what we can to get that Z axis moving again.

Please carefully inspect the red and green wires that lead to the Z motor and make sure that non of the them are damaged. If they appear to be in good shape, please remove the white connector again and take a close look at the male and female pins of the two sides to make sure there is not obvious damage there either.

Thank you,
Q

**Liu, Yibing**

Mar 18, 9:28 AM MDT

Dear Sir

I have tried again, when I jog the Z axis, the motor doesn't have any response. There isn't any noise or vibrate.

I didn't change the wire, and I removed the screws from the board under the supervision of phd.

Hence is this machine still under warranty?

**Q Rothing** (Pocketnc)
Mar 18, 3:00 PM MDT

Hi Yibing,

Thank you for that additional information, I thought that you had removed that white connector at some point.

Do you know if the Z axis moved and would home when the machine was unpacked from its box?

What is the serial number of your machine? See attached photo for reference.

Thanks,
Q

Attachment(s)
Serial Number.JPG

**Liu, Yibing**
Mar 18, 11:32 AM MDT

Dear Sir

In fact, I have checked the wires many times. And I have never remove the white connector.

I think removing the connector is to dangerous for me, I'm afraid to break it.

The day before yesterday, you company sent me the email:

## Minutes

| Project Minutes 1 | |
|---|---|
| **Date** | 23/09/2019 |
| **Present** | Jose Marques Hueso<br>Yibing Liu<br>Yuze Sun<br>Wei Jiang |
| **Action** | • Discussed the research direction.<br>• The related papers and materials used in FDM 3D printing are discussed. |
| **Plan** | • Read the papers given by the professor and the other materials carefully.<br>• Summarize the main methods and objectives of this study are briefly.<br>• Determine the research direction |
| **Recorder** | Yibing Liu |
| **Signature** | |

| Project Minutes 2 | |
|---|---|
| **Date** | 30/09/2019 |
| **Present** | Jose Marques Hueso<br>Yibing Liu<br>Yuze Sun<br>Wei Jiang |
| **Action** | • Talked about the assignment of our task.<br>• Discussed what work we need to do respectively. |
| **Plan** | • Continue to read the paper and understand the materials and their polymers deeply<br>• Learn how to use the LabVIEW and learn the G language |
| **Recorder** | Yibing Liu |
| **Signature** | |

| Project Minutes 3 | |
|---|---|
| **Date** | 11/10/2019 |
| **Present** | Jose Marques Hueso<br>Yibing Liu<br>Yuze Sun<br>Wei Jiang |
| **Action** | • Discussed the problems we met in the design progress with supervisor. |
| **Plan** | • Read the LabVIEW file and understand the serial-port communication between devices.<br>• Continue to read the material and do experiments in the laboratory. |
| **Recorder** | Yibing Liu |
| **Signature** | |

| Project Minutes 4 | |
|---|---|
| **Date** | 19/10/2019 |
| **Present** | Jose Marques Hueso<br>Yibing Liu<br>Yuze Sun<br>Wei Jiang |
| **Action** | • Tested the possibility of moving sample to the center of platform |
| **Plan** | • Learn how to use LabVIEW control the motor<br>• Read more materials about the LabVIEW |
| **Recorder** | Yibing Liu |
| **Signature** | |

| Project Minutes 5 | |
|---|---|
| **Date** | 26/10/2019 |
| **Present** | Jose Marques Hueso<br>Yibing Liu<br>Yuze Sun |

| | |
|---|---|
| | Wei Jiang |
| **Action** | • Made sure that I will have a CNC machine, I need to try to learn the CNC.<br>• Made a brief introduction to the goal and plan of Yuze's project, and discussed some details I met during the test. |
| **Plan** | • Continuously test the equipment, so that the laser can work, so that the software can have better accuracy.<br>• Begin to read some material about the CNC machine<br>• Use the stepper motor in the lab to test my design |
| **Recorder** | Yibing Liu |
| **Signature** | |

| **Project Minutes 6** | |
|---|---|
| **Date** | 01/11/2019 |
| **Present** | Jose Marques Hueso<br>Yibing Liu<br>Yuze Sun<br>Wei Jiang |
| **Action** | • Gave short feedback on last week's speech.<br>• Talked about the 3-point positioning method.<br>• Still cannot make sure when the CNC arrive. |
| **Plan** | • Read more literature about the chemical processing manufacturing method.<br>• Try to find a way to improve motor accuracy<br>• Use the simulator to understand the running of the CNC |
| **Recorder** | Yibing Liu |
| **Signature** | |

| **Project Minutes 7** | |
|---|---|
| **Date** | 08/11/2019 |
| **Present** | Jose Marques Hueso<br>Yibing Liu<br>Yuze Sun |

| | |
|---|---|
| | Wei Jiang |
| **Action** | • Some problems about maximum voltage and how to collect light from glass are discussed.<br>• We can write a brief request for the grilling machine and a device to change the output current to suit the maximum voltage |
| **Plan** | • Write down our requirements in detail, modify the code, so that the motor can stop at any time.<br>• Collect some online teaching videos about the CNC<br>• Try to find a servo motor, and use LabVIEW control it |
| **Recorder** | Yibing Liu |
| **Signature** | |

| **Project Minutes 8** | |
|---|---|
| **Date** | 22/11/2019 |
| **Present** | Jose Marques Hueso<br>Yibing Liu<br>Yuze Sun<br>Wei Jiang |
| **Action** | • Talk about the position where we need to place the camera and laser.<br>• Discuss the transistor circuit and know some officers responsible for mechanical workshop and laser cutting.<br>• Discuss that there is not enough space to put the color selecting system |
| **Plan** | • Try to understand the G code and learn to write G code to control the CNC<br>• Using stepping motor to further improve my design |
| **Recorder** | Yibing Liu |
| **Signature** | |

| **Project Minutes 9** | |
|---|---|
| **Date** | 29/11/2019 |

| | |
|---|---|
| **Present** | Jose Marques Hueso<br>Yibing Liu<br>Yuze Sun<br>Wei Jiang |
| **Action** | • Known that the material of all the circuit and antenna I need is printed on PEI.<br>• Some problems of laser are discussed<br>• The machine is not yet sure when it will be delivered to the school |
| **Plan** | • Solve the software error of laboratory computer, improve the circuit and make it work as bright as possible.<br>• The machine is not sure when it will arrive, so continue to study the color selection system, which means continue to learn the LabVIEW. |
| **Recorder** | Yibing Liu |
| **Signature** | |

| **Project Minutes 10** | |
|---|---|
| **Date** | 06/12/2019 |
| **Present** | Jose Marques Hueso<br>Yibing Liu<br>Yuze Sun<br>Wei Jiang |
| **Action** | • The date of completion of the mechanical work has been fixed<br>• Some problems that semiconductor lasers cannot work as well as + 5V and GND are discussed. |
| **Plan** | • Purchase an external power supply that can provide sufficient current for the laser.<br>• Read more papers on chemical composition and manufacturing methods to prepare for next semester's work.<br>• Try to find a way to install the motor on the optical stage. |
| **Recorder** | Yibing Liu |
| **Signature** | |

| Project Minutes 11 | |
|---|---|
| **Date** | 01/02/2020 |
| **Present** | Jose Marques Hueso<br>Yibing Liu<br>Yuze Sun<br>Wei Jiang |
| **Action** | • First meeting of the second semester, Confirmed Yuze's next job, continue to find the way to laser printing. Find the best speed for laser writing on the sample.<br><br>• Adjusted my task, make sure that there will be 5-axis CNC machine, no longer doing the wavelength part work.<br><br>My task has been updated<br>• Learn to control the CNC machine.<br>• Find the way to control laser on and off using G code.<br>• Replace the drill by the laser and use the whole system to laser printing in 3D on the sample. |
| **Plan** | In the next week, I continue to get familiar to the G code and teat the G code in online simulator. |
| **Recorder** | Yibing Liu |
| **Signature** | |

| Project Minutes 12 | |
|---|---|
| **Date** | 14/02/2020 |
| **Present** | Jose Marques Hueso<br>Yibing Liu |
| **Action** | **Completed actions**<br><br>• Getting familiar to the software Fusion 360.<br>• Have a basic understanding of G code.<br>• Run the G program in the online simulator<br>• Can control the movement of every axis of the CNC machine.<br><br>**Problems** |

| | |
|---|---|
| | • There is vibration during machine movement, but the sample is very small, which means that the laser can't write accurately.<br>• There is no external output on the lathe, I haven't found the way yet to use G code control the laser on. |
| **Plan** | • There is small problem when the CNC machine run a run a complete G program, I will solve it in next week.<br>• Read more to find a way to control the laser by G code.<br>• Try to reduce machine jitter when it is working. |
| **Recorder** | Yibing Liu |
| **Signature** | |

| **Project Minutes 13** | |
|---|---|
| **Date** | 11/03/2020 |
| **Present** | Jose Marques Hueso<br>Yibing Liu<br>Yuze Sun<br>Senpu Yuan<br>Abdulrhman, Mansour |
| **Action** | • The reason why the pattern of Pei is not depicted by laser is discussed.<br>• The CNC has arrived,, I can begin to use it |
| **Plan** | • Chemical treatment again with new KOH solution.<br>• Try to find the way to replace the drill by the laser.<br>• Contact the machine manufacturer for more information |
| **Recorder** | Yibing Liu |
| **Signature** | |

| **Project Minutes 14** | |
|---|---|
| **Date** | 17/03/2020 |

| | |
|---|---|
| **Present** | Jose Marques Hueso<br>Yibing Liu<br>Abdulrhman, Mansour |
| **Action** | • Discuss the problem I met in transferring the machine.<br>• Request to continue to use the laboratory to complete the project.<br>• Due to the impact of the new coronavirus, the project must end early. |
| **Plan** | • The last modification test for the machine<br>• Summarize the problem and report it to the professor |
| **Recorder** | Yibing Liu |
| **Signature** | |

## Project Plan

| Week1 | Week2 | Week3 | Week4 | Week5 | Week6 | Week7 | Week8 | Week9 | Week10 | Week11 | Week12 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Background Survey | | | | | | | | | | |
| | | | | earn G language & laboratory apparatu | | | | | | | |
| | | | | | | | Laser use training | | | | |
| | | | | | | | | Design and test system | | | |
| | | | | | | | | | | Document & summarize | |

*Table 5 Project Plan for Semester 1*

| Week1 | week2 | Week3 | Week4 | Week5 | Week6 | Week7 | Week8 | Week9 | Week10 |
|---|---|---|---|---|---|---|---|---|---|
| test the laser | | | | | | | | | |
| | use LabView design system to change the wavelengths | | | | | | | | |
| | | | test the system and improve it | | | | | | |
| | | | | | printing use our system | | | | |
| | | | | | | writing the dissertation | | | |

*Table 6 Project Plan for Semester 2*