ECE 445

Fall 2017

Semiconductor Contact

Probe Aligner

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Abstract:

Our semiconductor probe aligner replaces the manual, hands on control of the probe station Signatone S-725 positioners, with a more precise and convenient electronic control. The project aims to reduce human error made when attempting to align and place the probes tips on a semiconductor device for measurement. By preventing these errors, our project guarantees that neither the probe tips nor the semiconductor wafer will be damaged in the process of probe alignment.

In order to achieve these goals, the project allows the user to control the movement of each probe using a computer webpage interface. The probe movement will be driven by motors with gear drives, which receives instructions from the webpage interface. The project includes mechanisms that halt the movement of probes and warn the user when hazardous actions are about to be performed. These scenarios include but are not limited to pressing the probe tip too deep into the metal contacts, and aligning the probes to the wrong region for measurement purposes.

This report explains the intuition behind our project, the requirements our project expects to meet, the high level layout and description of our project design, and the potential ethics and safety issues involved.

Contents

1.Introduction

1.1 Objective

As the semiconductor technology improves, the size of each device in the wafer is decreasing exponentially[1]. Even though in industry the measurements of semiconductor devices at the micro and nano level are handled electronically, students and researchers in campus still use lab equipments mainly controlled manually by hand. One of the more challenging measuring instruments to handle is the probe station, which is used in the IC fabrication lab class here. Usually, the devices are on the scale of micrometers;thus, navigating the probes by hand requires the user to have advanced experience and precision. In addition, noticing the probe is in contact with the wafer with bare eyes, even with the help of a microscope, can be difficult. A mistake in either way can scratch the device and even damage the probes, disabling the probe station.

To solve these problems, we introduce this project that will control the movement of the probes electronically with motors and a computer interface. Our project senses the distance between the probes and the device so the probes won't bend, differentiates metal from non-metal so the probes will be placed at the right place, and prohibits all movement in the horizontal plane so the wafer won't be scratched. The user will use the computer as the interface to control the motors on the high level. With our features and electronic control, we can alleviate a lot of risk involved in the measurement of semiconductor devices using the probe station.

1.2 Background

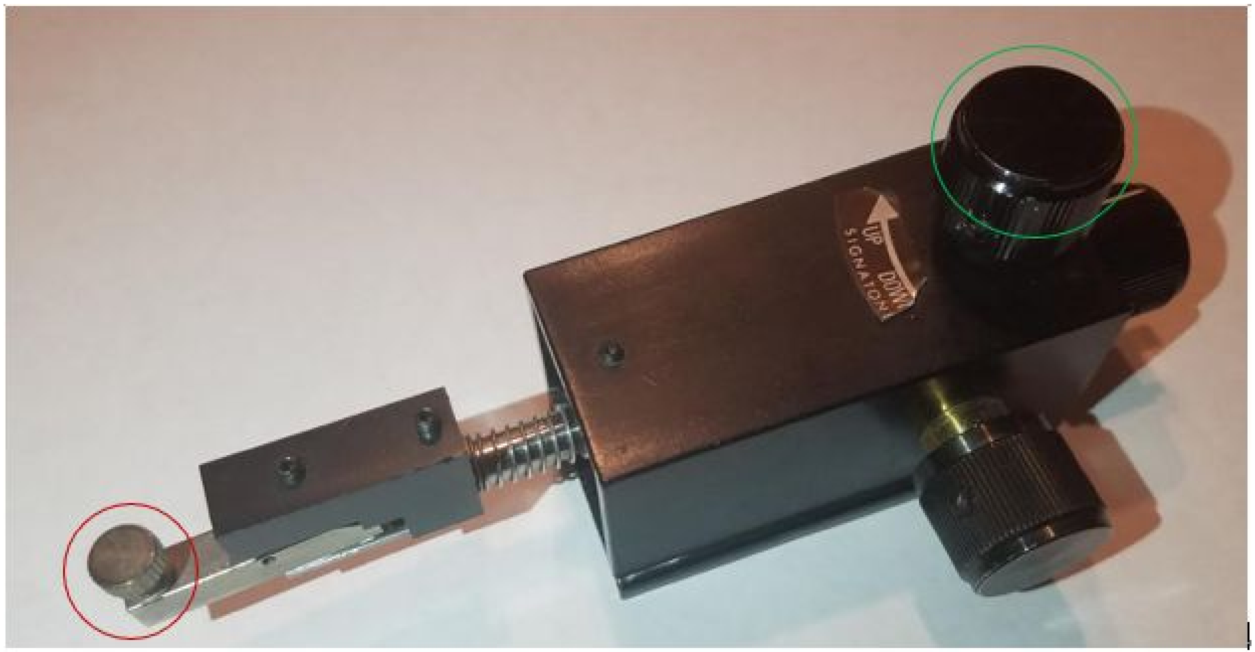
The core of the original instrument is the four probes, which serves to connect the metal contacts of the source, drain, body, and gate of an MOS device. The probe station can also measure other integrated circuit devices such as capacitors. Since the probes are measuring integrated circuits at the micron scale, they are very slim and fragile. And once they are bent or blunt, the measurement results will be affected drastically. In last semester's IC fabrication lab, two of the three probe stations used to measure the wafers were disabled; during earlier sections, some students bent the probes while trying to get measurements. As a result, most of the students taking the class that semester didn't get the right data.

Furthermore, the sharp probes can easily damage the devices on the wafer if not handled carefully. When we make the semiconductor devices, each deposition level is on the scale of nanometers, and the metal contacts are micrometers in thickness. If people don't have an abundant amount devices on their wafer, losing some devices due to scratching can potentially be a serious problem as well.

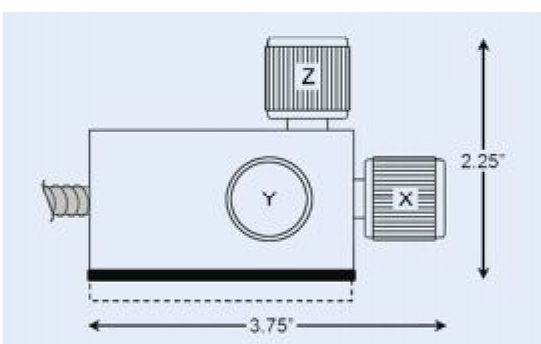
1.3 High level requirements

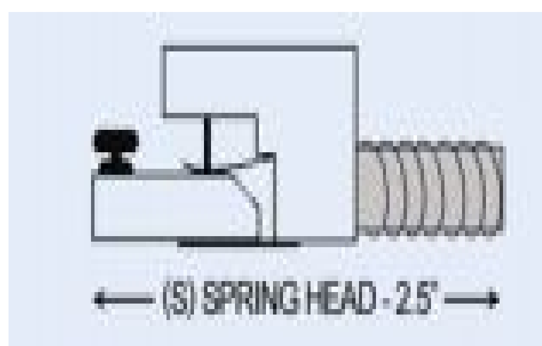
- Allow the probe to be moved by motors with precision in 3 dimensions(horizontal plane, up and down in vertical plane).
- Prevent the user from performing operations that potentially damages the probes or the wafer.
- Alert the user when the probes is linked on a region where there's no possible connection.
- Allow the user to have full control over the choice of moving a certain probe on a certain axis.
- The user should be able to see the image of the wafer under microscopic lens through the computer screen, where he/she will be controlling the probes.

1.4 Physical diagram and measurements



This unit is the micropositioner. The red circle indicates the probe tip holder position. The green circle indicates the knobs used to control the motion of the probe. The currently used probe tip holder is the U-E Style Probe Tip Holder. The side views of the micropositioner and U-E Style Probe Tip Holder are provided below from the data sheet [2].





U-E Style Probe Tip Holder

The radius of the knob is 1 cm. We will use a 1 micron diameter probe tips. The accuracy of the knob control is 5 microns by the leadscrew drive in all three dimensions. The covering area is 1.27cm x 1.27cm. By measurements, the knob x will change the probe x position by 30 microns per 360-degree. The knob y will change the probe y position by 30 microns per 360-degree. The knob z will change the probe z position by 20 microns per 360-degree.

2.Design

2.1 Block diagram and control circuit schematic

The block diagram for our design is shown in Figure 1. Our complete design is partitioned into the sensor unit, control unit, motor unit, computer, user interface unit and power supply. The motor unit enables the movements of probe in three dimensions. The sensor unit is mainly responsible for measuring whether the probe has contact with the wafer and recording the images in the microscope. The measurement may help user prevent damages to both the probes and the wafer. User interface unit gives user a vision of where the probe and metal region of wafer are so that user knows where the probe should be moved. It also provides the user with basic control over the operations performed. The computer processes the images sent from the camera and sends signals to control unit. Power supply provide power to different components of design.

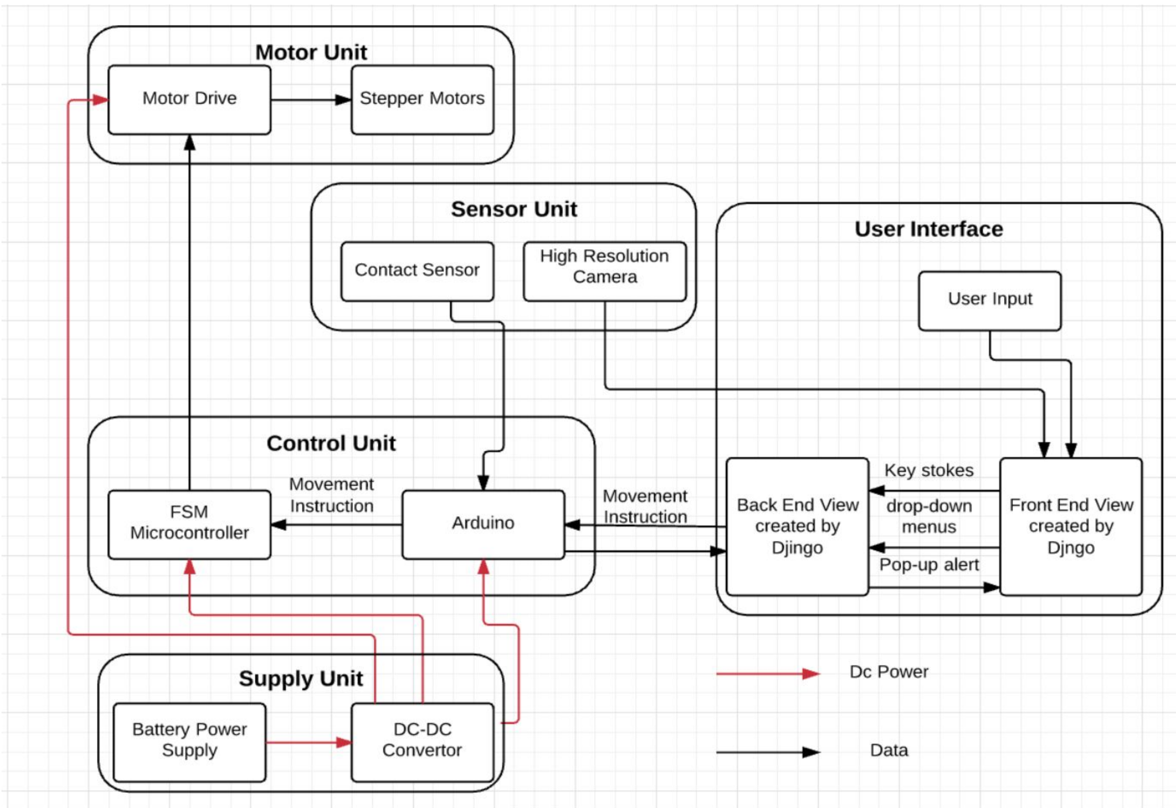


Figure 1. Block Diagram

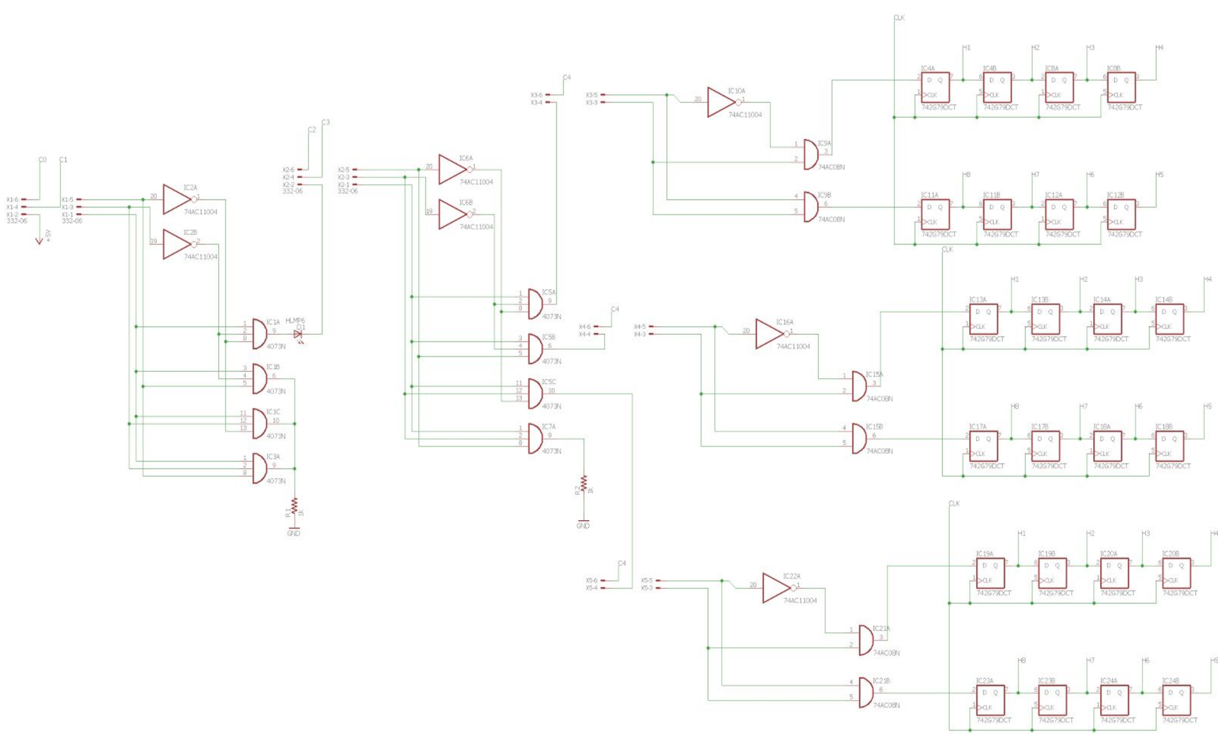


Figure 2. Control Circuit Schematic

Functional Overview

2.2 Motor unit

There are three knobs to control a probe in three dimensions. Therefore, motor unit contains three stepper motors. Each motor controls one knob of Signatone S-725 positioner. These three motors are connected with three knobs on the probe station separately with gear boxes. Each stepper motor is controlled by one SN754410 H-bridge drive. The schematic is shown in Figure 2. The motor drive not only supplies input power to run these three motors, but also have control mechanism to run motor accurately according to input signals from the control unit.

The stepper motor we're using will be the NEMA-17 [3]. It can provide 20N*cm holding torque with 200 steps per revolution. This stepper motor has two phases. The mechanism of the stepper motor is that current can flow and alternate through these two phases. When current flows through one phase, it will excite the coil and generate MMF to move the rotor clockwise for a certain degree. The current will then flow through the other phase to generate MMF to rotate even further in that direction, causing the motor to spin. If the stepper motor runs at a constant voltage, the speed can be controlled by switching frequency. The switching signals is a square wave sent out from control unit.

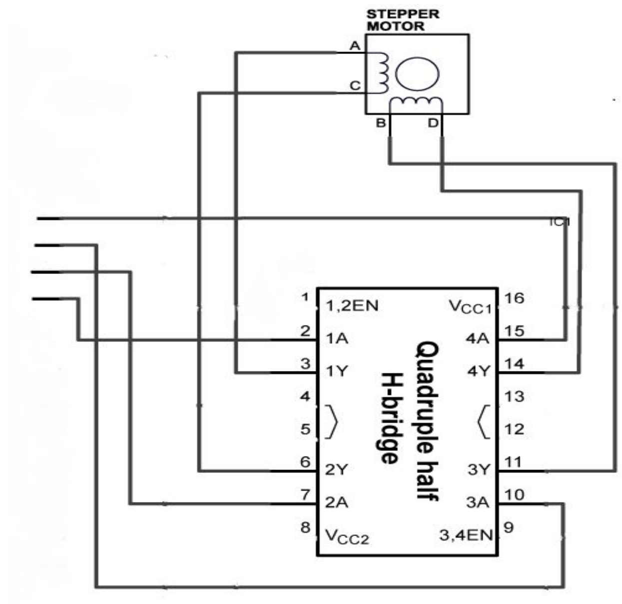


Figure 3. Stepper motor circuit

For the mechanical part of motor unit, 4:1 gear ratios gearbox is used. It is shown in Figure 3. There are two reasons to use gearbox. The first one is to have a firm hold on stepper motors and knobs of S-725 positioner. The second is to increase the torque of stepper motors when it runs at a very low speed.

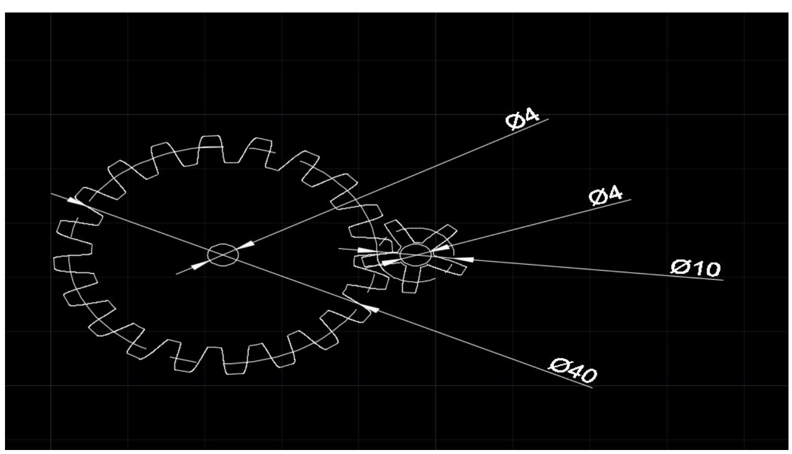


Figure 4. Gearbox physical diagram

The probe tip can move 30 micrometers if the corresponding knob is rotated one revolution. If we use 4:1 ratio gearbox, the degrees it need to move 30 micrometers become:

$$360^\circ \times 4 = 1440^\circ \quad (1)$$

Since the NEMA-17 stepper motor have 200 steps per revolution, each step corresponds to

$$\frac{360^\circ}{200} = 1.8^\circ / step \quad (2)$$

Therefore, each steps correspond to

$$\frac{1.8^\circ}{1440^\circ} \times 30\mu m = 37.5nm \quad (3)$$

Also, the least rotational angle a person can manually rotate is 2 degree, the distance it moves is

$$\frac{2^\circ}{360^\circ} \times 30\mu m = 0.16\mu m \quad (4)$$

Therefore, after using stepper motor and 4:1 gear ratio gearbox, our design is 4 times better than the manual control before.

Requirements	Verification
1.With certain amount of loading torque, three motors are still able to move at the desired speed. 2. The motor can stop almost immediately when no movement instruction is given and when the probe tip is in contact with wafer.	1.The NEMA-17 stepper motor has an maximum operating torque at 20Ncm. This is greater than the torque required to move the probe knobs. The speed of motor can be controlled by the switching frequency. 2. The switching frequency of stepper motor is very high, so the stepper motor can stop in a very short period of time. One step of motor only corresponds to 37.5nm, so there is tolerance distance for motor to stop without destroying the probe.

2.3 Sensor unit   High Resolution Camera

The High Resolution Camera will be attached to the microscope to receive image data. The data will be transferred to computer by USB port. The area allowed for probe operation can be seen by the user. Since this is an off the shelf product.The power requirement is given by the datasheet.

Requirement	Verification
The microscope camera have enough resolution to clearly show the colors of different regions so that the images can be processed.	A.We are currently looking to get a Celestron Digital Microscope Imager 44421. The microscope is mostly used for biology measurements, but should be sufficient for our project. B. Our image processor, written by code, is able to distinguish metal regions from non-metal regions.

2.4 Control unit

The control unit receives signals from the user interface and instructs the motor units to move in accordingly.

2.4.1 Micro-controller

The signals received from the user interface will be analyzed and processed by the Arduino board which is our micro-controller. Corresponding signals for motor selection and for FSM motor speed control circuit will be sent out. In detail, the Arduino board should send two-bit digital signal for motor selection and two-bit digital signal for FSM motor speed control circuit.[4]

2.4.2 FSM for Motor select

The motor select FSM contains four states. The state diagram is demonstrated below. S1 is the first motor activated state. The first motor controls the probe motion on z-axis. S2 is the second motor activated state. The second motor controls the probe motion on the x-axis. S3 is the third motor activated state. The third motor controls the probe motion on the y-axis. S4 is motor deactivated state. In this state, all motor motions will be prohibited. The initial state will be S4.

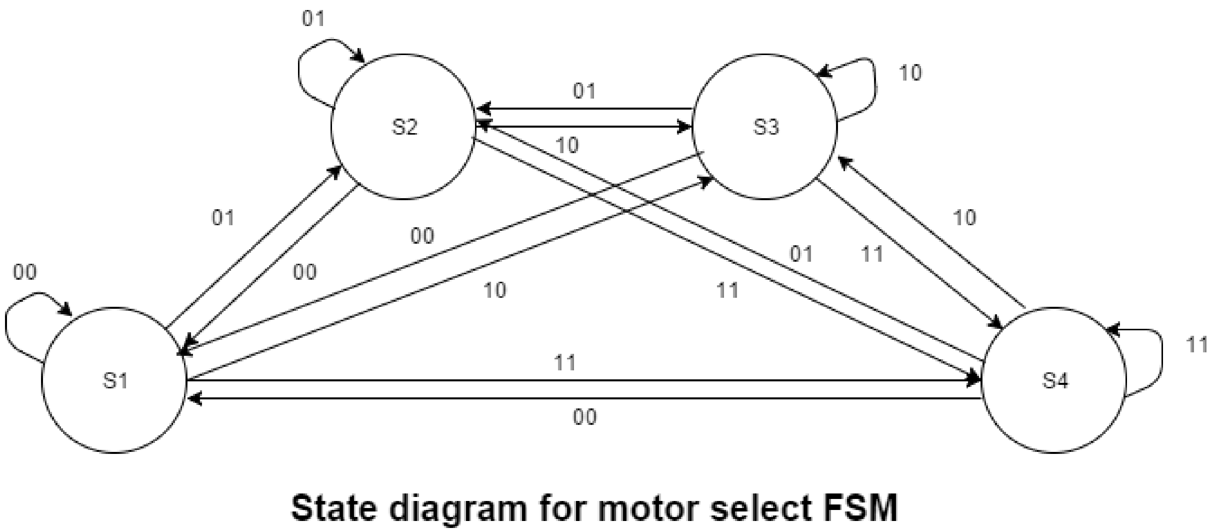


Figure 5. Motor Select FSM

The actual implementation of the FSM is a 1 to 4 demultiplexer. The diagram is demonstrated below. The Ci signals correspond to two-bit digital motor select signal from Arduino board. The Si signals correspond to four states in the FSM. The Din signal is connected to the output of probe select FSM as an input digital signal.

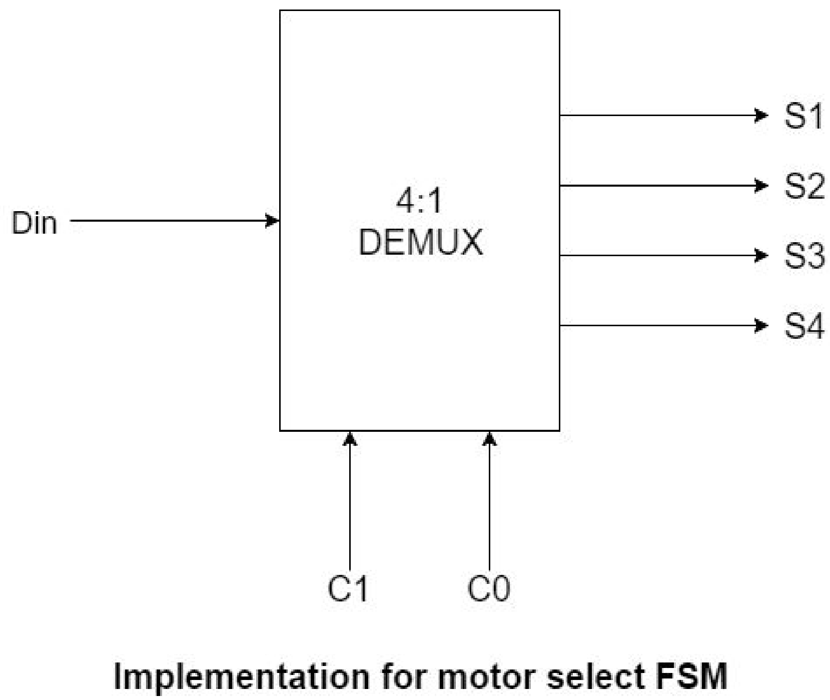


Figure 6. DEMUX

Requirement	Verification
The output of the DEMUX matches the desired control state.	Separately transmit the values for C1 and C0 to the input and see the output.

2.4.3 FSM for probe selection

The FSM for probe selection has the same structure of FSM for motor select. The only difference is that four states are corresponding to four different probes. However, for the simplicity purpose, we will only implement one of the probe. Therefore, only one state will be available. The other three states is the duplication of the implemented one.

Requirement	Verification

The output of the DEMUX matches the desired control state.	Separately transmit the values for C1 and C0 to the input and see the output.

2.4.4 Control for contact sensing

In order to detect whether the probe tip touches the metal contact, we will use a micro switch. Below are a cross section image and a circuit diagram of a micro switch.

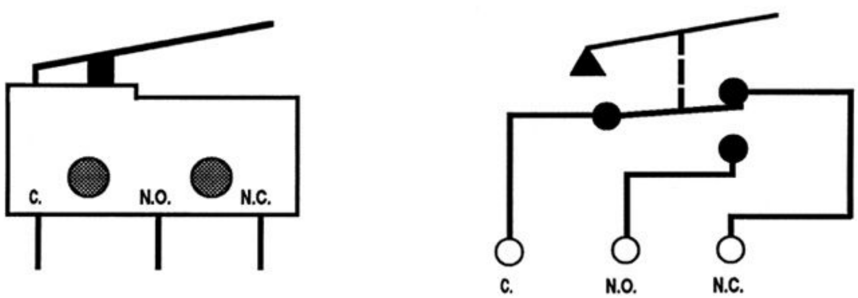


Figure 7. Micro Switch Circuit Schematic

When no downward force is applied to the top lever, current flows through the Normally Closed(N.C.) circuit powered by node C. When there's a downward force lifting the lever, current flows through the Normally Open(N.O.) circuit. Here's the positioner.

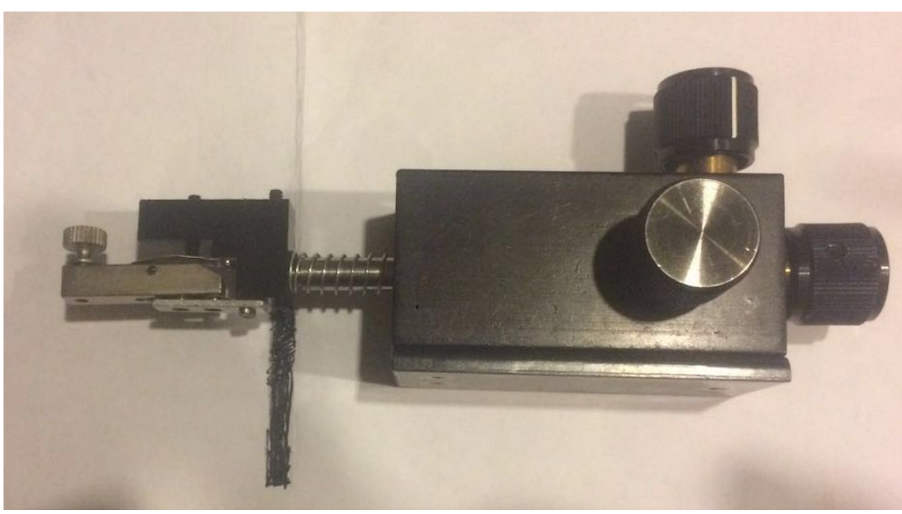


Figure 8. Probe Positioner with vertical handle

The entire probe tip handler on the right will shift down when the corresponding probe knob turns to the vertical downward position. We will attach a handle underneath the probe tip handler as shown above, and we will place the micro switch directly beneath the handle. Once the probe handler is lowered to a certain position, the micro switch will trigger. We will make sure it triggers as the position of the probe tip reaches the device. Since in the real probe station, the vertical position of probe positioner and the wafer platform doesn't change, this is achievable.

The N.O. circuit will be connected to the control unit and the user interface. Once there's current detected from the N.O. line, the control unit will disable all of the possible movements except moving up vertically. A signal will also be sent back to the user interface via arduino notifying the user that the probe tip is in contact with the device.

2.4.5 Control for forward and backward motor movement

To control the forward and backward motor movement, a 1 to 2 demux is used to select the proper movement. The user interface will send a digital signal to the Arduino board and then the Arduino board will send the signal with a proper clock cycle to demux to control the movement by user input. The motor need a 4-phase pulse signal to move forward or backward. The implementation of motor movement is a serial in/parallel out shift register. In each clock cycle, only one of the node in the H-bridge chip will be logic high. Therefore, a 4-phase pulse signal is achieved.

Requirement	Verification

1.The output of the DEMUX matches the desired control state. 2.The shift register correctly shift a 1000-0100-0010-0001 pattern in one clock cycle of the input signal. 3. The clock cycle of the shift register should be the same as the input clock signal.	1.Separately transmit the values for C0 to the input and see the output. 2. Use a function generator to set the clock cycle and set the input signal to be one to check the behavior of the shift register. 3. Connect both of the clock signal to an oscilloscope to check the correctness.

2.4.6 FSM for Motor speed and step control (extra feature)

If the manual feature works, we will implement an FSM using miniature snap-action switch and on board EEPROM memory for auto feature. This FSM will control the different motor speed operation and move the motor by the calculated step numbers from the user interface. Miniature snap-action switch is a protection of the probe. When it is activated, the current through the motor will be cut-off and the motor will be put into a hold state. After user finish the measurements and hit a key in the user interface. The motor will move backward and reset to the setted initial position. The two-bit digital signal will compose four states. S1 is the fast motion state. S2 is the slow motion state. S3 is the hold state. S4 is the reset state. The on board EEPROM memory will be used to store the step numbers of each motor. [5]

Requirement	Verification
The four states will go through fast, slow, hold backward	Separately input value in the FSM and see the output. Check if they show the expected result.

2.5 User Interface

The user will control the components mentioned below, which will trigger signals that will be sent to the control unit and motor unit via an arduino. When there’s USB detected, a script will trigger open a webpage made by Django, a python web development software package. This will be our platform where the user can see the image from the camera, select which probe to move at which speed with the mouse, and move the probes with the keyboard. Before placing a probe to a metal contact region, the user will freeze the camera , and the image will be processed by the computer. The user then selects a region where the probe is to be placed, and if he/she selects a region of non-metal material, an alert window pops up and the user will have to select again.

The user interface also receives signals from the control unit; specifically from the contact sensing module described above. When the back end view is informed that the probe needs to be stopped, the back end view will disable vertical downward movements from the probe.

User Interface in detail

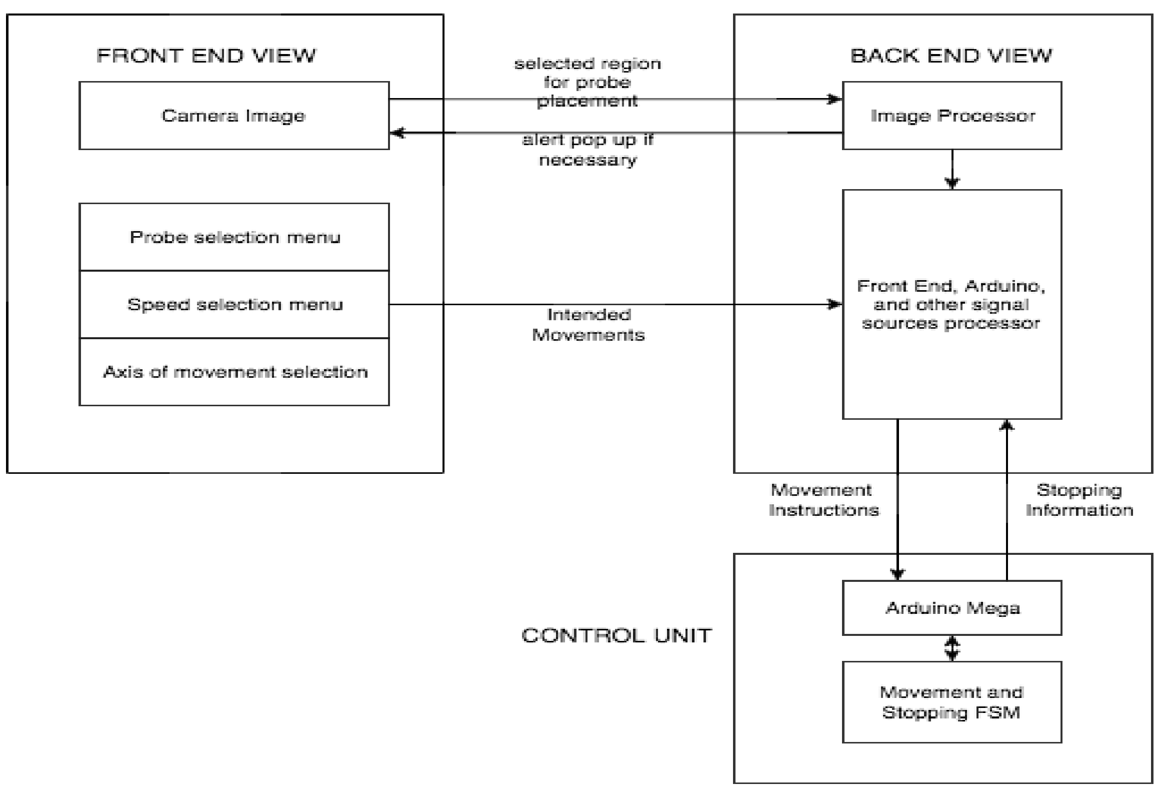


Figure 9. User Interface Signal Block Diagram

2.5.1 Computer screen

The computer screen will show the user the snapshot of the image captured under the lens by the camera. This image will be processed by a computer program to determine which regions the probes are allowed to touch. And show a drop-down menu to select which probe to move.

Requirement	Verification
The user should see the microscope image from the camera on the left side of the web page, and drop down menus for the select options.	A.The image from the camera should be displayed in the front end view. The user can freeze the camera when they found the view him/her wants. B.The front end view includes drop down menus for probe selection, axis of movement selection, and speed selection

2.5.2 Mouse

The mouse will be used to select from the drop down menu, and select a region on the snapshot on the computer screen to see if the region is metal contact or not. The user can also select from two speeds to operate using the mouse; a faster speed when the probe is far from the region of contact, and a slower one for more precision. [6]

Requirements	Verification
In the case that the user selects a region that is non-metal to place the probe tip on, a warning window should pop up to alert the user and	A.Once a region is selected, the region's pixels are analyzed to see if the average brightness of the pixels exceeds a

make them reselect a region.	threshold(TBD). The result of this process is sent to the back end view of the user interface. B. If the result is negative, one of the scripts in the back end view is triggered and an alert menu will pop up. C. As long as the user did not select an adequate region, the user cannot move the probe downward in the vertical plane.

2.5.3 Keyboard

The keys W,S,A,D will control the movements of the up, down, left, right respectively on the horizontal plane. The UP and DOWN keys will control the vertical plane up and down movements. [6]

Requirement	Verification
The probe should only move in one direction in one axis of movement at a time.	A.Before moving the probes, the user chooses the axis of movement from a drop down menu(up/down left/right horizontal, or up/down vertical) B. If two keys are pressed at the same time within the same axis of movement, the probe doesn't move.

2.6 Power supply

Battery

The power source for the design consists of a battery pack. It gives a 10V power supply to Dc-Dc convertor. Dc-Dc convertor can provide a constant 5V output to supply power to TTL control circuit.

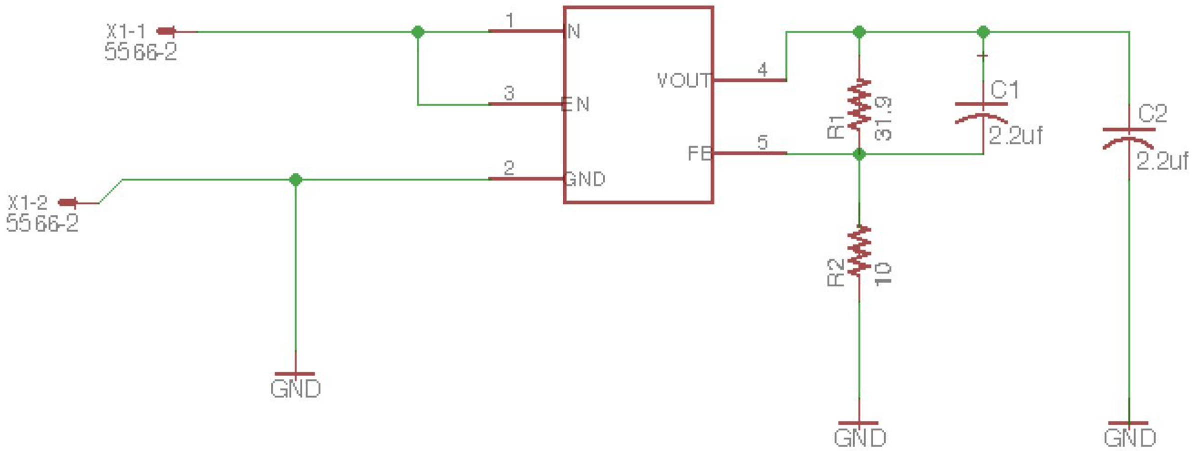


Figure 10. Power Source Circuit Schematic

Requirement	Verification
Output voltage can maintain at 5V output voltage to supply power to TTL control circuit.	The output voltage should fluctuate within 4.7V - 5.3V range. It can be tested by measuring output voltage through voltmeter.

2.7 Tolerance Analysis

The main focus of our project, other than providing an electronic interface to replace a manual one, is to guarantee precision. For our FSM that stops the motor when the probe tip is in contact with the wafer, precision is essential. As shown in the formula below, one step of the stepper motor moves the probe approximately 37.5nm. Theoretically, if we estimate the smallest movement a probe station user can apply manually on the probe knob is 2 degrees, corresponding to 166nm as shown in equation(4) of movement on the probe. Therefore, the probe tip will have four times more rotational distance tolerance to move the probe than the original manual control without destroying the probe tip. In order to protect the wafer and probe tip, we have to make sure that once the probe tip has contact with wafer, the time delay resulting from signals transmission to stop movement of stepper motor is very short. We have already improves the tolerance of original version 4 times better.

The clock cycle is another factor that will influence our precision. The clock cycle of the input signal from the Arduino board should be the same compared to the clock cycle for the serial in/parallel out shift register. The reason is that the shift register should accept high in only one clock cycle before the next input high signal reaches the data input of shift register. To accomplish the requirement, A 4-clock-cycle-time delay will be set by the user interface to prevent the motor from getting into undesired state. The tolerance of the syncroness should be within [-5%,5%], since the logic gate has a certain input delay as well. The lower bound is more restrict than the upper bound.

3.Cost

Our individual development costs will be 40 dollars/hour, 10 hours a week for each the three of us. We will/have spend 10 weeks of the semester on this project. So our individual development cost this semester will be:

$$40\frac{dollars}{hour} * 10\frac{hours}{week} * 10weeks * 3 * 2.5 = 30000$$

Part	**Cost**
Celestron Digital Microscope Imager 44421	$51.99
Arduino Mega 2560 Rev3	$38.50
Three Stepper motor - NEMA-17 size	$44.85
Adafruit Motor/Stepper/Servo Shield for Arduino v2	$19.95
Texas Instrument CD74AC139M96 Dual 2-to-4 Line Decoder/Demultiplexer	$16.99
10PCS Texas Instruments CD4081BE CD4081 CMOS Quad 2-Input AND Gate	$9.98
Elegoo 17 Values 1% Resistor Kit Assortment, 0 Ohm-1M Ohm (Pack of 525)	$10.86
Two TPS799 200-mA, Low-Quiescent Current, Ultralow Noise, High-PSRR Low-Dropout Linear Regulator	$10
Three SN754410 Quadruple Half-H Driver	$6

25 Pieces of CD4013 CD4013BE CMOS Dual D-Type Flip Flop DIP14	$35
Texas Instruments SN74HC04N Hex Inverters (Pack of 10)	$8

Therefore, our total development cost will be 30252.12 dollars.

4.Schedule

Week	Stanford Zhou	Zihao Xie	Zehua Chen
10/2	Learn how to write python scripts for Django, and USB detector. Get familiar with the programming languages used.	Order all of motors, TPS79901, SN754410. Learn knowledge of controlling stepper motor.	Consider the feature of the project and come up with the design of the control system to meet the request.
10/9	Implement the front end view of the user interface, set up the back end view. Insert the USB camera view to the front end.	Test motor with drive, talk with people at machine shop to figure out mechanical components of design	Build the circuit on a breadboard and test the each part of the control system.
10/16	Implement the image processing software in a python script. Link it to the back end view so that the data from the front end view and from the image can be processed together.	Build dc-dc convertor. Start to learn how to build drive circuit of motor, learn SN754410	Debug the circuit if any problems occurs.
10/23	Process the data in the back end view to	Get mechanical of positioner done and	Connect the motor part of the circuit into

	the appropriate signals to send to the Arduino.	test it with drive.	the control system .and check if the desired motor behavior is achieved.
10/30	Make sure the signals sent from the interface to the control unit is received appropriately as expected. Run some tests.	Build SN754410 drive circuit and design layout for machine shop, start to test motor with it.	Connect the user interface to the control system to check if the input signals match the designed requirements
11/6	Tweak the values of the signals to match our required performance.	Figure out the best voltage and switching frequency of drive circuit to control motor	Final check on the circuit and purchase soldering breadboard or send the design for a PCB
11/13	Run some tests with all the unit and sub-modules combined. Make necessary changes.	Test, debug and start to do PCB design.	Test the soldering breadboard or the PCB
11/20	Fall Break	Fall Break	Fall Break
11/27	Prepare for mock demo. Write the report.	Prepare for mock demo. Write the report.	Prepare for mock demo. Write the report.
12/3	Demo	Demo	Demo

5.Ethics and Safety

Our project will not harm people according to code 1. Our decision is made to improve the learning experience of ECE 444 students. The power source for our main circuit design is considered as low voltage. It will not cause a significant safety issue. However, the battery will potentially pollutes the environment if handled not correctly. We will take care of all the waste materials and dispose them with caution. The off-shelf components may use a regular 110v wall outlet. For the safety issue for those components, please review the safety documents in the user manual.

We commit to the IEEE code of ethics[7]. The access of the document is in the reference section of this proposal. Since plagiarism is prohibited, we will not use the implementation of an existing auto-probe station. Instead we will improve the old manual model of the probe station of our school. Our design will be original and approach the problem in a different way. We abide to code 9 and 10; we will study and reference, but not copy or steal any existing ideas related to our project without giving them their due, and make sure each member of the group understand the consequences of such actions.

In this proposal, we believe, as of right now, all the design features are achievable and are within the scope of our abilities. As code 3 states, this proposal is an honest, realistic projection of our potential. We will also divide the credentials of this project as it's due, according to code 7 and 10. Every member will be given credit solely based on their contributions toward the project.

In order to handle the wafer safely, we recommend the user to use a tweezer to move the wafer on and off the probe station.

References

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