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CNC MACHINE & MACHINING OPERATION WITH HIGHER RESPONSE RATE, LOW COST, POWER SAVING, AND ERROR COMPENSATION

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Abstract: *Computer Numerical Control (CNC) Machine is rapidly used for machining purposes in industries like aerospace, oil, energy, sophisticated medicines, etc. It utilizes and processes the numerical dataset which is converted into coordinates in order to control the whole machining operation by geometric code (G-code). This is generally called a specific CNC machine language. This paper presents proposed machining operation with a higher response rate, low cost, power-saving and error minimization which reduces real-time error as well as alignment error. For achieving the above-mentioned research outcomes, processing i3 G-code executer is used which gives the higher response rate to send G-code, 9-12 volts are indispensable in order to operate the proposed machine. ATmega 328P, which is an eminent microcontroller with a higher response rate and precision is used for controlling the machine. This paper also illustrates machining operation including changing the machine's speed, increasing the execution speed of G-code and many more. For accomplishing the Industry 4.0 revolution it is pivotal to reduce manufacturing cost and time as well as to enhance productivity.*

Key words: G-code, operation, numerical value, response rate

1.INTRODUCTION

Computer Numerical Control machine is rapidly used in the automation industry. The first generation of CNC machines is popularly known as Numerical Control (NC) machine [1]. NC machine was developed in 1952 [1]. Then the development of computers, the term CNC is introduced for many machining purposes [2]. It takes numerical data and converts it into G-code. G-code is known as CNC machine language. It is the automatic control of machine tools which is fully controlled by a computer. There is a set of instructions. Instructions are delivered to the micro-controller unit and then the micro-controller processes the whole machining operation. Motion is controlling multiple axis. Here three-axis is used. It is also known as programmable automation. Nowadays it is used in the automobile industry as well as the aerospace industry and machining industry. CNC machines can be used 24 hours and can be updated by improving the software setup. The main challenge is that it would have high flexibility, fast mobility [3]. Modern production is based on automation and mechatronics. The proposed CNC machine with a higher response rate, Low cost, power saving, and error compensation is also based on automation. This CNC machine has a specialized function which gives it a higher response rate, Low cost and many more. The objective is to achieve industry 4.0 revolution. In Industry 4.0 all manufacturing system is automated with wireless connectivity. One can visualize the entire system by controlling the operation. Industry 4.0 revolution is combining of Internet of Things (IoT), Industrial Internet of Things (IIoT), cloud computing as well as artificial intelligence [9]. To achieve the Industry 4.0 revolution, it is necessary to reduce manufacturing cost and time as well as enhancing productivity. CNC machine with a higher response rate, Low cost, power saving, and error compensation will occupy this affiliate.

2. METHODOLOGY

Generally, two types of control systems are used. One is the open-loop control system and another is the closed-loop control system. A feedback system is used in a closed-loop control system. The feedback device measures the output of the system. This CNC machine and the operation of the machine is controlled by the open-loop control system. The open-loop control system has some advantages. It is simple, low cost, and good reliability [1]. As the machine needs constant output so the open-loop control system is used.

In the content of the CNC machine, it can be divided into three segments. Mechanical sides, Software sides, and Electronic sides.

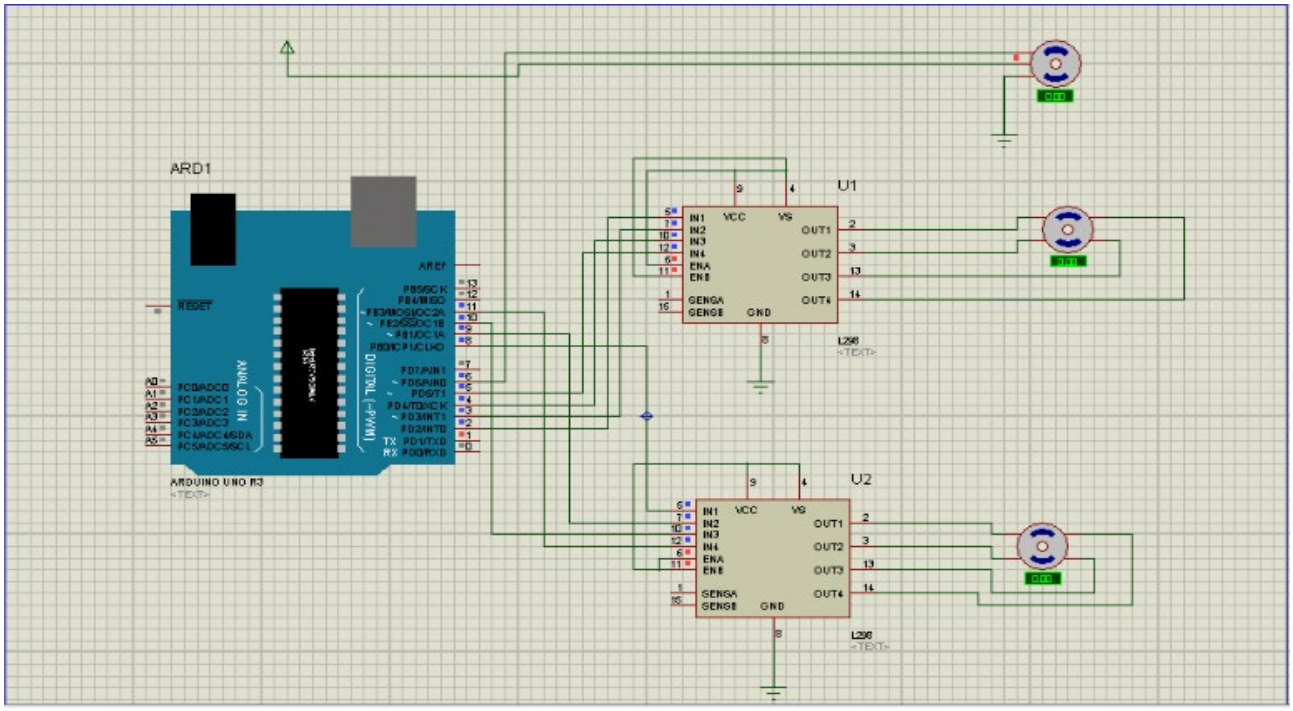

Figure 1: Schematic design of this device using Arduino (ATmega 328P)

ATmega328P is used to control the device as this is the eminent micro-controller and this micro-controller is embedded in the Arduino Uno board. The stepper motor is used for the movement of the linear axis *(X-Y* axis) and the servo motor is used for the movement of the Z-axis. Here 2 phase 4 wire stepper motor is used for linear motion which has 63mm effective stroke, 1.8-degree step angle. Its output voltage is 12V DC. Servo motor is for angular movement which has 2.5 kg-cm torque. It operates between 4.8-6V. Arduino (ATmega328P) Uno board is ready to send a set of instructions for controlling the operation. L293D motor control device is used for controlling the movement of these three axis. To run this project, motor drivers with a 12V DC power supply is connected. Here four ground pins are connected with ground. Then output pins will be connected with the stepper motor. There are four output pins of each motor driver. Then input pins are connected with Arduino, as Arduino used as a micro-controller of this project. Lastly, the servo motor is connected with a 5V DC power supply. The analog pin of the servo motor is connected to Arduino digital pin 6.

The same job is done for another motor driver and another stepper motor. After completing the connection of these elements (i.e two motor driver and a servo motor), the device is ready to connect with the 12V DC power supply.

The schematic design of this device is shown in Figure 1.

3 MACHINING OPERATION

Specialized software is used for controlling this operation. There is several software to operate this machine. Processing i3 g-code executer is used to operate this machine. First of all, a vector graphics software Inkscape is used to make the design and then convert the design into g-code with the extension of gcode. Processing i3 g-code executer is based on Java language. It is an integrated development environment (IDE) and open-source computer programming language. There are some set of instructions in the key-event. It focuses on the frame applet panel. When 'P' is pressed it select the serial port that corresponds to the micro-controller (Arduino) board.

3.1 G-Code

G-code means geometric code. It is popularly known as the CNC machine's language. It controls the whole machining operation of this device. It is also known as text files with the extension of .g or .gcode. A text editor, for example, Notepad is used in order to visualize gcode. Most of the commands start with the letter 'G'. Some examples of G-codes are G90-Absolute programming, G00-Rapid movement, G01-Linear movement, G02-Clockwise rotation, G03-Counterclockwise rotation, G71-metric selection, G-40-position cancel. Here M code is also used. Some examples of M code are M03 means spindle movement on clockwise, M00-program stop, M04-spindle on counterclockwise, M05-spindle stop, M30-return to start. F3500-Feed is millimeter per minute. For example, a rapid move to (48,9)

G00 X48.00 Y9.00 F8000.00

Here F8000.00 means feed with a speed of 8000 mm/minute. The value of XY is the function of co-ordinates. A semi-colon (;) is the way to comment G-code. The whole machining operation can be visualized by using a flow chart. A visual representation of the machining operation is shown in Figure 2.

4 RESULTS AND DISCUSSION

The proposed prototype of this CNC machine with higher response rate, Low cost, power saving, and error compensation is shown in Figure 3.

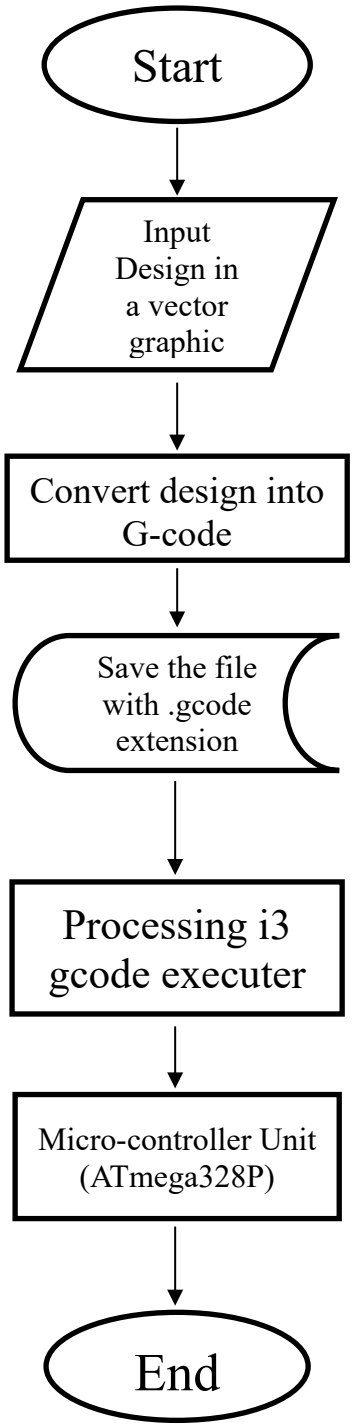

Figure 2: Flowchart of the machining operation

4.1 Response Rate

The response of any system isn't instantaneous [2]. When a system is started to run, it takes time for the output. It varies with time. All devices or machines can't give the same response rate. There are several micro-controllers in ATmega series like ATmega48P, ATmega88P, ATmega168P, and ATmega328P. Among these micro-controllers, ATmega328P gives a higher response rate. Table 1 shows the difference of micro-controllers based on EEPROM, RAM and Flash memory.

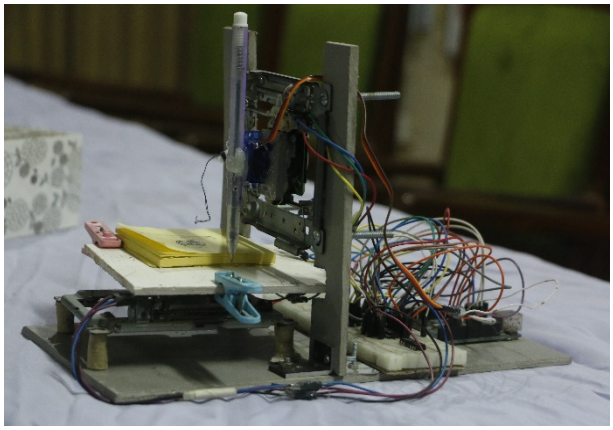

Figure 3: proposed prototype of CNC machine

After analyzing the memory size, Interrupt Vector Size, EEPROM, Flash memory, then come to know a clear concept that ATmega328P is the best option for memory response.

ATmega328P uses PWM signals which means Pulse width modulation. Compared to the other kind of modulation PWM gives a higher response rate. L293D has many specifications that prove that it is the best option for controlling a CNC machine. For inductive transient suppression, it uses external high-speed output clamp diodes [8]. It has high noise reduction capability.

Table 1: Difference of micro-controllers

Device	EEPROM	RAM	FLASH
ATmega48P	256 Bytes	512 Bytes	4K Bytes
ATmega88P	512 Bytes	1K Bytes	8K Bytes
ATmega168P	512 Bytes	1K Bytes	16K Bytes
ATmega328P	1K Bytes	2K Bytes	32K Bytes

4.2 Cost Analysis

All the components are listed below is available at low cost and also available in the domestic market. The price list of the components used in this project is shown in table 2.

Table 2: Price list of components

Component	Price (BDT)	Availability
PC or Laptop	22K	Available in market
ATmega328P (Arduino board)	325.54	Available in market
L293D IC	2*90	Available in market
2 phase 4-wire stepper motor	2*580.00	Available in market
Servo motor	145.29	Available in market
Power supply	650.05	Available in market

others	195.32	Available in market
Total Cost	24656.2	

4.3 Power Consumption

Increase consumption of power may be a threat to energy maintenance. Industries should reduce energy consumption. All the components listed below are operating at 12V maximum. So, the machining operation of this CNC machine saves power consumption

Table 3; power Consumption

Device/ Ratings	ATmega328P (Arduino board)	L293D IC	Stepper Motor (2 Phase 4-wire)	Servo motor
Operating voltage	5V	12V	12V	5V
Voltage range	5-6V	4-36V	9-12V	4.8-6V
Current ratings	I/O Pin: 0.04 A Vcc & GND Pin: 0.2 A	1.2 A	0.6 A	0.7 A

4.4 Error Compensation

Error is the difference between a measured value and true value. Sometimes it is impossible to made measurement with perfect accuracy. Error compensation of any machining operation is a very critical consideration [2]. Some primary tests were conducted by this proposed prototype CNC machine. From the test, absolute error is obtained. The following information shows absolute error.

W 1.42

H 1.44

After operating W 1.34 & H 1.35

Absolute error (W) = |1.42-1.34|=0.08 unit

Absolute error (H) = |1.44-1.35|=0.09 unit

Here error is minimized than the rest of the CNC machine. PID controller can be proposed for error elimination. A feedback device is needed for this operation. Steady-state error can be calculated by these formulae and then be eliminated.

$E(\infty)= \frac{1}{1+\lim G(s)} = \frac{1}{1+Kp}$; kp is the position constant(1) [1]

$E(\infty)= \frac{1}{\lim G(s)} = \frac{1}{Kv}$; Kv is the velocity constant… (2) [1]

$E(\infty)= \frac{1}{\lim s2G(s)} = \frac{1}{Ka}$;Ka is the acceleration constant…..(3) [1]

Thus steady-state error can be eliminated. Offset error, as well as real-time error, alignment error and the tendency for oscillations can be reduced by combining all three modes (Proportional, Integral, and differential) of PID control. The equation can be written as

$I_{out} = K_p{}^e + K_I \int edt + K_D \frac{de}{dt} + I_o$ … … … … … …(4) [1]

Here, I_{out} is the output from the controller when there is an error moving with time t [1]. I_o is the setpoint output when there is no error [1]. K_p, K_I, K_D are the proportional, Integral and Derivative constant.

A simulation result of this CNC machine is shown in Figure 4 which is actually the map of Bangladesh. Here CAMotics (It simulates 3 axis G-code program for CNC machining operation and then shows the result in 3D) is used for simulating the result. After analyzing the simulation result it could be said that this CNC machine has higher accuracy over the rest.

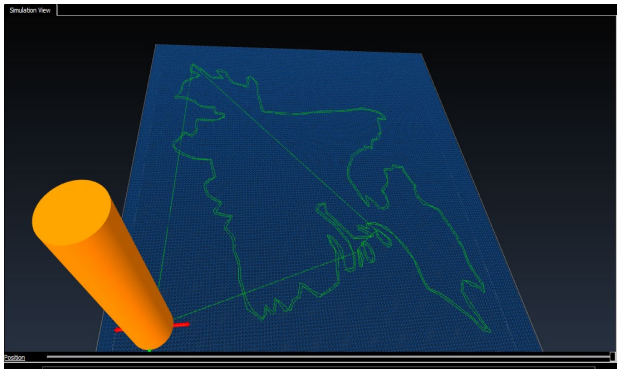

Figure 4: User interface of CAMotics and the simulation result of CNC G-code program.

4.5 Comparative Study

In literature [10], for error compensation technique, they proposed a temperature sensor with a magnetic mount that eliminated placement error. In literature [2], they proposed a geometric/kinematic error modeling technique. But this paper proposed a PID control technique that has a higher response rate, accurate setpoint, fast reaction to disturbance and many more. After analyzing the error minimization technique, it could be said that PID control is the best option for this affiliate.

In literature [3], the total cost is 5000000 IDR (Indonesian Rupiah) or 29702.09 BDT. But in this paper, the total cost is about 24656.2 BDT. After analyzing the value of cost, it could be said that this CNC machine can be affordable at low cost.

Normally CNC machines are operating at 220V/230V AC 1 Phase or 380V/400V/415V AC 3 Phase output voltages. In literature [11], the output voltage was supplied by the power grid with the rated voltage of 230V. Here, effective value fluctuated between 228V – 248V [11]. This CNC machine operates at a maximum of 12V DC output voltages. The current ratings of Input/output pins are 0.04A. Here the consumption of operating voltage is lower than literature [11]. Thus, it saves the consumption of power. The comparative study of error compensation technique, power consumption, and cost analysis are shown in table 4.

Table 4: Comparative study or analysis

Reference	Error Compensation Technique	Power Analysis	Cost Analysis
[2]	Geometric/ Kinematic error modeling technique	–	–
[3]	–	–	5000000 IDR or 29702.09 BDT
[10]	Temperature sensor with a magnetic mount technique	–	–
[11]	–	O/V:230V	–
Proposed	PID Control Technique	O/V: 12V DC	24656.2 BDT

5. CONCLUSION

CNC machine plays a significant role in the machining industry. By increasing the number of CNC machines in the manufacturing industry, the quality, as well as productivity, will be augmented. In addition, the CNC machine contributes to performing complex machining operations easily. This paper illustrates the machining operation with the core themes like response rate, error elimination, power consumption, and cost-effectiveness. According to this paper, it is said that this CNC machine can be considered as better response rate, power saving, cost-effective technology. This machining operation can be improved by using the batch file. The batch file is a script command file. Command will be given to the PC one time and the machining operation will be performing sequentially and automatically.

6. REFERENCES

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7. NOMENCLATURE

Symbol	Meaning	Unit
W	Wide	(mm)
H	Height	(mm)
∞	Infinity sign	Dimensionless
$\int$	Integration sign	Dimensionless
A	Ampere	-
V	Volt	-
K	Thousand	-