Design and Implementation of Microcontroller Based Stepper Motor Control System for 3-Axis Airfoil Maker CNC Machine

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Abstract- This paper emphasizes design and implementation of 3 Axis Airfoil Maker Machine using Arduino microcontroller based on computerized numerical controller (CNC) machine. In this work, there are two main points that are design and construction of machine and programming the motor control algorithm. The size of machine is portable and desktop version. This machine requires three stepper motors to move X, Y and Z directions according the command instructions from PC based CAM software. When the desired airfoil coordinates are inputted to CAM software, the output G-code are produced and then, this codes are sent to microcontroller by using USB interface. Microcontroller decodes these commands to drive stepper motors. The movement control program is written on C programming. This program will determine how many rotations that cause the distance of the machine movement according to each axis. The main aim of this research is to produce the precision airfoil as a part of wing model which is used to radio controlled (RC) airplane. It eventually reduces time consume and rate of error and also increase the accuracy of shape of airfoil production.

Keywords: CNC Machine, Airfoil, C programming, Microcontroller, CAM software, G-code, Stepper Motor

I. INTRODUCTION

CNC machine is a process used in the manufacturing sector that involves the use of computers to control machine tools. Tools that can be controlled in this manner include lathes, mills, routers and grinders. The CNC stands for Computer Numerical Control. CNC operates on digitized data, a computer. CAM program is used to control, automate, and monitor the movements of a machine. The CNC controller works together with a series of motors and drive components to move and control the machine axes. Open source software is used for executing the G-code for machining applications. The development of such machines can be considerable on a smaller, low-cost scale. A simpler commercial size CNC with Mach 3 software on a desktop PC have been developed, but requiring a parallel port. The PC is interfaced with low-cost embedded microcontrollers through the serial port. The CNC machine designs above rely on the use of stepper motors of limited power in open loop mode. A major new development in computer technology is the availability of low-cost open source hardware, such as the Arduino microcontroller platform. For many reasons, Arduino microcontroller based stepper motor control system has been chosen open source software and optimized for 3-axis airfoil maker CNC machine. Figure 1 shows overall block diagram of 3-axis airfoil maker CNC machine.

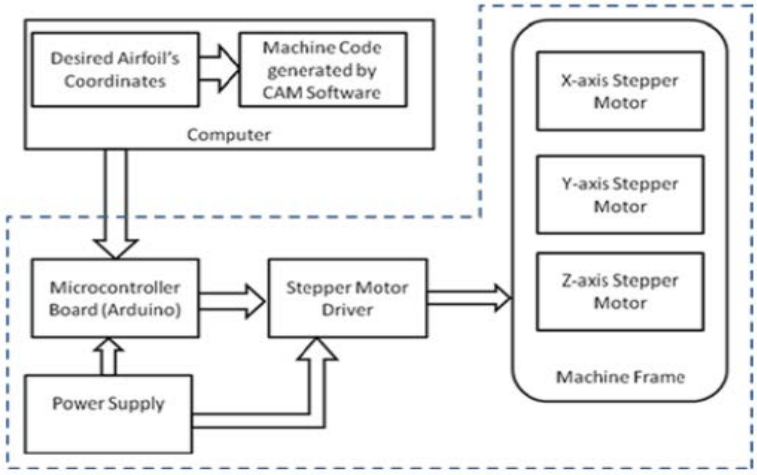

Figure 1. Overall Block Diagram of 3-axis Airfoil Maker CNC Machine

II. METHODOLOGY

A. AIRFOIL NOMENCLATURE

A wing is the combination of airfoil shaped ribs. Lift force produced by wings are depended on the design of airfoil shape .Two other outputs of the airfoil are drug and pitching moment. Figure 2 shows the combinations of airfoils for wing.

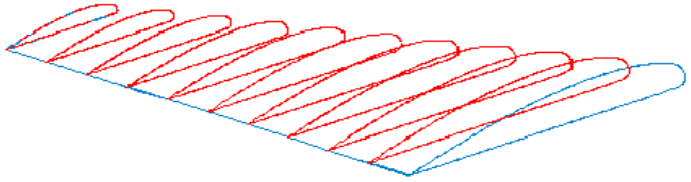

Figure 2. Combination of Airfoils for Wing

As shown in Figure 3, the following parameters are defined in an airfoil.

Chord length: length from the leading edge (LE) to the trailing edge (TE) of a wing cross section that is parallel to the vertical axis of symmetry

Mean camber line: line halfway between the upper and lower surfaces

Camber: maximum distance between the mean camber line and the chord line, measured perpendicular to the chord line

Thickness: distance between upper surface and lower surface measured perpendicular to the mean camber line.

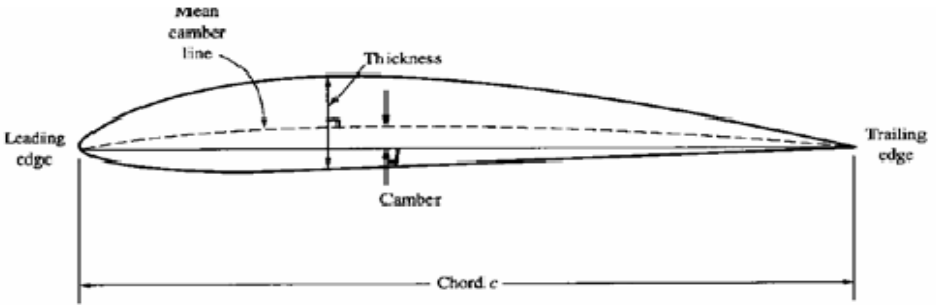

Figure 3. Airfoil Nomenclature

B. Types of Airfoils

There are four different types of airfoil. They are

(a) Symmetrical Airfoil: It is used for aerobatics airplane, particularly monoplanes.

(b) Semi-Symmetrical Airfoil: It is used for secondary trainers , sailplanes and sport aerobatic biplanes.

(c) Flat-Bottom Airfoil: It is used for gentle flight

(d) Under-Cambered Airfoil: It is used for scale models, sailplanes and some high-lift situations

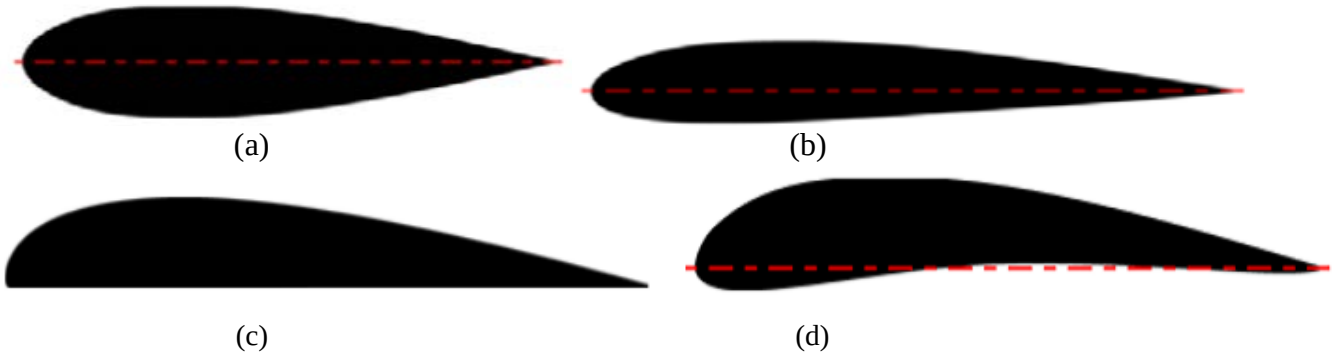

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Figure 4. Types of Airfoil: (a) Symmetrical Airfoil, (b)Semi Symmetrical Airfoil, (c) Flat-Bottom Airfoil, (d) Under-Cambered Airfoil

D.Airfoil Selection

In this paper,NACA 1408 (4-digit) Semi-Symmetrical airfoil series is selected. First number is camber in percentage of chord, second number is location of maximum camber in tenths of chord measured from leading edge (LE) last two digits give maximum thickness in percentage of chord.

E. Airfoil Coordinates

Airfoil coordinates are simply points that define the shape of the airfoil. The numbers are given in percentage of the wing chord. The airfoil can be made up from 50 to 100 coordinate pairs. Figure 5 shows the NACA 1408nAirfoil Coordinates and Figure 6 show s the plotting the NACA 1408 Airfoil Coordinates.

X	Y upper	Y lower
1	0.00028	-0.0004027
0.9914866	0.00062857	-0.0004466
0.9662362	0.00167121	-0.000942
0.9251087	0.00330651	-0.0017283
0.8695046	0.00533514	-0.002745
0.8013175	0.00727837	-0.0039473
0.7228695	0.01001957	-0.0052889
0.6368319	0.01226593	-0.006643
0.5461347	0.01420668	-0.0079618
0.4538664	0.01563766	-0.0090424
0.3631692	0.01644857	-0.0098535
0.2771316	0.01633461	-0.0102909
0.1986835	0.01523939	-0.0102157
0.1304965	0.0132667	-0.0095475
0.0748924	0.0106489	-0.0080837
0.0337649	0.00721173	-0.005995
0.0085145	0.00363826	-0.0031349
0	-4.034E-05	-4.034E-05

Figure 5.NACA 1408 Airfoil Coordinates

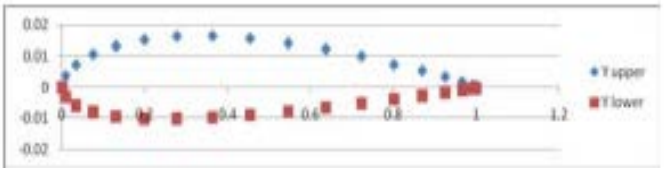

Figure 6. Plotting the NACA 1408 Airfoil Coordinates

F. G-code for NACA 1408 Airfoil

G-Code is the language used to describe how a machine will move to accomplish a given task, using numerical control (NC) - it is the most widely used NC programming language. Figure7 show the g-code for NACA 1408 generated from KCAM software.

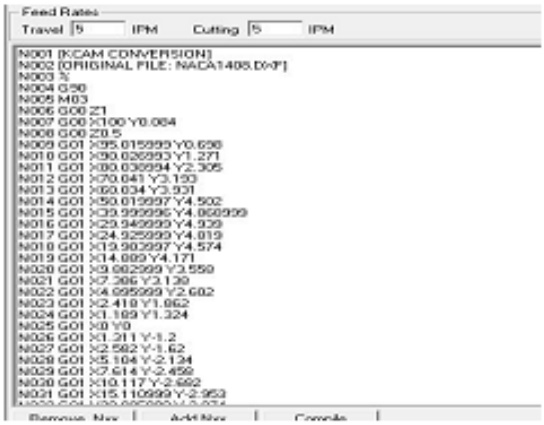

Figure 7. G-code for NACA 1408 generated from KCAM software

G.System-Elements

In the control circuit for 3-axis airfoil maker CNC machine, it consists of microcontroller (Arduino ATmega 2560), easy driver circuit, L298N driver circuit and NEMA 17 stepper motors. The arduino is an open source electronics prototyping platform based on flexible, easy to use hardware and software. Arduino is best known for its hardware, but it is also needed software to developed program required for that hardware. The software is free, open source and cross platform. For this research, it is use Arduino MEGA microcontroller board based on ATmega2560 is used because it board has many digital output pin and storage memory than other Arduino board. Stepper motor have bipolar and unipolar stepper motor. Bipolar stepper motor is better holding torque than unipolar stepper motor. NEMA 17 stepper motor is bipolar. NEMA 17 is common size used in 3D printers and smaller CNC mills. Smaller motors find applications in many robotic and animatronic applications. NEMA 17 stepper motor has maximum torque at low speed , good choice for application requiring low speed with high precision. Easy driver circuit is used to drive stepper motor. Easy driver can drive up to about 720mA per phase of a bipolar stepper motor. It defaults to 8 steps microstepping mode. It is a chopper micro stepping driver based on the Allegro A3967 driver chip. It can take a maximum motor driver voltage of around 30V and includes on board 5V regulation. Figure 10 show the easy driver circuit. L298N driver circuit can be drive inductive loads such as relays, solenoids, dc and bipolar stepping motor. This circuit offers a bridged mode of operation allowing bidirectional control of a single motor of up to about 4A.

III.DESIGN CONSIDERATION AND EEPERIMENTAL RESULTS

A. Designed and Construction of Control Circuit Board of Stepper Motor Control System

In this research , Arduino Microcontroller platform with Atmega2560 core is used. It can be easily interfaced with PC where, as also with the motor drivers(Easy and L298N) and stepper motors too. Figure 8 shows circuit connection of 3-axis airfoil maker CNC machine.

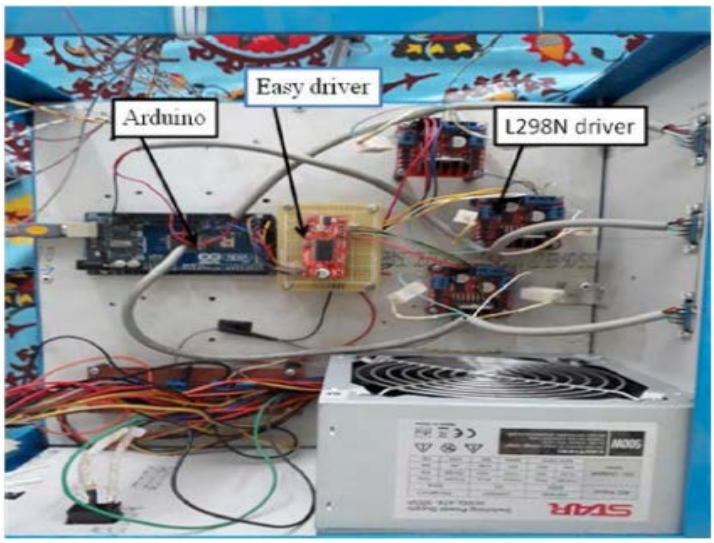

Figure 8. Circuit Connection of 3 –Axis Airfoil Maker CNC Machine

In this circuit, it is designed for needing Ampere(A).
For One Stepper Motor : 3.3V , 1.5A
Required for 12V Stepper Motor : 12V , 5.45A
Easy Driver Load Current : 1.5A
L298 Driver Load Current : 4 A
Total Easy and L298 Driver Load Current : 5.5 A

B. Hardware Machine Frame Requirements

The machine frame is designed and constructed as the following desired parameters shown in Table 1. Figure 9 shows the machine frame.

TABLE 1: Machine Frame Requirement

No:	Components of machine frame	Desired Length/number
1	3/4″GI square pipe	19 feet
2	1/2″ GI square pipe	10 feet
3	6000 2RS-Ball bearing	26 Nos

4	L-bean	3 feet
5	14mm bolt and nuts	38 Nos
6	screw	12 Nos
7	3mm bolt and nuts	24 Nos
8	1/2″ACME thread rod	4.5 feet
9	1/2″nut	3 Nos
10	2″ x 1″ wood	1 feet 7 inches
11	1′ x 1.5″wood board	1 Nos
12	12″ slide ray	1 Nos
13	rivet	8 Nos

Figure 9. Machine Frame

Figure 10 shows the final assembly of machine frame, stepper motor and motor control circuit.

Figure 10. Final Assembly Of Machine Frame, Stepper Motor And Motor Control Circuit

C. Software Implementation

Figure 11 shows the flow chart of application execution. At start, power supply and computer is turned on. After that all stepper motor are initialized to its zero position. This zero position is given through software. The circuit board is ready to accept instructions from computer. These instructions are in the form of G-codes. It will wait still instructions to be received. After instructions are received, it starts to decode it into its own language that is in the voltage and current form. As per instruction, stepper motor move in accordance with it. The stepper motor moves according to X-Y Co-ordinates and Z Co-ordinate stepper motor is used to drill the hole.
When task is completed, it is the end of the flow of execution.

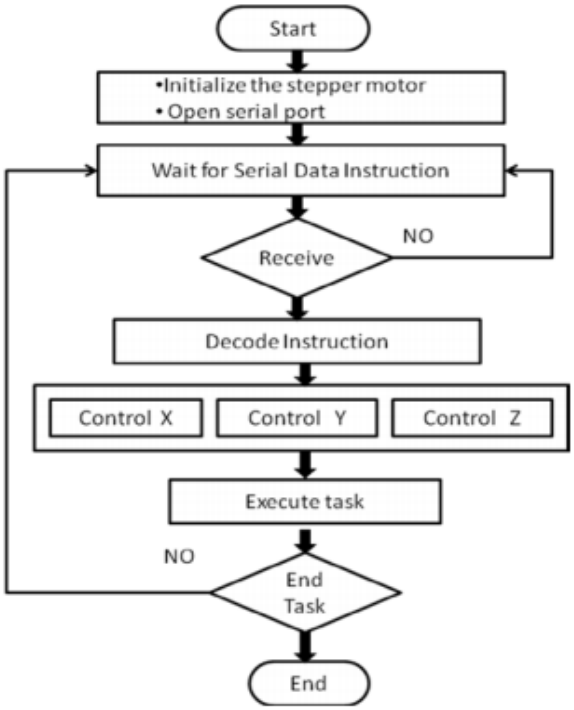

Figure 11. Flow Chart of Stepper Motor Control System

D. Arduino Program for Motor Control System

As the first step, the Arduino C program to develop source code compiled using Arduino software. After the software is compiled, it is upload to the control board. This program drives bipolar stepper motor. The motor is attached to digital pin 8 to 11 of the Arduino. The motor should revolve one revolution in one direction, then one revolution in the other direction. The motor will step one step at a time, very slowly. The higher the potentiometer value, the faster the motor speed. The motor is less responsive to changes in the sensor value at low speeds. Figure 12 shows the motor control program on Arduino and Figure 13 shows the experimental testing of the three stepper motors with motor control program.

Figure 12. Motor Control Program on Arduino

Figure 13. Experimental Testing of the three Stepper Motors

E. Generation of G-code Required for Airfoil Coordinates

This is used to send the G-code files (**.NC**) to an integrated hardware interpreter (ATmega2560).This software will take a G-code program in file and send it line-by-line to the ATmega 2560 microcontroller. The G codes will send over the serial ports through USB communication between the computer and microcontroller**.** KCAM software is a type of software designed to send G-Code to CNC machines. Figure 14 shows the using KCAM software for airfoil coordinates and G code.

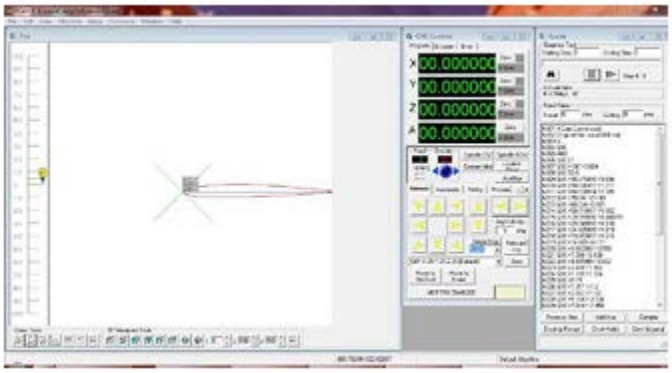

Figure 14. Using KCAM Software for Airfol Coordinates and G-code

F. Experimental Results

According to X-Y axis co-ordinate position the CNC Router will be moved and whenever it stops then starts the operation of Z axis. Z axis performs Up-down operation for milling purpose. Figure 15 shows the final results product of NACA 1408 Airfoil Model.

Figure 15 . Final Product of NACA 1408 Airfoil Model

IV CONCLUSIONS

Using small machine tools to fabricate small scale parts can provide both flexibility and efficiency in manufacturing approaches and reduce capital cost, which is beneficial for small business. In this research paper, Arduino based 3-axis

airfoil maker CNC machine is designed and implemented under very limited budget. From this research, a machine can be achieved which has high accuracy and low cost as compared to large CNC machine. The type of workpiece has to choose wood as a sample for airfoil. The running time for this wood is expected in approximately 10minutes. Airfoil operated by Arduino based control system has been produced as the correct plotting coordinates for NACA 1408 airfoil model.

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