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Automated Lathe Machine

Hairul Mubarak Hassim*, Abdullah Ariff Ariffin Othman, Muhammad Akmal Hanif Azman, Muhammad Fadhil Supaat, Siti Mariam Basharie & Khairulnizam Othman

[1] Product Research and Development Group,
Department of Mechanical Engineering, Centre for Diploma Studies,
Universiti Tun Hussein Onn Malaysia, Pagoh Higher Education Hub, KM 1, Jalan Panchor, Muar, Johor, 84600, MALAYSIA.

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Abstract: Woodcraft is one of the many handcrafts that exist in this country. The woodcraft can be done variously especially turning. Since there is always demands from tourists, woodcraft industries required precise, accuracy, speed and consistency in its production. One of the most popular mechanical equipment, CNC (Computer Numerical Control) machine. However, it is hard to afford CNC machine since it is expensive and too big to be stored in their workshop. Many of wood crafter still using a conventional method which done manually with a high specific skill. This method is difficult, takes times and impossible to be done by a non-skilled person. Based on the problem, the idea is to replicate a conventional lathe machine into an automated one which works exactly like the CNC machine. This machine built in small size and cost much cheaper than the market's CNC machine. The 2-axis machine will be controlled by Arduino Uno which has been interfaced with Grbl firmware. Autodesk Fusion 360 is used to design the required shape of handicraft and save it in G-code. Arduino Uno will receive and process G-code and send it to a motor driver to translates it into axial motion according to point coordinates. After testing, the replicated automated lathe machine can move nearly accurate and can work on wood with a maximum length of 100mm.

Keywords: Woodcraft, CNC, Machining, Arduino, 2-axis Machine

1. Introduction

Malaysia offering of woodcraft handcraft mostly comes from small and medium industries (SME) [1]. The skill of handcrafting is passed from an earlier generation to preserve the quality of the crafting. In contrary to modern technologies, these wood crafters use their hands to manoeuvre the cutter on a rotating wood [2]. It is hard to measure the accuracy of the cutting of the workpiece which means that only an expert in wood crafting can produce a product in a small dimensional error. Hence, it is impossible to work be done by a non-skilled person [3].

As the younger generation are distancing themselves to this industry to find a more glamourous work, it is becoming more important to assimilate the skills to today's technologies. Computer

*Corresponding author: hairulm@uthm.edu.my

Numerical Control (CNC) machine enable the product to be produced in a shorter time. The worker with no or little knowledge or any handcraft skill can produce the part. However, CNC machine is too expensive to be afforded by SME wood crafter especially for those starters which have a small model to start their business. CNC machine size also only come in a big size, make it difficult to store in a wood crafter garage.

There are two components required to assimilate these technologies. First, the NC machine must be small and cheap enough for the SME industries to purchase it. Second, the handcrafted skill needs to code so that it can be read by the NC machine. Therefore, to built an affordable NC lathe machine, Arduino microcontroller is used to act as the brain of the machine, mimicking the function with the existed CNC machine's controller unit.[4] The lathe machine works automatically by transferring the design file from CAM and CAD software into the microcontroller with a Grbl firmware to generates the electronic signals to the motors and move over the axis rail [5]. Even a non-skilled worker of handcraft skill can produce greater accuracy product.

2. Methodology

The main objective is to design and fabricate a small automated NC lathe. Initially, several sketches were drawn for conceptual design. Several concepts from traditional CNC lathe and advanced CNC machine were taken as reference. Concepts that have been adopted are how to rotate the workpiece, the carriage slide movement and connection between the motor shaft with a lead screw.

After finishing the sketch, the dimension of the project is created. Other than that, Solidwork software used to draw the project in 3D. The design is drawn detailed to enable further understanding and a clear vision of how the project works.

There are three main parts in the design of the automated lathe machine. The first is the X and Y axis assemblies, the second part is the workpiece holding device and the third part is the circuit of the electronic device. The sequence of the fabrication started in the first part and ended in the third part. Figure 2.1 shows the components of the assembly of X and Y axis assemblies and workpiece holding device.

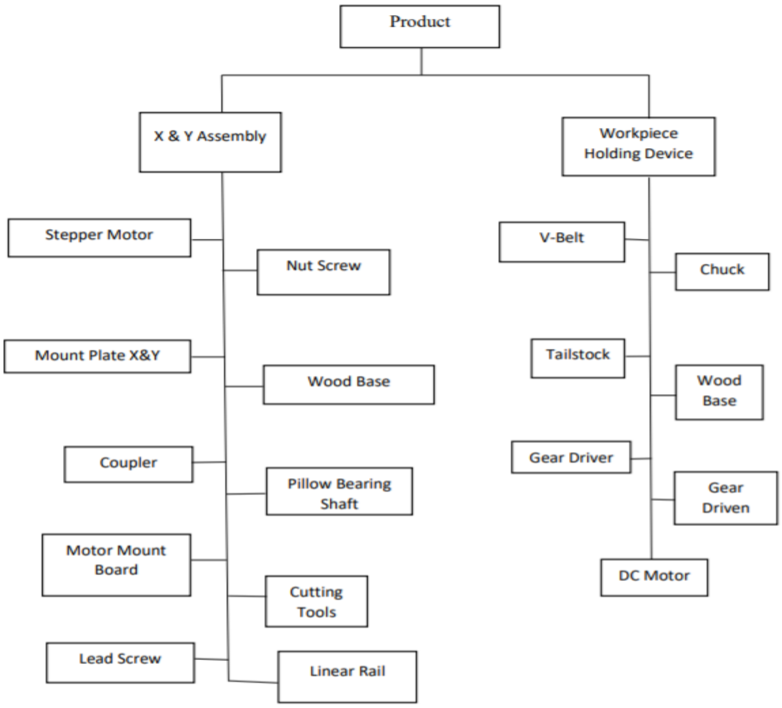

Figure 2.1: X and Y assembly and Workpiece Holding Device

2.1. X and Y axis assemblies

Both X-axis and Y-axis assemblies comprise of two sub-parts. The processes for these two sub-parts are identical except for their dimensions and functions. For X-axis assembly, a 300 mm lead screw is connected to the motor shaft by using coupling to enable nut screw to travel on the lead screw. The nut screw is mounted with the X-axis mount plate which uses to the carry Y-axis assembly mount plate. To divide the load of X and Y-axis mount plate, a pair of linear rails have been used to avoid the lead screw to solely bear load applied.

For the Y-axis assembly, a 200 mm lead screw and a pair of linear rails are used to carry tool post. Similar to X-axis assembly, the nut screw will move forwards as the motor rotates. It will move in a vertical position and front to back to enable the cutting tool on the tool post to penetrate the workpiece.

The fabrication of X assembly starts by cutting the woodblocks with dimensions of 300 x 20 mm (the length x width) for mounting the linear rail in the x-axis. Two linear rails with 12 mm width and 300 mm lengths are mounted on top of the wooden blocks with a screw. This wooden block on the table acts a lathe bed. NEMA 17 Stepper motor is then fixed to the table [6]. The motor then is fixed between the linear rail by mounting it on the table. Motor shaft is connected to the coupler and then fixed with an 8 x 300 mm lead screw. Both ends of the lead screw are fixed with a pillow bearing shafts to act as support to the lead screw and use small wooden blocks to match the motor’s shaft height. Woodblock with 50 x 80 x 20 mm is cut and a hole of nut screw outer diameter is drilled at the centre of it. The ball screw is fixed inside the previous wood block. Nut screw with internal threading of 2 mm pitch is attached on the lead screw. This ball screw will advance when the stepper motor’s shaft rotates. the x-axis mount plate is done by cutting wood to 300 x 150 mm.

The fabrication of Y assemblies starts by cutting the woodblocks with dimensions of 220 x 20 mm. Two linear rails with 12 mm width and 200 mm lengths are mounted on top of the wooden blocks with a screw. The wooden blocks that attached with Y-axis linear rails are mounted on the X-axis mount plate. 100 x 100 mm wood is cut to create a Y-axis mount plate. Second NEMA 17 Stepper motor is fixed between the Y-axis linear rail. motor shaft is attached to the coupler, then fixed using 8 x 200mm lead screw. Both ends of the lead screw is fixed with a pillow bearing shafts to act as support to the lead screw and use small wooden blocks to match the motor's shaft height. the woodblock with 50 x 30 x 20 mm is cut and a hole is drilled at the centre of it appropriate to the nut screw outer diameter. Nut screw is fixed inside the previous wood block. Nut screw with internal threading of 1 mm pitch is fixed on the lead screw. The tool post is created by cutting two tool holders from wooden blocks with 100 x 100 mm. The tool holder is placed on the other tool holder block with bolt screw. The cutting tool is fixed on the tool holder and tightened by adjusting the bolt screw. The end product of the X and Y assemblies is shown in Figure 2.2.

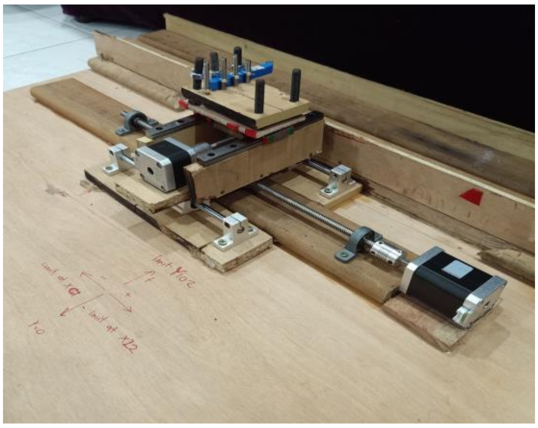

Figure 2.2: Fabrication of X and Y assemblies

2.2 Workpiece Holding Device

For this part, the headstock frame with a chuck is built. The chuck will clamp the workpiece while the tailstock will support the other end of the workpiece to ensure the workpiece at held straight. To make the workpiece rotates, the chuck will be connected to a shaft and the shaft will be connected with DC motor through a gear belt system. There will be two gears used namely driver and driven gears. The driver gear is connected to DC motor shaft when the motor rotates the gear also rotates. To transmit power, driven gear is linked with the driver gear using a vee belt [7].

Two 80 x 30 mm wooden blocks are for headstock frame. In the centre of each headstock frame, 20 mm hole is drilled. bearing is mounted inside the hole. A long shaft inside the bearing is attached to the other bearing. four jaw chuck is attached and fixed to the shaft. Headstock frame is mounted on the table. The other end of the shaft is connected to gear driven. The driven gear is linked with gear driver using a vee belt. The gear driver is connected with the DC motor. The tailstock is displaced 100 mm away from the chuck. The tailstock is mounted on the table. Figure 2.3 shows the end product of the workpiece holding device.

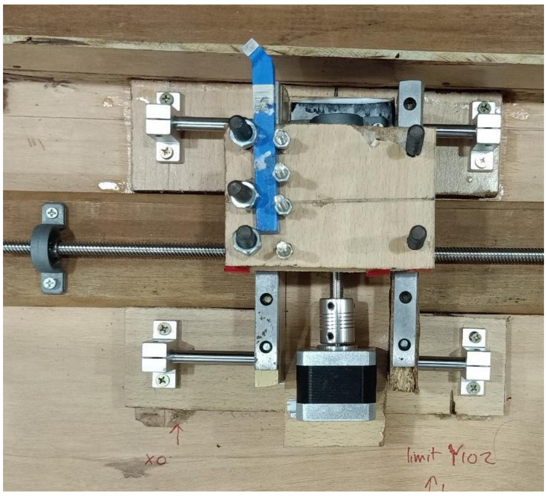

Figure 2.3: Fabrication of Workpiece Holding Device

2.3 Electronic Device

The power source required for CNC shield is 13V DC and 20V DC for stepper motors. For this, 36V DC output power supply is selected and the potentiometer is adjusted to 13V and connected to CNC shield. CNC shield is installed A4988 driver on it along with heat sink. Then CNC shield will be assembled with Arduino according to its pin circuit. Stepper motors than are connected to the CNC shield. The limit switch will be used in each axis to make sure the linear motion of carriage does not exceed the safety measurement. Table 2.1 shows the electrical components used for automated lathe machine. The two stepper motor NEMA 17 that is fixed in X and Y assemblies are connected to an Arduino board is shown in Figure 2.4. One of the stepper motors is used to move the cutter in the X direction while the other stepper motor is used to move the cutter in the y-direction.

Table 1: Electrical Component of Automated Lathe Machine

No	Name	Description	Figure
1	Linear rail	Help to get a smooth sliding motion. The carriage contains ball bearings that provide contact with the steel rail and helps the axis of motion to retain its position across a linear path.	
2	Coupling	Connects two shafts of rotary equipment at their ends for power transmission from one to the other.	
3	Lead screw	It translates rotational motion into linear motion. A threaded shaft provides a helical path for ball bearings of nut screw to rotate.	
4	Pillow bearing shaft	Provide support for a rotating shaft without slip.	

5	Arduino microcontroller	Arduino Uno R3 is a microcontroller board based on ATmega328. It has 14 digital input and output pins, 6 analogue inputs, a 16 MHz ceramic resonator, USB connection, an ICSP header, power jack and a reset button. Its operating voltage is 5V with input voltage around 7 to 20V.	
6	Stepper motor driver	NEMA 17 Stepper motor is a brushless, synchronous electric motor that can rotate in a specified angle for precise position or velocity from numbers of step input data. Operates using the theory of magnets to make the motor shaft rotate a precise angle or distance when a pulse of electricity is provided.	
7	Stepper motor	NEMA 17 Stepper motor is a brushless, synchronous electric motor that can rotate in a specified angle for precise position or velocity from numbers of step input data. Operates using the theory of magnets to make the motor shaft rotate a precise angle or distance when a pulse of electricity is provided.	
8	DC motor	A rotary electrical machine that converts direct current electrical energy into mechanical energy.	
9	Jump wire	Transmit power and data from Arduino to stepper motors.	
10	Cutting tool	Penetrate the workpiece surface and remove the material according to a depth of cut and feed given.	

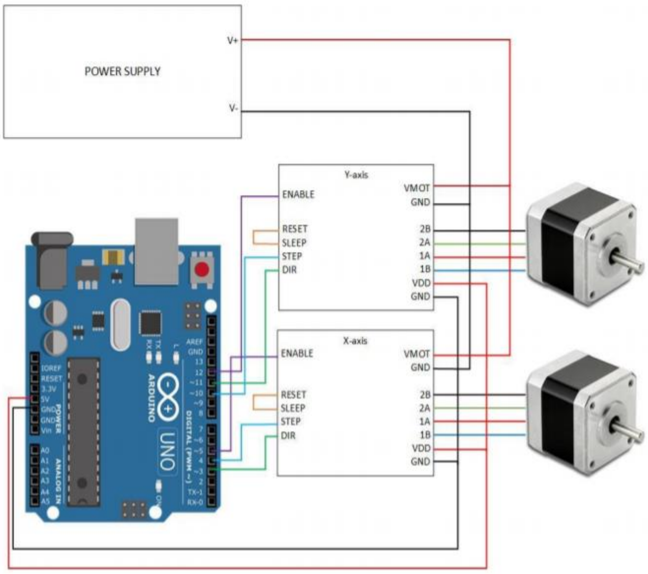

Figure 2.4: Circuit schematic of a driver, microcontroller, motor and power supply [8]

3.0 Results and Discussions

After the fabrication of the automated lathe machine has done, there are a few aspects that should be considered to ensure the machine runs perfectly. First and foremost, running test was done to analyse all the motor run perfectly. In this phase, the stepper motor was tested to make sure it can translate the Pulse Width Modulation (PWM) of Arduino into the desired distance on the lead screw.

3.1 Spindle Speed Measurement

To determine the number of steps for the motor to move 1 mm, the below equation is used. The quantity step per revolution of the stepper motor is 200. This value can be derived by dividing 360°(complete rotation) with the motor's step angle of 1.8°. Both X and Y-axis lead screw pitch is 2 mm and the full step of 1 is utilized in this study.

$$\frac{Step/rev}{lead\ screw\ pitch} \times driver\ micro\ step$$

$$\frac{200/1}{2} \times 1 = 100\ step/mm \tag{3.1}$$

The maximum torque that can be handled by DC motor is 0.196 Nm while the voltage supplied in is 20V and 4.5A. The spindle speed is determined to be 459 rpm using the formula of

$P = VI$ and

$P = \tau\omega$

where P, V, I, τ and ω are power, voltage, current, torque and angular velocity respectively.

3.2 Accuracy Test

The accuracy test was conducted to determine the level of precision of the automated lathe machine during movement in X and Y-axis. This test input was 4 lines design with 100 mm and 30 mm each for X and Y-axis. The line is then measured using a ruler and compared it to the set length. The test is done by input G-code command G01 X100 and G01 Y30 which G01 means for linear motion, X100 means for point coordinate 100 at X-axis and Y30 means point coordinate 30 for Y-axis. The interface of Arduino software to enter the value of X and Y is shown in Figure 3.1.

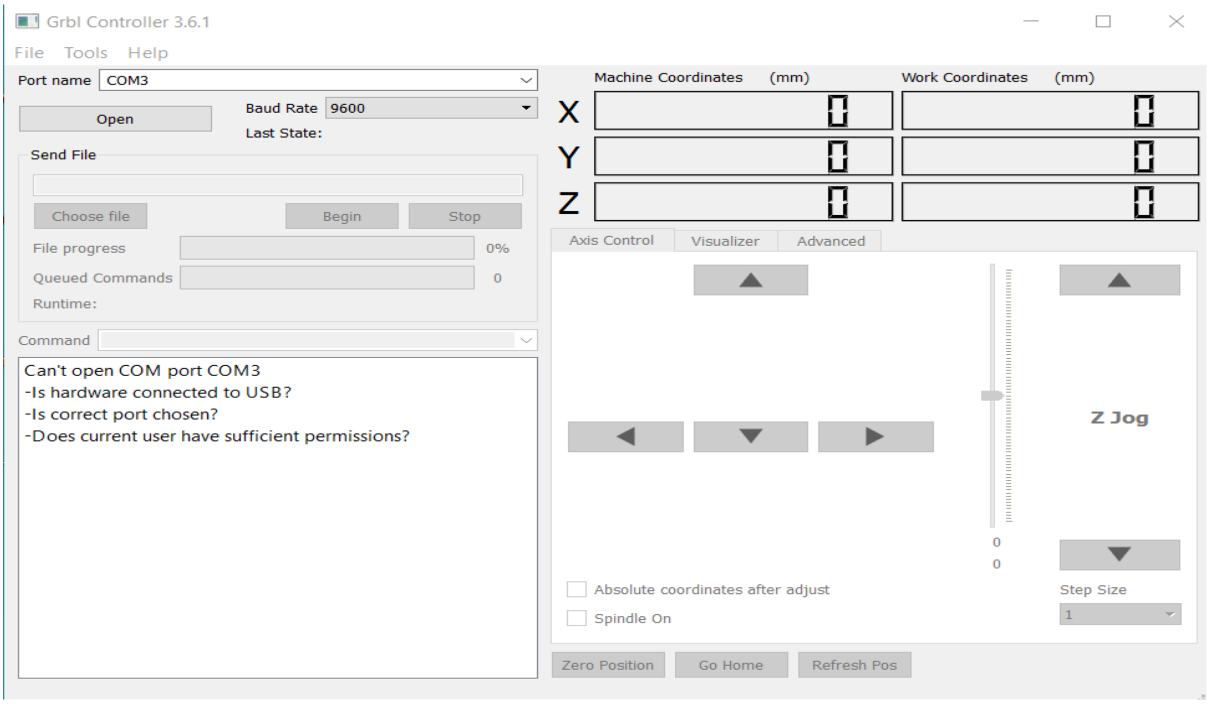

Figure 3.1: Interface of Grbl Controller Software to enter length value of X and Y

The percentage error of precision is calculated by using equation 3.2.

$$Error\ \% = \frac{(Measured\ length - Setting\ length) \times 100\ \%}{Setting\ length} \tag{3.2}$$

Using equation 3.2, the accuracy error % of the automated lathe machine in the x-direction is given in Table 2 while the accuracy error % for y-direction is given in Table 3. It is shown that the movement accuracy error % of x and y is less than 10%.

Table 2: Accuracy Error % Test for X-axis

Test No	Setting Length (mm)	Measured Length (mm)	Error %
1	60	63	5
2	60	64	6.67
3	60	64	6.67
4	60	63	5
5	60	63	5

Table 3: Accuracy Error % Test for Y-axis

Test No	Setting Length (mm)	Measured Length (mm)	Error %
1	30	30	5
2	30	28	6.67
3	30	28	6.67
4	30	28	6.67
5	30	28	6.67

4.0 Conclusions

The concept of low-cost mini automated lathe machine has been used, which can easily control with the computer. This machine can easily transportable and assembled everywhere since it is small and much lightweight than a regular CNC machine. This machine also used cheap and user-friendly Arduino Uno microcontroller which has been proven is easier to use and can be understood easily. The user just needs to draw their design in Autodesk Fusion 360 and translate it into G-code command. The computer then will send the code to Arduino Uno to be processed into signal pulse before sending it to the motor driver to be translated to axial motion according to point coordinates. Accuracy and precision are nearly maintained and the machine can perform turning process well by penetrating the cutting tool to the wood workpiece.

Acknowledgement

The project can be improved by upgrading the motor driver to the one that supports 36V and above. The function is that when the high duty cycle of PMW is high, the speed of the motorcycle increases. Also, replace the motor driver with a smaller micro step option. The function is to make the motor rotates accurately in a small angle than in full or half-step mode. Selecting a smaller micro-step also can reduce vibration and reduce noise. Next, replace the driver with better specifications so that it can support high torque. This can be done by converting Arduino Uno microcontroller with Arduino Mega 2560 which has higher database storage capacity. Then, replacing the stepper motor with the higher specification in terms of torque so it can move the load easily without stuck.

In terms of material selection, choose materials that can absorb vibrations more efficiently to prevent any damage to any component. Alternatively, optimize full use of linear rail with high smoothness and moving precision, this to make sure that the machine moves accurately as computer's order. Besides, enlarge the limitation of size product. Then, use lightweight material for X and Y table such as metal plate to enable the motor to support the load.

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