Preliminary Development of Concrete 3D Printing Machine Controller Based on Mach3 Control Board

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Abstract: The implementation of 3D printing concept for civil buildings significantly affects construction time, cost, and design flexibility. This paper proposed the configuration of a concrete 3D printing controller using PC-based and March 3 6 to control the X-Y-Z axis movement, sense the axis travel limit, and concrete nozzle feeder. The component configuration of object study 3D printing use five MCDLT35SF as servo motor driver of the X-Y-Z axis, five Panasonic AC servo motor as X-Y-Z axis actuator, one Nema motor stepper as an extruder, eight limit switches as axis travel limit. The parameter configuration value has been determined referring to the properties of actuator and sensor installed. Those parameters setting is slaving axis, port address, kernel speed, and In-out pin setting. Slaving axis method is used to accommodate the axis that needs two actuator motors, such as on X-axis and Y-axis machine. The proposed controller configuration was verified experimentally, all actuators and travel limits could respond as a command.

1 INTRODUCTION

Additive Manufacturing (AM) can be the focus of industry and government investment or can even be used to make objects or components in everyday life (Gibson, 2015).

One of the additive manufacturing technologies is the 3D Printing Machine for Buildings. 3D printing is a manufacturing activity that produces 3-dimensional objects or products from a design program. The printer will read the program design file and print layer by layer made of geopolymer mortar until the entire object is reached. The advantage of this machine is that it can make buildings automatically and quickly (Nithesh, 2018). The working principle of 3D Printing for buildings is to print one layer to the next according to the height, length, and height of the 3D object design according to the program specified.

Computer-based control is a development of analog control in the past. Computer-based control can provide input directly to the driving tool, besides that this control can also receive input signals from the correction tool used. One of the computer-based controls is the Mach3 Novusun 6 Axis. This device has the advantage of having 6-axis ports, and ease of setting the parameters, besides that this device is specifically designed for the use of CNC (Computer Numeric Control). Its device is supported by Cura as CAM software in the 3D printing process. Where the G-code 3D printing that comes out on the Cura software has been adjusted to the G-Code on this device. With these advantages, Mach3 Novusun 6 Axis was chosen as the control device for concrete 3D printing machine.

Several researchers have studied Mach 3 implementation as machine controller. Gonzale developed CNC milling using March 3 and PLC S71200 for controlling the three-axis movement of CNC milling (Meza, 2018). Boral state implementation of the Mach3 and the Smoothstepper

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controller is very effective and allows achieving the high rotational speeds of motors without losing steps (Boral, 2019). Alvares explained using Mach 3-Matlab for retrofitting the industrial robot ASEA IRB2-S6 (Alfares ,2017).

The aim of this research is to configure the controller for concrete 3D printing machine using March 3 control board and to ensure the performance of device control runs properly and appropriately. Hence, it is necessary to determine the appropriate parameters.

2 METHOD AND RESULT

Developing the controller configuration for a concrete 3D printing machine has several stages: identification of the certain input-output component of machine, determination of wiring component system, identification of detail component as pin number and its function, determination of value for each parameter set, and verification of the system functionality. Figure 1 shows the stages of the development study to configure and determine the parameter setting of the concrete 3D printing machines.

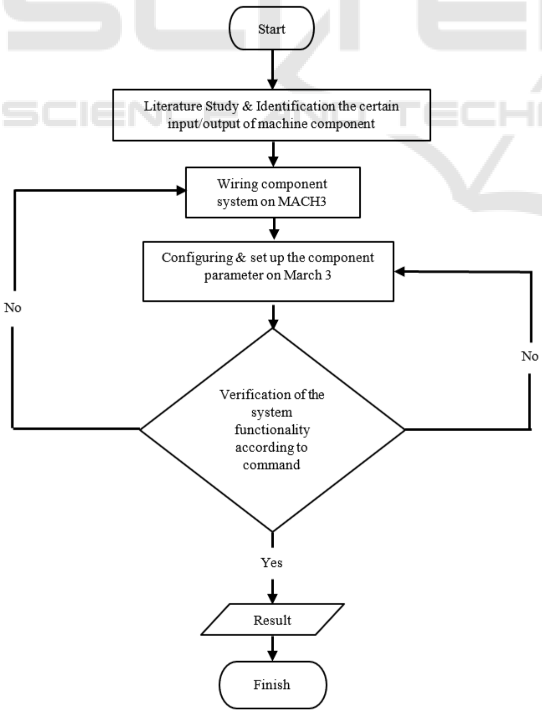

Figure 1: Development study to configure and determine the parameter setting of concrete 3D printing machine.

The certain input-output component of concrete 3D printing has three axes movement actuator (X-Y-Z axes), one nozzle actuator as feeder concrete, and several limit switch sensors and others.

Figure 2 shows the wiring diagram of concrete 3D printing machine. Mach3 control board is connected to PC (Personal Computer), power supply, limit switch of each axis, and servo motor driver. Determination of the relation between components system could be seen on wiring diagram.

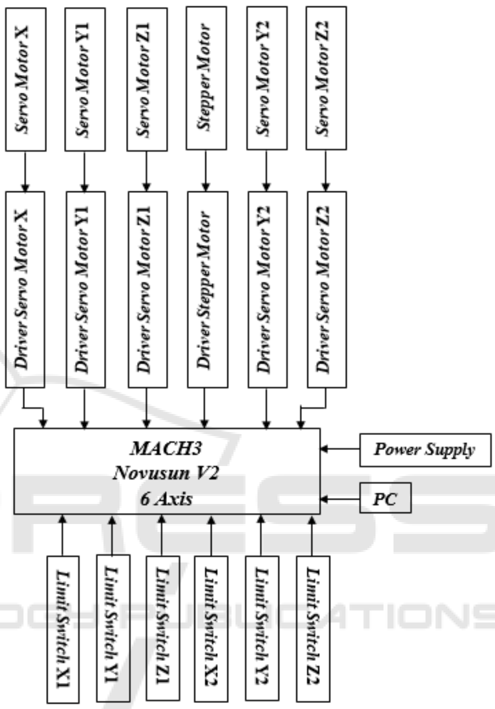

Figure 2: Wiring diagram of concrete 3D printing machine.

MACH 3 is designed to control machine tools such as lathes, plasma cutting machines, and 3D printers (Gorman, 2017). MACH3 mostly works on PCs with windows operating systems to control the movement of stepper motors and servo motors by processing G-code data. Mach3 software display is seen in Figure 3.

Several parameters on the MARCH 3 breakout board system should be set up such as unit, port address, slaving unit, kernel speed, input and output pin, and motor tuning. Figure 4 shows the setting stages of MARCH 3 parameters.

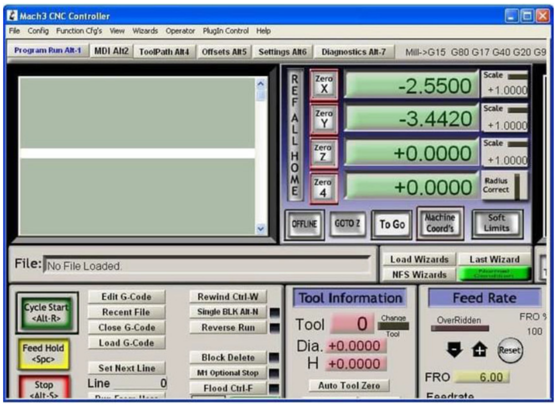

Figure 3: March 3 software display (ArtSoft, 2008).

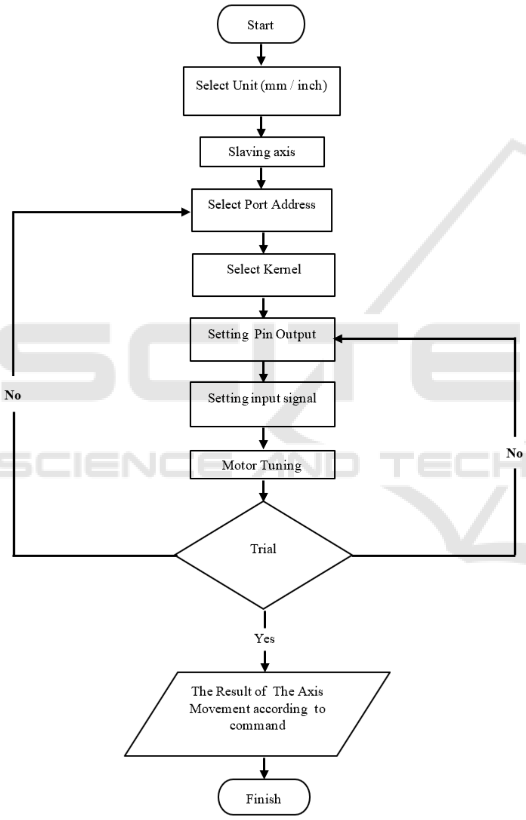

Figure 4: Setup March 3 parameter.

The control system uses Novusun 6 Axis Mach3 BOB as the controller. It is connected to 5 MCDLT35SF servo motor drivers (X, Y, Z, B, and C axis), 1 TB6600 stepper motor driver (A axis), 5 Panasonic AC Servo Motors 750W (X, Y, Z, B, and C axis), 1 Nema 34 Stepper Motor (A axis), 8 Limit Switches, and 24V Power Supply. Figure 5 is illustrated the March 3 wiring diagram for 3D printing.

The main menu of Mach 3 has a "config" menu which has a "Select Native Unit" sub-menu. The menu is provided to determine the standard unit of measure to be used. In this feature there are two units, namely mm and inch (ArtSoft, 2008). The features of the native unit can be seen in Figure 6.

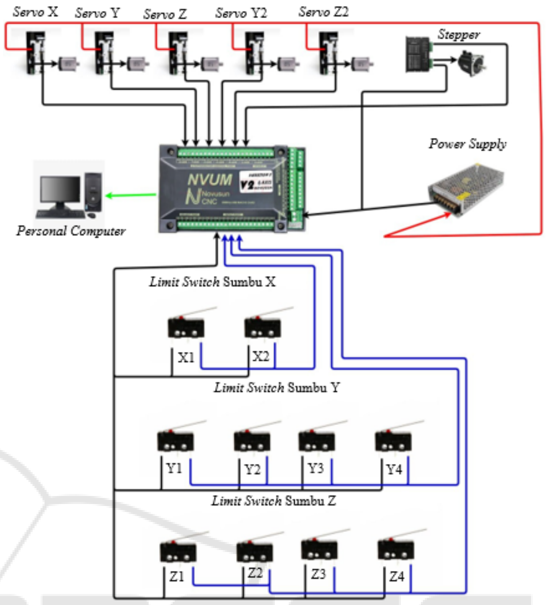

Figure 5: Wiring diagram March 3.

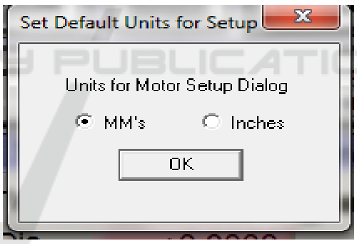

Figure 6. Native unit setting.

The axis of large machines often requires two actuator motors installed on each side of axis slider. It could use the Config>Slave Axis dialog to configure Mach 3, hence one axis movement (ex. X-axis) is the main motor and supports another motor (perhaps the C axis is configured as linear rather than rotary) (ArtSoft, 2008). The parameter setting is shown in Figure 7.

The port address on March 3 is set with a value of the parallel port address of the PC author. If the PC author has a parallel port address of 0x378, hence the port address should be set to 0x378 as shown in Figure 8.

Figure 7: Slaving axis unit setting.

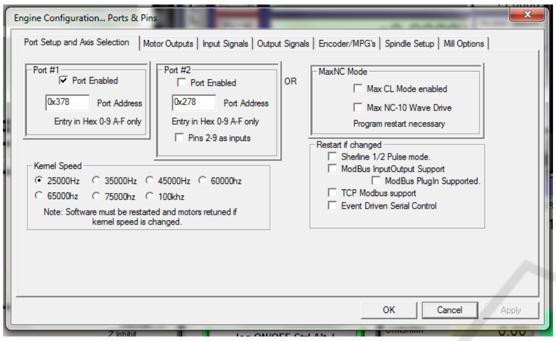

Figure 8: Port address setting.

Kernel speed is the speed parameter of the signal number that is sent from the computer to the Mach 3 BOB. It is adjusted to the capacity of our computer processor [3]. This setting can be seen in Figure 9.

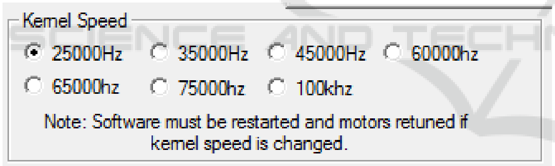

Figure 9: Kernel speed setting.

Determine where the motors for your X, Y, and Z axes are connected, and click in the Enabled column to get a checkmark to enable these axes. If any axes are enabled that are not supposed to be, click on the Enabled column to change the green tick to a red "X" [3]. The output motor pin settings that the author did can be seen in Figure 10.

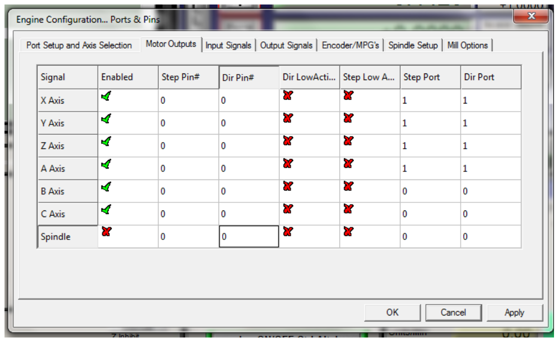

Figure 10: Pin-out motor setting.

The input signal will provide an input signal to the Mach 3 program. Pin numbering refers to the port address used. In the author's trial, the author uses a limit switch as a sensor for the limit of the axis movement and the Push Button Emergency Stop as an emergency switch. The input signal settings that the author made can be seen in Figure 11.

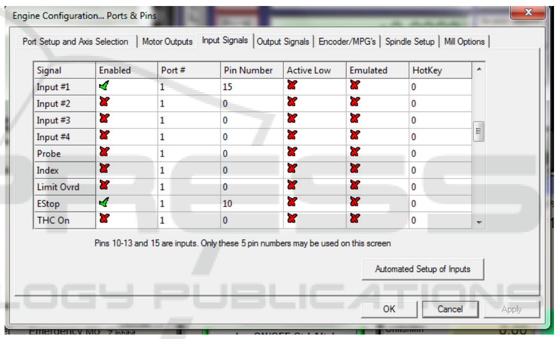

Figure 11: Input signal axis setting.

2.1 Calculation of the Motor Tuning

Motor tuning aims to set the step value of each axis. The motor tuning value is calculated based on several parameters such as output driver pulse, tooth pitch of timing belt, and number of teeth on the slider drive gear. Several formulations for the calculation of servo motor tuning are shown in formulas (1), (2), (3), and (4).

$$\text{Shaft revs/unit} = 1/\ (tp \times Ns) \qquad (1)$$

$$\text{Motor revs/unit} = \text{shaft revs/unit} \times (Ns/Nm) \qquad (2)$$

$$\text{Pulse/motor revs} = PPR \times 4 \qquad (3)$$

$$\text{Step/unit} = \text{Pulse/motor revs} \times \text{Motor revs/unit} \qquad (4)$$

If the output driver is 2500 pulse per rotation [p/r], tooth pitch of timing belt is 0.2inchi or 5.08mm, teeth number on motor is 20. Using formulation (1) until (4), the value of motor tuning is shown.

- Shaft revs/ unit = 1/ (5.08 x 90) = 0.00218 rev/mm.
- Motor revs/unit = 0.00218 x (90/20) = 0.00981 revs/mm
- Pulse/ motor revs = 2500 x 4 = 10,000 pulse/revs
- Step/ unit = 10,000 x 0.00981 = 98.1 steps/mm

Motor tuning of the stepper motor is calculated by formulas (5), (6), (7), and (8).

$$\text{Screw revs/unit} = 1/\ \text{pitch} \quad (1)$$

$$\text{Motor revs/unit} = \text{screw revs/unit} \quad (2)$$

$$\text{Motor step/revs} = 360°/\text{step motor} \quad (3)$$

$$\text{Step/unit} = \text{Motor step/revs} \times \text{Motor revs/unit} \quad (4)$$

Several values of motor stepper are known, such as step motor is 1.8° and screw pitch is 45mm. Hence the motor stepper value can be calculated.

- Screw revs/unit = 1/45 =0.022 revs/mm.
- Motor revs/unit = 0.022 revs/mm.
- Motor step/revs = 360°/1.8° = 200 steps/revs
- Step/ unit = 200 x 0.022 = 4.44 step/mm.

Figure 12 shows the servo motor setting for X-axis. The motor tuning value is set at 98.1 step/mm. The motor stepper tuning value of the A-axis with 4.44 step/mm is shown in figure 13.

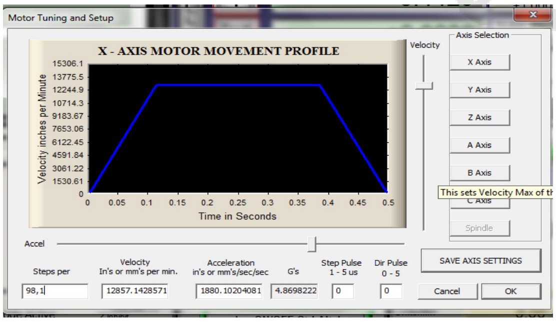

Figure 12: Servo motor setting.

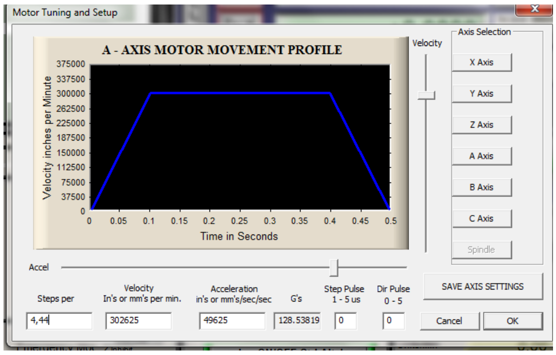

Figure 13: The setting of motor stepper.

2.2 Verified the Functionality of System

Experimentally verified was conducted for (i)Testing of axis movement direction and (ii) Rotation speed of axis motor. Each servo motor axis such as X-axis, Y-axis, and slave Y-axis (or B-axis), Z-axis and slave Z-axis (or C-axis), and A-axis were tested in clockwise and counterclockwise direction. Table 1. Show tested data of movement direction motor axis. The experiment results show that each axis servo motor has been rotated refer to G-code command.

Table 1: Tested data of movement direction.

Command	Axis	Drive Motor	Direction
X-50	X	Axis motor X	CCW
X50		Axis motor X	CW
Y-50	Y	Axis motor Y	CCW
		Axis motor B	CW
Y+50		Axis motor Y	CW
		Axis motor B	CCW
Z-50	Z	Axis motor Z	CCW
		Axis motor C	CW
Z+50		Axis motor Z	CW
		Axis motor C	CCW
A-50	A	Axis motor A	CCW
A+50		Axis motor A	CW

Testing of rotation speed of axis servo motor was the way to verify the velocity parameter of axis movement without mechanical components of axis machine. Three velocity parameters were tested, 62.3 mm/second, 187.24 mm/second, and 249.69 mm/second. The specification of servo motor has 98 steps per unit and 2500 pulse per rev, hence rotation speed could be calculated. Experimentally tested rotation speed was measured by tachometer.

3 CONCLUSIONS

The controller of concrete 3D printing has been developed using Mach 3 control board with PC-based type and supported by Cura as CAM software in the 3D printing process. The parameter setup has been properly determined; hence each X-Y-Z axis machine actuator, extruder actuator, and each limit sensor are well connected with controller. The proposed controller configuration was verified experimentally, all actuators and travel limits could respond as commands.

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