DEVELOPMENT OF A CARTESIAN ROBOT FOR SILVER NANOWIRE (AgNw) TESTING

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Abstract - One of the ongoing research project in the University of the Philippines is developing a silver nanowire (AgNw) conductive sheet. The conductive sheet is designed to be used for touchscreen applications. Hence, there is a need to characterize and testthe electrical characteristics of the silver nanowire. Specifically,this project developed a testing platform for the testing of AgNw.The project addressed both the mechanical and electronic designof the test platform.
The testing platform adopted a Cartesian form. Parts weremodeled using OpenSCAD and then prototyped using fusedfilament fabrication. Two stepper motor, one for each Cartesian axis, provide actuation and employs screw driving. A controllerboard was also made that housed a PIC microcontroller andstepper motor drivers to provide control for each axis. Thecontroller also accept interrupts from the data probe to providea means of communication between them.
The Cartesian robot's performance parameters was tested.Specifically the Cartesian robot's repeatability, and accuracy wascharacterized. The frame is rigid that repeated motions arepossible. The platform is easily configured for different sizes andtests. This opens up the possibility of being used for other testingpurposes.

Index Terms - AgNw Testing, Cartesian Robot, Robotics, Automation

I. INTRODUCTION

Touchscreens whether resistive or capacitive requires a conductive sheet to map out location.The conductive sheet is made by coating an elastic plane, usually polymer-based, with a resistive substance to form a composite combining the desired traits for resistive touch applications.A composite is a combination of two or more materials with different properties, forming another material with the combined desired properties.The silver nanowire (AgNw) is a planar conductive polymer-based nanocomposites. AgNw [1] is made of silver nanostructures with a diameter between 10-100nm and length ranging from 20 to 200μm.
Robots [2] are machine programmed to do a specific task free from an outside controller, such as a human.They are used in applications requiring repeated motions. We can adopt the use of robots to automate the testing of the silver nanowire as well.
The testing platform will automate the data sampling and provide consistent quality sampling.A manipulator is a robot affixed to a surface with a limited workspace.
Since the AgNw is planar in shape, a Cartesian robot, a kind of manipulator, should perform well as a testing platform.
A Cartesian robot moves along the axes of a Cartesian coordinate system.Other types [2] of manipulator differ to the Cartesian robot with the coordinatesystem used. There is a cylindrical coordinate system robot and also a spherical coordinate system robot. The articulated arm is also another kind, which employs a series of link with a combination of prismatic and revolute joints. The parallel robot employs a closed loop of links compared to the open loop of the articulated robot.The project will require intensive testing with large sample sizes.Using a Cartesian robot to test the silver nanowire will automate the testing phase of the project.
Hence, the project's goal was to design and prototype a Cartesian robot design tailored for testing silver nanowire.The Cartesian robot was manufactured using 3D printed parts, specifically using fused filament fabrication (FFF).A controller board was fabricated, populated, and interfaced to control the Cartesian robot.
A control system was done in such a way that will provide testing automation and easy integration of the test probe.
Tests were done to evaluate the Cartesian robot's design.

II. REVIEW OF RELATED LITERATURE

A. Cartesian Robot Components

1) **Frame:** The frame houses the actuators and the sensors of the cartesian robot.
2) **Actuation:** Actuators provide motion to the robot. At least one actuator is needed to move a joint.

Motors are used as actuators by providing a rotary motion that can be used as is or with the aide of a transmission, converted to linear motion.
Other types of transmission is the pneumatic and the hydraulic actuators. Pneumatic actuators use gas while hydraulics use liquids, both are considered fluid. These kind of actuatorswork by having a container that that has at least one inputand output port. Either a piston, for linear motion, or a vaneor another rotating element, for rotary motion, is affixed. Fluidis pumped to the input and the piston or the rotating elementactuates.

3) Sensor: Cartesian robots usually have open loop system. Nevertheless, there is an option for the addition of sensors for a closed loop system. These sensors measure absoulute or relative distances.

III. METHODOLOGY

A. Mechanical

The testing platform have three degrees of freedom to move along the three Cartesian axes.

1) Configuration:The Cartesian robot have three degreesof freedom adopting a fixed bridge configuration. Each axis is driven by a stepper motor direct coupled to a leadscrew. The robot is divided into four: frame, X-Axis Assembly, YAxisAssembly, Z-Axis Assembly. The workspace encompass a 210x297mm cube.
2) Model and Assembly: Parts were parametrically modeled using OpenSCAD. This will allow easy changes to each parts to better fit other parts such as the stepper motor or the leadscrew.

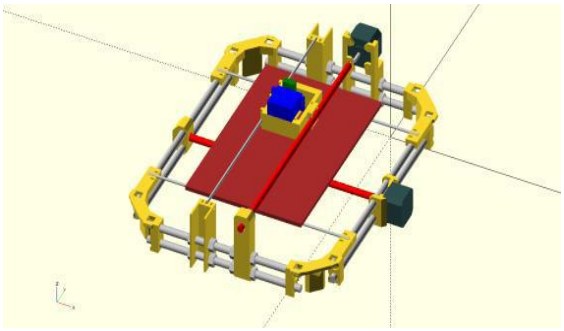


Figure 1: Isometric View of the Testing Platform

Aside from the parts that will be fabricated. All the otherparts (motors, leadscrew, bearings, etc.) were parametrically modeled. All the parts are then fitted together and inspected.

The Cartesian robot was designed [4] to have a mix of minimum and redundant constraint parts. Printing with minimal supports was considered in the modeling of the parts. The parts modeled were then be fabricated using fused filament fabrication. The thermoplastic to be used is Polylacticacid (PLA). The first part to be assembled is the frame, followed by the X-Assembly, and then Y-Assembly Bridge. When the parts were connected every corner was checked for squareness. The bridge abutment was placed and secured in the midpoint of the frame edges.

The frame consist of 4 3D printed corners. Each corner actsas a joint with two pairs of threaded rod that is orthogonal to each pair. The threaded rod pair is parallel and one is above the other. Each threaded rod is fastened by two nuts to hold it in place.

The testing platform corner also participates in the x-axisassembly. Each corner acts as an abutment to one smooth rod for the x-axis assembly. The smoothrod is fastened with zip tie.

Each assembly composes of an actuator, a driving system, a guide, and limit switches. The x-axis assembly is fastened to the frame and composes a stepper motor, a leadscrew, two smooth rods, a bed, and the end parts of the assembly.

The x-axis assembly stepper motor is fastened to a motor holder. The motor holder is split into two and is used to mount the motor to the frame.

The y-axis assembly is composed of a stepper motor, 2 pairsof abutment, a leadscrew, and a smoothrod, and a carriage. The 2 pairs of abutment is fixed at the frame and opposite each other to form the bridge. The abutment is fastened to the frame with nuts. The leadscrew and smoothrod connects the two abutment.



Figure 2: Corner with Threaded Rods Fastened

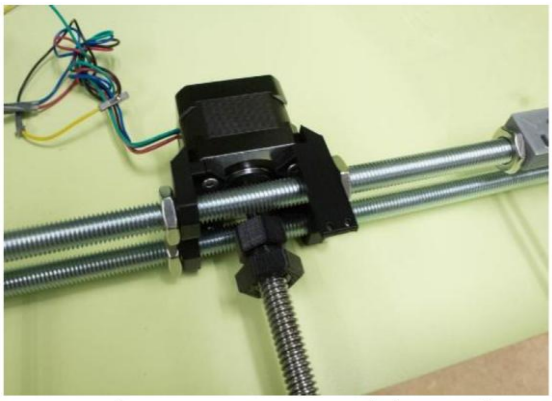


Figure 1: X-Axis Stepper Motor Coupled to Leadscrew

The stepper motor abutment is mounted by two printed stepper motor holder.

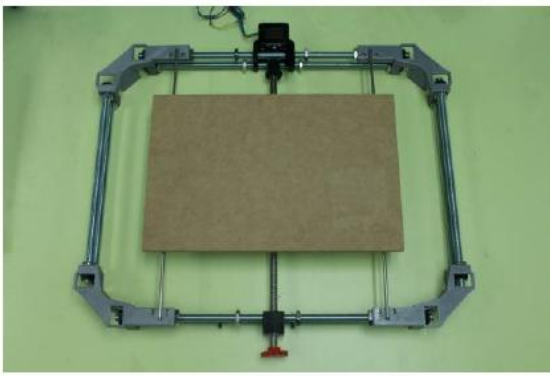


Figure 4: Testing Platform with the X-Axis Assembly Installed

The end of the y-axis assembly leadscrew is carried by an abutment with a radial bearing.



Figure 2: Y-Axis Stepper Motor Coupled to Leadscrew

The z-axis assembly is mounted to the y-axis carriage. It composes of an actuator and the test probe.



Figure 3: Y-Axis Assembly Leadscrew End

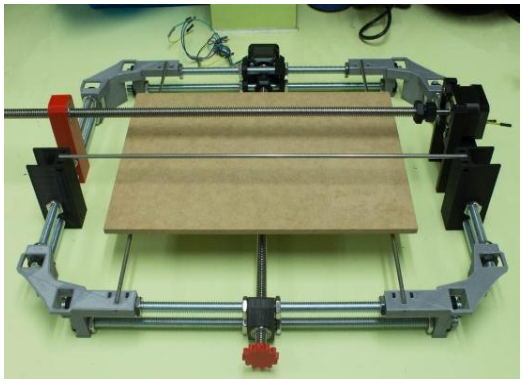


Figure 4: Testing Platform with the Y-Axis Assembly Installed

B. Electronics

The controller houses the MCU, the motor drivers, and other peripherals. The MCU handles the parsing, conversion, translation of G-Codes, stepper motor control, and interrupt handling. The motor driver pin out is designed to handle commercially available break out board to facilitate easy debugging and replacement. For this project the A4988 motor driver is used to drive the stepper motors. The stepper motors driven are bipolar stepper motors. All the stepper motors have the same specifications.

C. Control

A simple open loop was designed to handle the interruptsfrom the data probe, the motor control, and the G-code translation.

The controller should be able to support the home and move G commands.

For the serial connection between the test sampler and the testing platform, a simple two wire interface was developed.One wire will act as an output and another an input. For thetest platform, this is a simple change notification pin and aGPIO configured as an output. The test sampler should senda single pulse to the change notification pin to indicate it isready to sample data. The testing platform output will signal ahigh after the testing platform motors are done actuating andmoving to the coordinate specified.

D. Setup

The setup of this project is composed of the testing platformand a data sampler.

Table 1: Testing Setup Process

Testing Platform	Data Sampler
Init Move	
Send Pulse to Data Sampler	
	Move End Effector Down
	Sample Data
	Move End Effector Up
	Send Pulse to Testing Platform
Move to Next Coordinate	
Send Pulse to Data Sampler	
	Move End Effector Down
	Sample Data
	Move End Effector Up
	Send Pulse to Testing Platform
…	…

The data sampler is a module connected to the end-effectorof the testing platform. The data sampler is developed by another project doing the characterization of the AgNwcomposite. The testing platform is interfaced to a data sampler using a two wire interface. The test starts with the platform moving to the initialposition. The testing platform will then signal an output to the data sampler. This indicates that the testing platform is done actuating. The data sampler is now free to sample data. After data sampling, the data sampler will then send a pulse to the testing platform indicating that it is finished. The testing platform is now free to actuate to the next coordinate and after that will send an output to the data sampler. The process is repeated.

E. Testing

The testing platform performance will be tested. These characteristicsis important before upgrading the testing platform or the control algorithm. Measurements were done with a digital caliper with a resolution of 0.01mm.

The following tests will be done in the following order:

Resolution is the smallest step distance the robot can travel.Resolution is a factor of the stepper motor angle, leadscrewlead, the motor driver stepping. The target resolution can be calculated by:

Resolution = $l*360*stepangle^{-1}*\mu_{PFS}^{-1}$

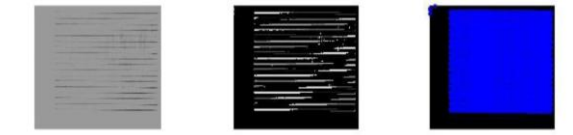
Resolution is tested by commanding the stepper motor tomove one step angle. The distance traveled will then be measured.
Repeatability is the successive attempts to move to a specificlocation.
Repeatability is tested by indexing the bed in each axis. The test probe is then"zeroed". The test probe moves +x then returns to zero and then -x. Data will be sampled at each approach to zero. 5 cycles will be done per testing. A digital caliper with a resolution of 0.01mm was used.

Geometric accuracy gives a measure on how square therobot design is. It will show any deviation from the straight line motion in an axis.

The geometric accuracy is measured by having the end effector move in a straight line along the x and y axes. The plotted lines will then be scanned and then processed to measure the geometric accuracy of the testing platform.

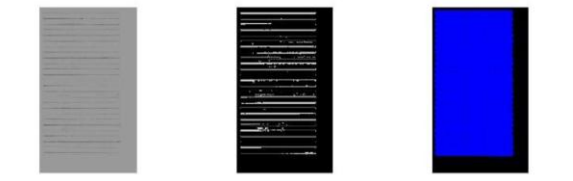
Positional accuracy is how close the target position isfrom the actual position. Positional accuracy is tested by commanding the controller to move the test probe +x.
The actual distance traveled is then measured. The target and actual distance will then be compared. The test for accuracy is done by having the testing platform draw straight lines on a paper along an axis across the paper in discrete intervals. For the test done, 18 lines each 10mm apart were draw for the x-axis test. For the y-axis test 26 lines that are 10mm apart were drawn.

The paper drew on by the testing platform was scanned and then subjected to image processing to extract the lines and compare it with the expected straight lines. To check the positional accuracy of the testing platform, the distance between lines were checked.



(a) X-axis Accuracy Test Scan (b) X-axis Image Edge (c) X-axis Lines Detected

Figure 5: X-Axis Test



(a) Y-axis Accuracy Test Scan (b) Y-axis Image Edge (c) Y-axis Lines Detected

Figure 6: Y-Axis Test

IV. RESULTS AND ANALYSIS

A. Repeatability

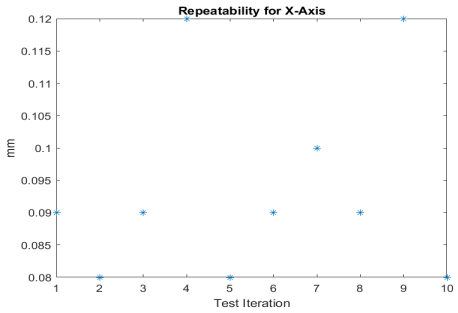


Figure 7: Sample Repeatability for X-Axis

For each repeatability test, ten iterations were done. Fiveiterations where the testing platform moved +10mm then back to zero and another five iterations where the testing platform moved -10mm then back to zero. The range of samples tabulated is from 0.08mm to 0.12mm. Some error in the data tabulated is due to the moving and poor precision of the caliper. The mean absolute error (MAE) for the sample x-axis repeatability test is 0.086.

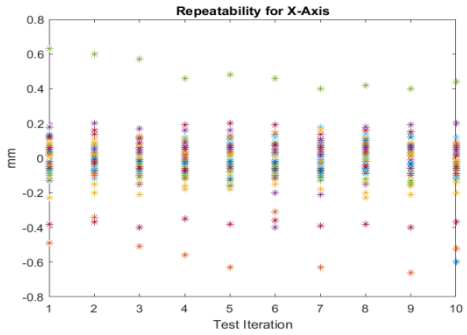


Figure 8: Distribution of Data for X-Axis Repeatability

The distribution of samples is tightly clustered. This showsthat the frame is rigid enough to allow repeatable motions done on the testing platform. The mean absolute error for the x-axis repeatability is 0.0431. Observe that the green, orange, and maroon iterations areoutliers. Even though the error measured is not close to zero, the caliper readings still showed tight measurements. This means that the initial reading is an error to the caliper.

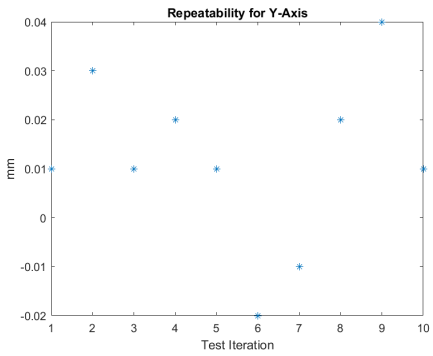


Figure 9: Sample Repeatability for Y-Axis

The range of samples tabulated is from -0.02mm to0.04mm. The repeatability test for the y-axis showed greater variations in readings. No apparent pattern was observed. The mean absolute error for the y-axis repeatability is 0.0612.

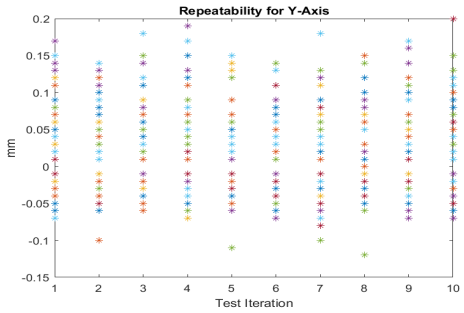


Figure 10: Distribution of Data for Y-Axis Repeatability

The distribution of samples is still clustered to some degree.

The abutments are affixed to the frame on the bottom and this causes some rolling in the part. Nevertheless, the results still show that the y-axis is capable of repeatable motions.

B. Geometric Accuracy

The drawn lines were compared with the generated straightline. The green line is the extracted straight line while the blue line is the extracted drawn line.

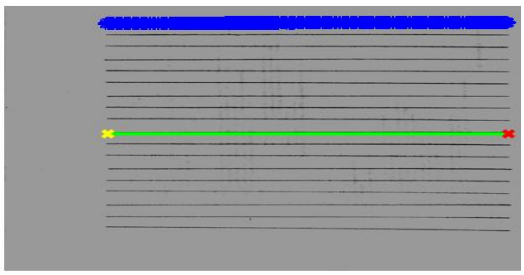


Figure 11: Straight Line Drawn and Line Extracted

Each color in the scatter plot represents a line drawn duringthe accuracy test. The results show that the lines drawn by the testing platform for the x-axis are geometrically straight. Some data samples that are scattered is from the noise generated by the edge function during image processing. The mean absolute error for the x-axis geometric accuracy is 0.0037.

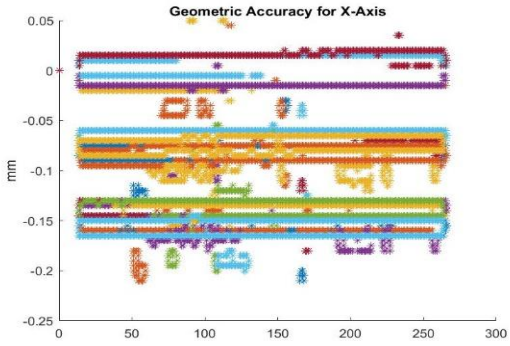


Figure 12: Distribution of Data for X-Axis Geometric Accuracy

The y-axis geometric accuracy also shows a geometricallystraight line. Some scattered data sample was obtained during image processing. The observed readings near the x-axis equal to 0 is an error from scanning the image. The scanner must have scanned a gap between the corner of the scanner workspace and the edge of the paper. The mean absolute error for the y-axis geometric accuracy is 0.0152.

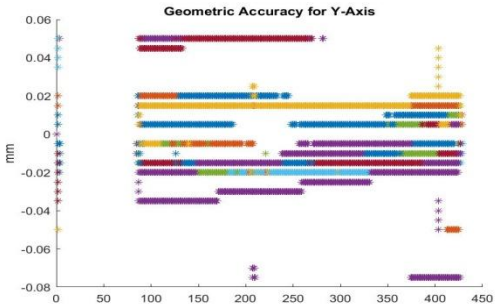


Figure 13: Distribution of Data for Y-Axis Geometric Accuracy

C. Positional Accuracy

Each dot in the scatter plot represents the distance betweentwo adjacent lines. The distance between the lines drawn lie close to 10mm. The boundaries of the lines were extracted and this might have caused the reading to be offset because of the thickness of the pen lead used. The pen used was not sharp. The mean absolute error for the x-axis positional accuracy is 0.4794.

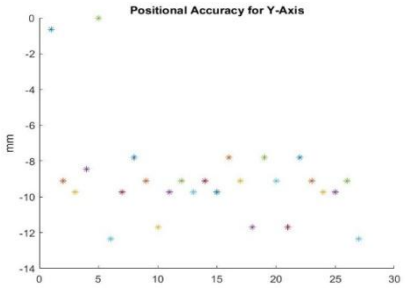


Figure 14: X-Axis Positional Accuracy

The y-axis positional accuracy shows a good result withthe distance being uniform. The resulting values might be the result of the pen used not being sharp. The mean absolute error for the x-axis positional accuracy is 1.0685.

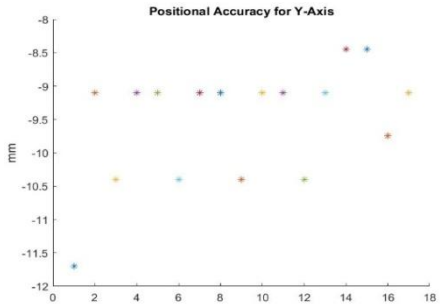


Figure 15: Y-Axis Positional Accuracy

CONCLUSION

This project concludes that a testing platform for silvernanowire testing can be built. A fixed bridge Cartesianrobot setup would work as a platform. The testing platform can adopt different testing probes and mount it to the testing platform. Repeatability shows the testing platform is able to do repeated motion with minimal error. Straight lines were drawn by the testing platform showing good geometric accuracy. The Positional accuracy of the testing platform showed even distances between the lines.

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