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Design of Styrofoam Cutting Machine Based on CNC 2 Axis Using Hot Wire

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ABSTRACT

The development of the creative industry in the manufacture of decorations from styrofoam materials is increasing rapidly, the need for a 2-axis CNC-based automatic styrofoam cutting machine (Computer Numerical Control) using hot wire can facilitate the process of cutting styrofoam in large quantities and uniformly with machine drive on the X and Y axes. The purpose of this study is to design and manufacture a CNC based styrofoam cutting machine that can be programmed so that it can facilitate the cutting of styrofoam in large quantities and uniformly with movement on the X and Y axes. The method used is an experimental method in which the G-Code processing process is sent to the software which then produces 2 axis movements, namely on the X and Y axes. Then the styrofoam cutting process is continued using a hot wire whose temperature has been regulated using voltage and current which produces styrofoam cutting according to the size of the styrofoam used, which is 88 cm long, 42 cm high with a thickness of 2 cm and the accuracy level obtained for the X axis of 99.84% and the Y axis of 99.91%.

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1. INTRODUCTION

The development of the creative industry is currently experiencing rapid growth. This can be seen in various sectors, including the production of Styrofoam decorations. Styrofoam decorations have gained popularity due to their versatility and wide range of applications. They can be used for various occasions, including wedding celebrations, graduations, promotions, condolences, and even as props for student art assignments. Additionally, they are utilized in practical settings such as creating safety pads for goods or adding flair to carnival events and cultural festivals.

Another notable advancement in the industrial sector is the introduction of CNC, which stands for Computer Numerical Control. CNC is a system that utilizes computers to control various industrial machines, such as lathes, milling machines, and laser machines. This technology revolutionizes the manufacturing process by enabling precise and automated control over these machines. With CNC, complex designs can be accurately replicated, resulting in increased efficiency and consistency in production. This system has significantly impacted industries that heavily rely on machining processes, enhancing productivity and pushing the boundaries of what can be achieved in precision manufacturing.

The utilization of CNC technology has significantly improved the accuracy and efficiency of the machining process. A typical CNC system comprises computers, controllers, and associated machines. Computers play a crucial role in storing product designs and generating programs that will be used by the controllers to govern the machines. The controller, acting as an intermediary, processes the computer-generated programs and transmits signals to the machines, orchestrating the precise execution of the machining process. The machines themselves encompass a range of industrial equipment that the controller operates to carry out the machining tasks.

Within the realm of styrofoam cutting, there exist both manual and automatic tools. Manual styrofoam cutting tools include cutters and hot wires, which require human intervention and control. These tools are adept at shaping and carving styrofoam materials, providing a hands-on approach for artists and craftsmen. On the other hand, automatic styrofoam cutting tools are integrated with CNC systems, enabling the machines to execute the cutting process autonomously. These automated tools offer enhanced precision, consistency, and efficiency, making them indispensable in large-scale production settings. The combination of CNC technology and a diverse array of cutting tools has revolutionized the styrofoam industry, empowering artisans and manufacturers to bring their creative visions to life with utmost accuracy and efficiency.

The increasing development and needs of industry, higher education institutions and vocational schools for CNC (Computer Numerical Control) machines in Indonesia are mostly based on the emergence of GRBL technology (software to control CNC movements that can be uploaded to the Arduino library). To fulfill its function, Styrofoam must be shaped in such a way to get the expected shape. The trick is to cut the material according to the desired shape. This cutting can be done in the form of two-dimensional cutting movements or 3D movements [1]. Styrofoam is also commonly found in the community in the form of several products, as a substitute for balsa wood to make aircraft aerofoil in aeromodelling, as well as for other uses [2]. CNC is a machine that is controlled by a computer using a numeric programming language as a movement command [3].

In general, in the work of CNC machining, it takes work that is fast and has good quality but with lower processing costs. This has become an attraction for industrial consumers to use CNC machines compared to using conventional machines. With the advantages in terms

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of productivity will be a separate competitiveness for industries that use CNC machines. The development from manual machining to machining that uses the CNC system is an advantage in increasing accuracy and speed settings as desired [4].

All CNC machines work on the same principle, the machine places a kind of tool in a sequence of positions determined by the program and the styrofoam cutting CNC machine also has the same working principle using hot wire as a styrofoam cutting tool [5]. In simple terms, the working principle is that electric power passes through a hot wire (usually 0.30 mm Nickel wire) then the wire is heated to the desired temperature according to the input voltage. The wire arc is heated through an electrical resistance around 180˚C by passing a current through the wire [6]. Hot wire is a method that is widely used in styrofoam cutting [7].

In 2017, a research was conducted entitled "Design of 2 Axis CNC Machines". The way the CNC machine works is to make products with the same shape and dimensions from the production process which is carried out repeatedly by using the dental plaque test parameters [8]. In 2020, a research entitled "Design and Development of Semi-Automatic Styrofoam Cutting Tools Using the RULA Method was conducted in Kalisari Village". The workings of the CNC machine are semi-automatic styrofoam cutting tools using the RULA (Rapid Upper Limb Assessment) method which is a method developed in the field of ergonomics that investigates and assesses the working position of the upper body [9]. In 2020, a research entitled "Design and Development of CNC Wire Cutter for Styrofoam Products was conducted". The way the Cutter CNC 2 axis Styrofoam cutter works is to convert electrical energy into heat energy. This CNC wire cutter already uses numerical control using CNC programming and the cutting precision is much faster [10].

This research makes a CNC-based styrofoam cutting machine to make it easier to work and the size of the styrofoam cutter itself will be made small. This tool can cut Styrofoam according to the size of the image on the laptop, cut using Hot Wire and a GRBL controller in the form of G-Code, to drive the heating system using a stepper motor that can move towards X and Y.

In response to the need for improved efficiency and convenience in working with Styrofoam, extensive research has been conducted to develop a CNC-based Styrofoam cutting machine. The aim of this research is to create a compact and user-friendly tool that simplifies the cutting process. The CNC-based styrofoam cutter is designed to accurately cut Styrofoam based on the dimensions of an image displayed on a laptop. This innovative tool utilizes a combination of a Hot Wire cutting mechanism and a GRBL controller, which operates using G-Code instructions. The GRBL controller acts as the brain of the system, coordinating the movements and actions required for precise cutting.

To enable the heating system, a stepper motor is employed, providing the capability to move along both the X and Y axes. This integration of technologies allows for precise control and synchronization of the cutting process, ensuring that the Styrofoam is shaped exactly according to the desired image and dimensions. The development of this CNC-based Styrofoam cutting machine represents a significant advancement in the industry, facilitating enhanced productivity and accuracy for professionals, students, and enthusiasts working with Styrofoam in various fields such as arts, crafts, prototyping, and model making.

While the first RoadMap CNC machine uses a 2-axis system, the second using a semi-automatic styrofoam CNC cutting machine using the RULA foam cutter method and the third, a 2-axis CNC machine by sending the G-Code file to the microcontroller via the universal G-Code Sender software.

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2. METHODS

The research involved in developing this CNC-based Styrofoam cutting machine employs a comprehensive range of experimental methods to ensure its successful creation. Through meticulous design, manufacturing, assembly, and testing processes, the researchers have dedicated themselves to perfecting every aspect of the machine. Their unwavering commitment to excellence and relentless pursuit of innovation have resulted in a remarkable technological advancement that promises to revolutionize the way Styrofoam is cut and shaped. The styrofoam cutting machine can be seen in **Figure 1**.

Figure 1. CNC2 Axis Based Styrofoam Cutting Machine Using Hot Wire.

The tool designed uses an aluminum profile V slot 240 with a thickness of 2 cm and the dimensions of the machine are 1080 mm long, 330 mm wide and 600 mm high. The type of cutter used is nickel wire with a thickness of 0.3 mm.

This CNC machine operates through a systematic and structured process, as depicted in **Figure 2**. The machine follows a step-by-step sequence to execute its functions effectively and efficiently. Each stage of the process is carefully designed and coordinated to ensure seamless operation and optimal performance. The clear visualization provided in **Figure. 2** offers a comprehensive overview of the machine's workflow, enabling users to understand and navigate its operation with ease.

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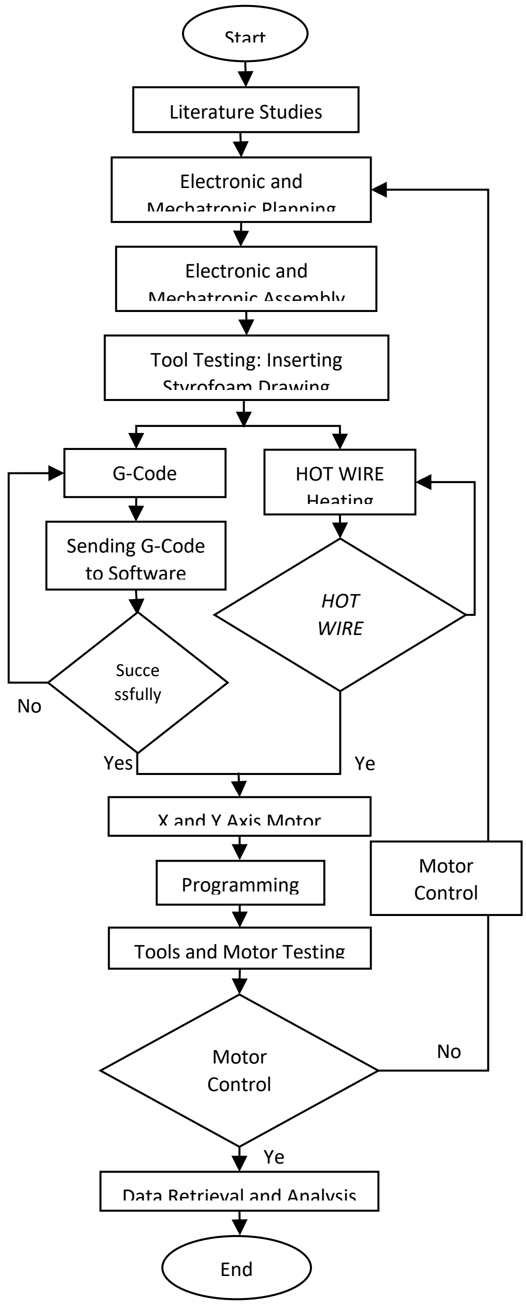

Figure 2. Workflow diagram of 2 axis cnc based styrofoam cutting machine using hot wire.

Based on the flow diagram in **Figure 2.**, the process of operating a 2-axis CNC-based Styrofoam cutting machine using a hot wire begins with conducting a literature study to gather relevant reference sources. This preliminary research phase provides valuable insights and knowledge that inform the subsequent stages of the process. Following the literature study, the mechanical and electronic design process takes place, wherein the intricate details of the machine's components and circuitry are meticulously planned and engineered.

Once the design phase is complete, the mechanical and electronic assembly process ensues, during which the various parts and components are carefully integrated to bring the machine to life.

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Following the mechanical and electronic assembly process, the next step in the operation of the 2-axis CNC-based Styrofoam cutting machine is the design of the Styrofoam image. This involves creating the desired shape or pattern that will be cut out from the Styrofoam material. Once the design process is finalized, the experimental method is implemented.

In the experimental method, the G-Code processing begins by sending the G-Code instructions to the machine's software. This code contains the precise commands that dictate the machine's movements and actions. Simultaneously, the hot wire heating process is initiated to heat the wire to the required temperature for efficient cutting.

If the G-Code is successfully sent and the hot wire heating process achieves the desired temperature, the machine proceeds to the X and Y axis motor control process. This involves precisely controlling the movement of the cutting tool along the X and Y axes to execute the design with accuracy. However, if any issues arise during the G-Code processing or the hot wire heating process, the machine loops back to address and resolve these concerns before proceeding further.

Once the X and Y axis motor control process is successfully completed, the programming process commences. This stage focuses on optimizing the machine's performance by fine-tuning the parameters and instructions to enhance cutting precision and efficiency. Finally, the motor is thoroughly tested to ensure it operates smoothly and effectively, meeting the desired performance standards.

This systematic and iterative process ensures that each step is meticulously executed, and any potential issues are promptly addressed. By adhering to this carefully orchestrated workflow, the CNC-based Styrofoam cutting machine maximizes its capabilities and produces high-quality, precise cuts in line with the intended design.

Figure 2. is a block diagram of a 2 axis CNC-based styrofoam cutting machine using hot wire consisting of input, process and output. Based on the block diagram in **Figure 2.**, the input starts from working on the Styrofoam image design and the G-Code program, then the G-Code processing process is processed on the microcontroller, namely the TB6600 driver for the Nema 17 stepper on the X axis and the TB5660 driver for the Nema 17 stepper on the Y axis.

After the testing of the motor, the microcontroller takes charge of adjusting the DC-DC converter to ensure that the voltage and temperature applied to the hot wire are precisely as intended. This critical adjustment guarantees optimal performance and safety during the styrofoam cutting process.

The microcontroller's role extends further as it generates an output signal that regulates the current flowing through the hot wire. This controlled current, achieved through the DC-DC converter, is then utilized in the styrofoam cutting process. As a result, the hot wire becomes the instrument through which the styrofoam material is expertly shaped and sculpted.

Simultaneously, the Nema 17 stepper motors responsible for controlling the movement along the X and Y axes receive commands from the microcontroller. These precise instructions dictate the motion required to achieve the desired cuts and patterns on the styrofoam material. The synchronized coordination between the microcontroller, DC-DC converter, hot wire, and Nema 17 stepper motors ensures a seamless and efficient cutting process, yielding remarkable results.

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3. RESULTS AND DISCUSSION

In this study, there are results and analysis of the trial system testing of Styrofoam cutting machine based on CNC 2 Axis using Hot Wire:

3.1. X and Y Axis Calibration Settings

Voltage and temperature regulation play a vital role in the CNC-based styrofoam cutting machine, specifically in controlling the temperature of the hot wire. The regulation process involves careful calibration of voltage and current to achieve the precise and optimal temperature required for the styrofoam cutting process. **Table 1.** shows the X-axis calibration process on a NEMA 17 stepper motor.

Table 1. Y Axis Calibration Process.

Y AXIS CALIBRATION PROCESS				
Stepper Motor	**Micro Stepping**	**Pulley Teeth**	**Belt Pitch**	**Result**
Deg/step: 1.8	Pulse/step: 16	Pulley teeth: 16	Pitch: 2	Steps/mm: 100
Steps/rev: 200	Pulse/rev: 3200		mm/rev: 32	mm/step: 0,01

With the number of pulley teeth set at 16 and a belt pitch of 2 pitches, the stepper motor is configured with a default step angle of 1.8 degrees per step and a microstep setting of 16 pulses per step. These specifications are crucial in calibrating the X axis of the machine. Through careful calibration and testing, the results indicate that the machine achieves a precision of 100 steps per millimeter in its X axis movement. Next one, **Table 2.** shows the Y-axis calibration process on a NEMA 17 stepper motor.

Table 2. Y Axis Calibration Process.

Y AXIS CALIBRATION PROCESS				
Stepper Motor	**Micro Stepping**	**Pulley Teeth**	**Belt Pitch**	**Result**
Deg/step: 1.8	Pulse/step: 16	Pulley teeth: 20	Pitch: 2	Steps/mm: 80
Steps/rev: 200	Pulse/rev: 3200		Mm/rev: 40	Mm/step: 0,0125

With the number of pulley teeth as many as 20 teeth and belt pitch as many as 2 pitches, the default condition of the stepper motor is 1.8 deg/step with the number of micro steps as many as 16 pulses/step. Based on the default specifications of the machine components used, the Y-axis calibration results are 80 steps per mm.

3.2. Temperature Variation and Current

Taking hot wire temperature measurement data based on voltage (V) and current (A) on the device using multimeter. **Table 3.** shows the minimum voltage used at 1.3 V obtained hot wire at 27˚C temperature and maximum voltage used is 10.1 V on the grounds. If the voltage is greater than the maximum voltage, it will cause the hot wire (nikelin wire) smoldering which will then cause the cutting results to be less precise and offset will be large so that the measurement error will also increase and the cutting results are not maximum.

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Table 3. Measurement Based on Voltage, Current and Temperature of Hot Wire.

Measurement		
Voltage (V)	**Current (A)**	**Hot Wire Temperature (˚C)**
1,3	0,00	27
2,2	0,00	27
3,1	0,07	31
4,1	0,15	38
5,1	0,23	52
6,1	0,29	76
7,1	0,38	85
8,1	0,47	104
9,1	0,56	170
10,1	0,67	190

3.3. Styrofoam Cutting

Styrofoam cutting is the process of cutting Styrofoam, a type of plastic foam material, into desired shapes and sizes. Styrofoam cutting is typically performed using specialized tools like hot wire cutters or foam cutting saws. Hot wire cutters utilize an electrically heated wire to melt the foam, while foam cutting saws use rotating blades to slice through it. This cutting technique is commonly employed in various applications such as crafting, modeling, and packaging. It enables the creation of intricate shapes and designs, making Styrofoam a popular material for artistic and creative projects. Its lightweight and insulating properties also make it suitable for protective packaging. With the right tools and techniques, Styrofoam cutting offers a range of possibilities for achieving unique and visually appealing results.

Based on **Table 4.** and **Table 5.**, styrofoam measurement dimensions are calculated based on the size contained in the software and the size obtained in the cutting results.

Table 4. Styrofoam Design and Cutting Measurement Result.

<table>
<tr><th colspan="3">Measurement Result</th></tr>
<tr><td>Design (mm)</td><td>

(517 x 57)</td><td>
(39 x 32)</td></tr>
<tr><td>Result (mm)</td><td>

(520 x 60)</td><td>
(35 x 40)</td></tr>
</table>

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Table 5. Styrofoam Design and Cutting Measurement Result.

	Measurement Result	
Design (mm)	 (170 x 108)	 (618 x 103)
Result (mm)	 (140 x 100)	 (630 x 100)

3.4. Styrofoam Cutting

The error values recorded for the X and Y axes are obtained by comparing the dimensions of the styrofoam as measured after the cutting process with the intended dimensions. These error values are influenced by the presence of melt that occurs during the styrofoam cutting process, leading to slight variations in the dimensions along both the X and Y axes. The melt can cause the styrofoam to expand or contract, resulting in dimensional differences between the original design and the final product. By considering and analyzing these error values, adjustments can be made to improve the accuracy and precision of the styrofoam cutting process. Those difference in dimensions produces a percentage of the error value as shown in **Table 6**.

Table 6. Counting Error Values of X Axis.

X Axis Error Value				
Software Dimension (SD) [mm]	**Measurement Results (MR) [mm]**	**Error [mm] (SD - MR)**	**Error % (Error / XSD)**	**Average**
517	520	3	0,5	0,16%
39	35	4	0,10	
170	140	30	0,17	
618	630	12	0,019	
450	470	20	0,04	

Based on **Table 5.**, obtained x-axis accuracy = 100% - 0,16% = 99,84%. In **Table 6.**, obtained Y-axis accuracy = 100% - 0,09% = 99,91%. Error values on the X and Y axes indicate that there is a percentage difference in value between the design in the software and the

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measurement directly. With an accuracy value for the X axis of 99.84% and Y axis accuracy value of 99.91%.

Table 7. Counting Error Values of X Axis.

X Axis Error Value				
Software Dimension (SD) [mm]	**Measurement Results (MR) [mm]**	**Error [mm] (SD - MR)**	**Error % (Error / XSD)**	**Average**
57	60	3	0,05%	0,09%
32	40	8	0,25%	
108	100	8	0,07%	
103	100	3	0,02%	
80	85	5	0,06%	

The x-axis and y-axis accuracy of the machine are exceptionally high, boasting values of 99.84% and 99.91% respectively. These impressive figures signify the machine's ability to generate cuts with a remarkable level of precision and accuracy. The small percentage difference observed between the designed shapes in the software and the actual measurements obtained further reinforces this notion.

The utilization of a CNC (Computer Numerical Control) system plays a pivotal role in achieving such outstanding accuracy. This sophisticated system enables precise and automated control of the cutting process, resulting in consistent and reliable outcomes. The machine's ability to execute intricate designs with minimal deviation speaks volumes about its capability to deliver high-quality cuts.

Upon analyzing the data, it becomes evident that the small differences between the designed shapes and the actual measurements are indicative of the machine's exceptional precision. The average error of 0.09% suggests a slight increase in the measured dimensions compared to the designed shapes. However, this minuscule discrepancy reinforces the overall high level of accuracy achieved.

The error values obtained, with the largest being 0.25%, further emphasize the machine's ability to produce shapes with exceptional accuracy and precision. Even with the presence of minor imprecisions, the machine consistently delivers impressive results, meeting the demands of various cutting applications.

The CNC-based styrofoam cutting machine showcases remarkable accuracy in both the x-axis and y-axis, ensuring cuts of exceptional precision and accuracy. With a small percentage difference between the designed shapes in the software and the actual measurements obtained, the machine consistently delivers high-quality results. The employment of a CNC system further enhances its precision, enabling precise and automated control throughout the cutting process. Overall, this CNC-based machine proves to be a reliable tool, capable of producing intricate and accurate cuts, and meeting the demands of diverse cutting applications.

4. CONCLUSION

In the production of this machine, a series of experimental methods are employed. These methods encompass the movement of the X and Y axes, the delivery and processing of G-Code, and the regulation of heat in the hot wire through precise voltage and current control.

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The complete system, designed and constructed for this CNC-based styrofoam cutting machine, has undergone meticulous design, manufacturing, and testing processes. The machine operates on a 2-axis CNC system, utilizing hot wire technology. The X-axis boasts an impressive accuracy of 99.84%, while the Y-axis achieves an outstanding accuracy of 99.91%.

It is important to note that the dimensional differences observed between the software designs and the actual measurements are directly influenced by the melting process caused by the hot wire cutting.

However, there are certain limitations associated with the current design of the machine. The hot wire is made of nickel-chromium (nickelin) with a diameter of 0.3 mm and can only accommodate a maximum voltage of 12 volts. Higher currents can cause the hot wire to smolder, thus posing a limitation on the machine's performance. Additionally, the dimensions of the styrofoam media used in the machine are restricted to a length of 88 cm, a height of 42 cm, and a maximum thickness of 15 cm. As a result, future development of the machine will require the utilization of a thicker hot wire and the expansion of the working area dimensions.

Overall, the CNC-based styrofoam cutting machine has been successfully designed and constructed, demonstrating impressive accuracy in its cutting capabilities. While there are limitations to be addressed for further advancements, this machine serves as a foundation for future enhancements that can accommodate larger dimensions and more robust hot wire configurations.

5. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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