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Design and Develop of Open Architecture CNC Movement Control System for Analysing Precision Motion of EDM Machine

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Abstract: Since the third Industry Revolution (IR3.0), automation become a key technology in industry especially CNC machine. An EDM machine is CNC based that able to reduce the process time, increase the productivity of manufacturing process, and duel with complex task. Therefore, it was one of the best choices to become the education element in manufacturing field. However, high in cost and complexity in structure were the weaknesses and limitations of EDM machine. An open architecture CNC movement control system was studied in order to create a high flexibility, affordable, and simple movement control system for EDM machine. LabVIEW was chosen as the main controller software and NI MyRIO as the main processor in this movement control system. The hardware was built by using open architecture components which reusable and low in cost. This system was able to control the movement of X, Y, and Z axis of the EDM machine in term of distance travel. The time counter in LabVIEW program was used as the feedback system due to absent of encoder as the position feedback element. The relationship between traveled time and distance traveled was determined for the adjustment and programs for single direction, dual direction, specific distance movement, multi axis movement and stop when sensor triggered were developed. The desired value was compared with the actual distance travel in order to calculate the percentage of error of the control system. The percentage of error for X, Y, Z and the gap created was 0.37%, 0.38%, 0.49% and 2.9% respectively. This experimental study will fulfill three objectives. First is to design an open architecture CNC movement control system in X, Y, and Z axis for EDM application. Second is to integrate and analyze the CNC movement control system with the machine hardware. Lastly is to analyze the performance of the developed movement control system with respect to the CNC movement system.

Keywords: Open architecture, CNC, movement control system, EDM machine, LabVIEW, NI MyRIO

1. Introduction

Electrical Discharge Machining (EDM) process is a non-conventional manufacturing process which able to remove unwanted material of a work piece in order to get the desired shape by using electrical discharge sparking [1]. The working principle of the electrical discharge is rapid and continuing of current discharge between the tool and the work piece due to the different polarity of two electrodes. This current causes an electric spark to occur between electrode &

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wire, hence the unwanted material of the work piece will be removed. The tool and the work piece have no mechanical contact during the whole EDM process. In order to start EDM process, the work piece must be an electrical conductor material so that the electrode discharge spark is able to be created.

In manufacturing field, EDM process plays an important role to solve those complex and difficult situations such as sharp inside corner of work piece, complex geometry, and deep cutting. Basically, there are two types of EDM process which are Die-Sinking EDM and Wire-Cut EDM. Both of them have different characteristics but they serve the same purpose. In this project, it only focused on die sinking EDM machine as the study element. The system that executes the mechanical part of EDM machine is servo mechanism system or servo system in short. This servo system is able to move the mechanical part of EDM machine with a certain or specific distance by generating the servo commands using EDM computer. This movement control system is normally a Computer Numerical Control (CNC) system that work with respect to the International Standards Organization (ISO) 6983 which known as G-M code[2].

Basically, the CNC machine control system is divided into two types which are closed system and open system. The closed system normally works with particular types of machine where open system is based on industrial PC's (IPC) with CNC control software [3]. Recently, the traditional controller of machine device has been progressively supplanted by the PC-based open architecture controller, which is independent of the CNC merchant and on which it is conceivable to execute client characterized application programs [3]. A personal computer acts as the hardware and works with a real-time operating system software. It is able to reduce costs and increase the flexibility of the control system. By creating an open architecture platform, the CNC application framework would become more flexible and modular. The users of the system are able to customize the designed function to fulfill the demand for different applications. Subsequently, the software is able to be reused by changing the coding or programming. With this advantage, the performance of the overall system is improved by just upgrading the hardware system.

There are a lot of different communication interfaces which use different combinations of hardware and software to command or control the CNC machine [4]. Most of the languages used were based on text form such as C, C++, JAVA, and others platform which is complicated. In this research, Laboratory Virtual Instrument Engineering Workbench (LabVIEW), introduced by the National Instrument has been selected as the real-time operating system software. Different with other programming language, LabVIEW operates under graphical language and is easy to apply compared with the platform that using text coding [5]. Other than that, LabVIEW provides many tools in different fields, for example control, display, and analysis. The die-sinking EDM machine has been chosen as the study element in this research. The design and development of the open architecture CNC movement control system for the EDM machine is using the LabVIEW software with respect to particular hardware.

Currently, most of the commercialize EDM machines are not suitable for education purpose due to complexity in connection between components and programming. Existing EDM machines in college and university were old model with less features and difficult to control. Also, EDM machine consumes high operating power and costly as well [5]. This cause EDM machine not affordable by industry and university in term of starting as well as maintaining costs. Hence, develop a simple, portable and affordable open architecture CNC movement control system for EDM machine is necessary in order to overcome the disadvantages and limitations of the EDM machine. If the open architecture CNC movement control system is successful developed in this project, it will bring a lot of benefits in education field especially in high technology manufacturing application.

This study chosen ROBOFORM 100 EDM die sinking machine as the research element. In the end of the research, the prototype of an open architecture CNC movement control system had been developed for X, Y, and Z axis. After developed the system, the analysis of the CNC movement control system with machine hardware was done as well as the performance of the developed control system with respect to the CNC movement system.

2. Computer Numerical Control (CNC)

Numerical control is controlling a machine tool based on a pre-programmed machining and movement instruction automatically [7]. Based on the definition, Computer Numerical Control (CNC) means computer executing those pre-programmed machining and instructions for a machine. Base on previous research [7-10], CNC machine was the study element for the manufacturing research. The modern precision manufacturing requires extreme accuracy in dimension of product and precision in positioning. ROBOFORM 100 die sinking EDM machine (Fig.1) was a CNC based machine that work under ISO 6983 (G-M code). For human being, it is impossible to achieve such performance and maintain the consistency of output. Thus, manual "handwheel" control had been replaced with CNC motion control. EDM has been refined using pulse generators, planetary and orbital motion techniques, CNC and the adaptive control systems [10]. In manufacturing, the most commonly process that using CNC machine are milling and turning [11]. To compare with manual processing, CNC machine occupied several advantages such as higher flexibility, increasing in productivity and quality, reliable and safe operation [7]. CNC machine is basically divided into two parts which are hardware and software. The configuration of hardware includes I/O card, motor drives, motion control cards and various others. In software part, Human Machine Interface (HMI) and interpreter CNC machines are operated under ISO 6983 [3]. The structure of hardware and software were complex and unable to access to inner features of CNC. To overcome this problem, a lot of studies about the open architecture of CNC control system had been carried out and developed to simplified the control system to more user friendly.

Fig. 1 - ROBOFORM 100 die sinking EDM machine

2.1 Open Architecture Control System

Control system is the heart of automation system and it is able to perform several functions. In general, control system manages the information flow to and from the instrument system for process monitoring and control, also to and from the human interface system for manual interaction with the process [13]. Basically, there are two types of control system in CNC machine which are closed system and open system. Closed control system is the control system that specific to the particular machine type while open control system is able to adapt with different type of machines for distinct purpose [14]. Most of the open architecture control system was close system to provide efficiency flexibility and low cost for the developed system. There were many researches regarding development of open architecture control system. One of the researches had introduced the open architecture on numerical control system based on window CE [15]. Another study regrading open architecture control system was carried out the study about the extensibility of NC program interpreter for an open CNC system [16]. The development of CNC machine control system with PC-based by using LINUX CNC software had been done in one of research [3]. Most of them are using text form language to command their system which were complicated. One study had conducted to build a prototype of CNC machine by using open architecture system [18]. Two researchers from University Tun Hussein Onn Malaysia had conducted the study about the development of new open softCNC system [3] and ISO 6983 interpreter for open architecture CNC system [17]. Also, this study used the open architecture technology to develop a movement control system for EDM machine [20-21].

2.2 LabVIEW

LabVIEW, short for Laboratory Virtual Instrument Engineering Workbench, which is a programming environment that can create a program using graphical notation. This is totally different with traditional programming language such as C, C++ or Java that program with text. LabVIEW also support a wide~~ly~~ range of different devices and this makes LabVIEW popular in system development recently due to high flexibility and user friendly. A single LabVIEW-based program can be directly applied to various tasks without having to change the program code. LabVIEW features including LabVIEW's libraries of reusable code, support for building GUIs, use of the dataflow paradigm and automatic memory management. LabVIEW divided into two elements: block diagram and user interface (front panel). In LabVIEW, programmer can select and customize all the visible entities on the front panel without writing code [4]. LabVIEW had been chosen as the interpreter of ISO 6983 of CNC machine in many researches. In this study, LabVIEW as the main controller of the movement control system and NI MyRIO as the main controller board. LabVIEW block diagram of movement control system for EDM machine had been developed (Fig. 2). The NI MyRIO Express VI had used in MyRIO Toolkit in LabVIEW program. The VI such as PWM, time counter, input & output for digital and analog had been used in development of movement control system. Basic structure in programming which were time loop, case structure, and while loop had selected in this development.

2.3 Hardware Components

Since the open architecture had been decide to use as the movement control system. The components had been survey and purchase. The main controller processor was NI MyRIO 1900. It is a portable reconfigurable I/O (RIO) device that can be used in robotics, design control and mechatronics system. In this project, NI MyRIO 1900 acts as the "brain" of the system in order to control the devices that connected with it by implementing the programming. The following was the driver to drive the DC servo motor. Three high ampere DC motor drivers was used in this development in order to drive the high current DC servo motor of the EDM machine. The DC servo motor that origin from the EDM machine was ABB minertia motor Mini Series DC servo motor. An inductive proximity sensor was implemented into Z-axis. It played the role of create a gap between work piece and Z-axis that same with the behavior of EDM machine. All the components powered by an external power source that able to provide a constant current flow. Two measurement instruments were used to determine the actual distance traveled and the gap created which were distance meter and digital Vernier caliper respectively. All the components had been connected with each other (Fig.3).

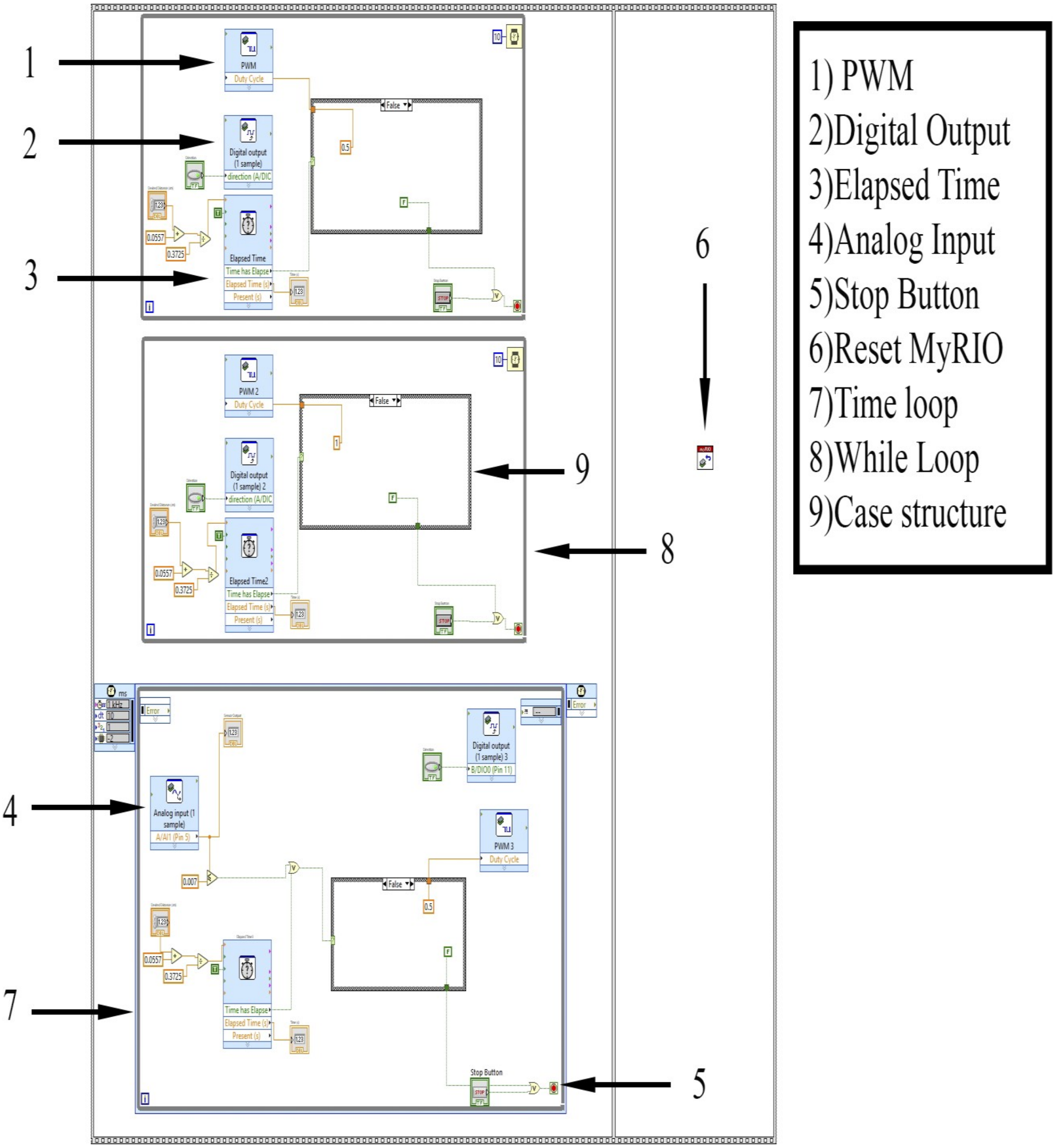
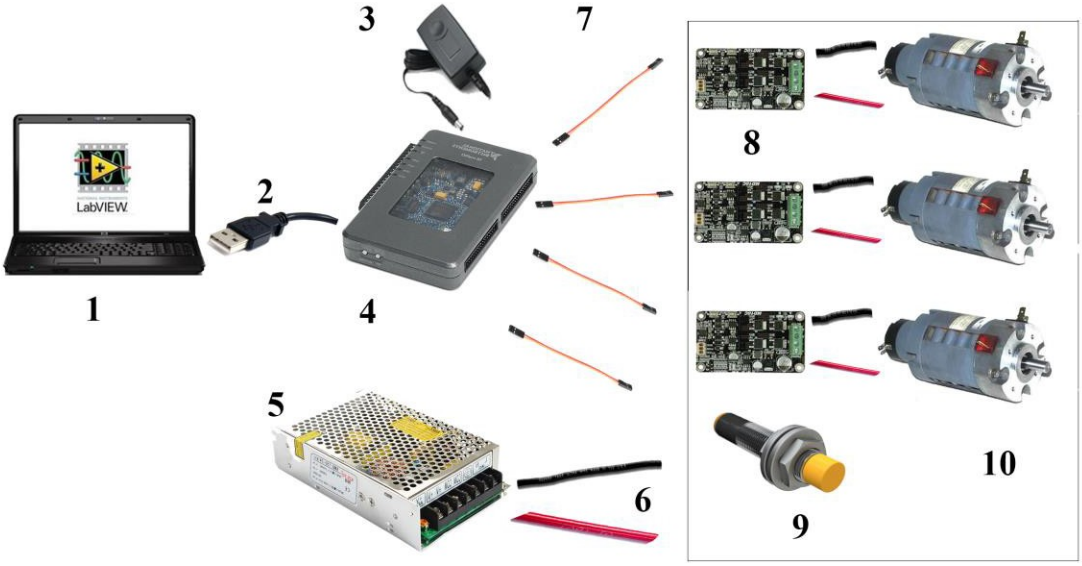


Fig. 2 - Block diagram of movement control system for EDM machine

NI MyRIO 1900 had connected to laptop by using USB port and it function by power source adopter. Three motor drivers connected to NI MyRIO by using jumper wires. Each motor driver contained three input pin which were Pulse Width Modulation (PWM), direction, and ground pin. The output pin of the driver connected to DC motor which had A and B pole and the motor driver function by external power source. The inductive proximity sensor contained 3 wires which were voltage, ground, and signal pin. The signal pin connected to NI MyRIO directly and it function under 12V power source. The hardware system was developed accordingly and implemented to the EDM machine to perform together with LabVIEW program.



1)Laptop (LabVIEW software)
2)USB Port
3)Power Source Adaptor
4)NI MyRIO 1900
5)Power Source
6)Wires
7)Jumper Wire
8)DC Motor Driver
9)Inductive Proximity Sensor
10)DC Servo Motor

Fig. 3 - Architecture diagram of hardware system

2.4 Experimental Procedure

Before connecting the devices and components, the block diagram of LabVIEW software had been designed with different features. Examples code was studied through online and references book in order to adapt the skill and knowledge in block diagram design. The block diagram was designed in few different types that consist of different function and command which were single direction movement, forward and backward movement, specific distance movement, movement stop when sensor triggered, and multiple axis movement. As precaution, gloves and shoes were worn throughout the experiment to prevent electrical shock or static electricity of electrical devices. The connection among devices must be correct and tight in order to prevent any short circuit issue. The tests for each command are repeated five times to obtain the average result. In the beginning of the experiment, the motors went through the tests of availability and all the devices had been checked. The motors of axis X, Y, Z were calibrated and measure the actual moving distance by distance meter.

By comparing the value of moving distance for desired and actual, adjustments had been done by changing the codes in LabVIEW program. For inductive proximity sensor, 3D printing technique was used in create a sensor holder in order to install at Z-axis. The sensor was adjusted until it parallel with the tip of Z-axis. LabVIEW program was used to stop the movement once the sensor triggered and gap had been created. The gap between Z axis and workpiece was calibrated and measure by using Vernier Calliper. The results of measurement ware noted down in a table for calculation purpose. The block diagrams went through one by one with connected devices. The errors of block diagram had been identified with several tests and correction was made after that. The results of each program were recorded and the actual movement also recorded in written and video form. From the data obtained from experiment, the distance travelled for axis movement was increasing while the time travelled increased. Each of the experiment had repeated five times to get the average value in order to plot the graph. Fig.4 showed the graph of distance travel against travelling time.

From the graph in Figure 4, the relationship between distance travel and travel time of axis movement was directly proportional, which mean when travel time increasing, the distance increased as well. The best fit of the graph was obtained and a linear equation (1) had generated from the graph base on Y=mX+c.

$$Y = 0.3793X - 0.0936 \qquad (1)$$

The value 0.3793 was the gradient of the graph and -0.0936 was the intercept point of the graph. The relationship between the two variables had been found out and the adjustment of the set value in LabVIEW program had been done so that the input column in LabVIEW program was desired distance travel instead of traveling time. The LabVIEW program for multi axes movement had been adjusted and control panel (Fig. 5) had been done.

Table 1 - Relationship of time and distance travelled

Time (s)	Distance Before Travel, Y0 (cm)	Distance After Travel, Y1 (cm)	|Y1-Y0| (cm)	Average (cm)
1.0	88.6	88.9	0.3	0.3
	88.9	89.3	0.4	
	89.3	89.5	0.2	
	89.5	89.8	0.3	
	89.8	90.1	0.3	
1.5	87.5	88.0	0.5	0.5
	88.0	88.5	0.5	
	88.5	89.0	0.5	
	89.0	89.5	0.5	
	89.5	90.0	0.5	
2.0	87.3	87.9	0.6	0.6
	87.9	88.5	0.6	
	88.5	89.2	0.7	
	89.3	89.9	0.6	
	89.9	90.5	0.6	
2.5	87.4	88.3	0.9	0.9
	88.4	89.3	0.9	
	89.3	90.1	0.8	
	90.1	91.0	0.9	
	87.1	88.0	0.9	
3.0	88.0	89.0	1.0	1.0
	89.0	90.0	1.0	
	90.0	91.1	1.1	
	91.1	92.1	1.0	
	92.1	93.1	1.0	
3.5	87.3	88.5	1.2	1.2
	88.3	89.6	1.3	
	89.6	90.8	1.2	
	90.8	92.1	1.3	
	92.1	93.2	1.1	
4.0	87.7	89.1	1.4	1.4
	89.1	90.5	1.4	
	90.5	92.0	1.5	
	88.4	89.8	1.4	
	89.8	91.2	1.4	
4.5	89.8	91.4	1.6	1.6
	88.9	90.5	1.6	
	90.5	92.2	1.7	
	88.9	90.5	1.6	
	90.5	92.1	1.6	
5.0	93.4	95.2	1.8	1.8
	91.5	93.3	1.8	
	93.3	95.2	1.9	
	95.2	97.1	1.9	
	91.6	93.3	1.7	

The control panel for multi axis movement which were X, Y and Z axis had developed. Each control panel of an axis had been separated in order to avoid mistake and easy for the user. The control elements for each axis contain of input column, direction pin, stop button and time output indicator. For Z axis, an analog output indicator for inductive proximity sensor had been included to determine the status of the sensor. The performance of adjusted LabVIEW program had been tested and the graph plotted (Fig. 6-8). The graph of gap created (Fig. 9) by the inductive proximity sensor had also plotted.

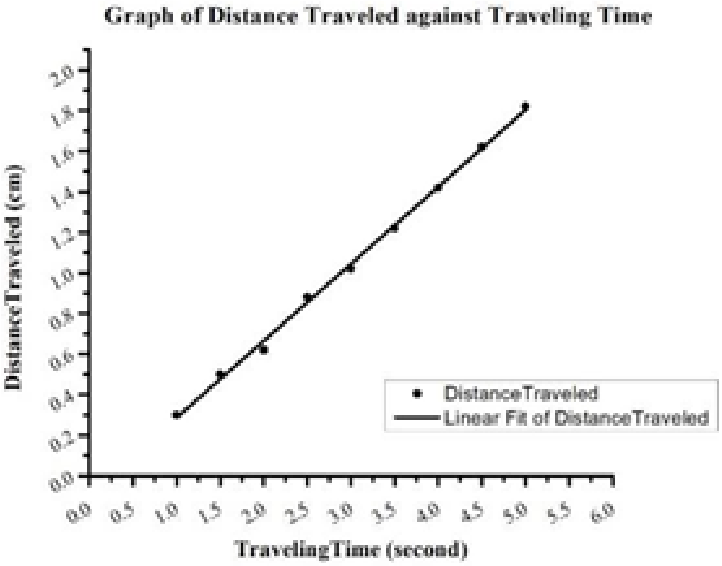


Fig. 4 - Graph of time against distance travelled

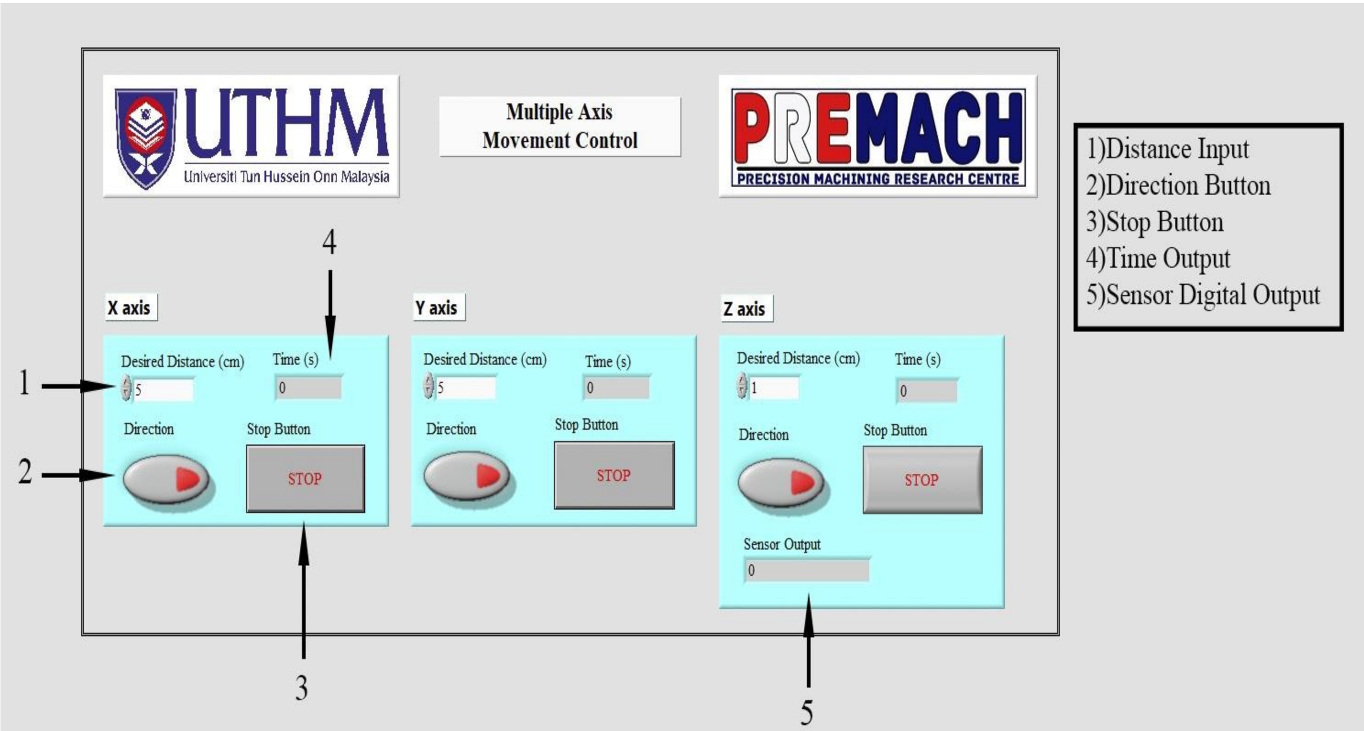


Fig. 5 - Control panel of multi axis movement

Fig. 6 showing comparison between theoretical and actual distance travel for X-axis. Both of the lines were overlap with each other. The average percentage of error obtained and calculated from the graph was 0.37%. Fig. 7 showing comparison between theoretical and actual distance travel for Y-axis. The average percentage of error obtained and calculated from the graph was 0.38%. Fig. 8 showing comparison between theoretical and actual distance travel for Z-axis. Same with previous graph, the lines were overlap with each other. The average percentage of error obtained and calculated from the graph was 0.49%. The movement control system able to maintained the average percentage of error under 0.50% for three axes.

From the graphical method, the different between theoretical and measurement gap distance was obvious. The different seem many because the scale used in the graph was small. By comparing the error calculated with datasheet, the error in datasheet was $\pm$10% depending the material of the target. The calculated result of the gap distance was not exceeded the percentage of error and this mean that the datasheet had proven the actual result was correct.

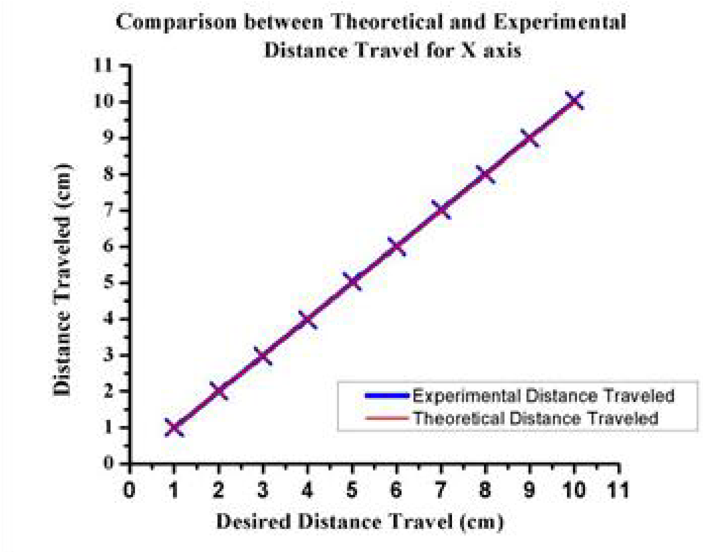


Fig. 6 - Performance of X-axis

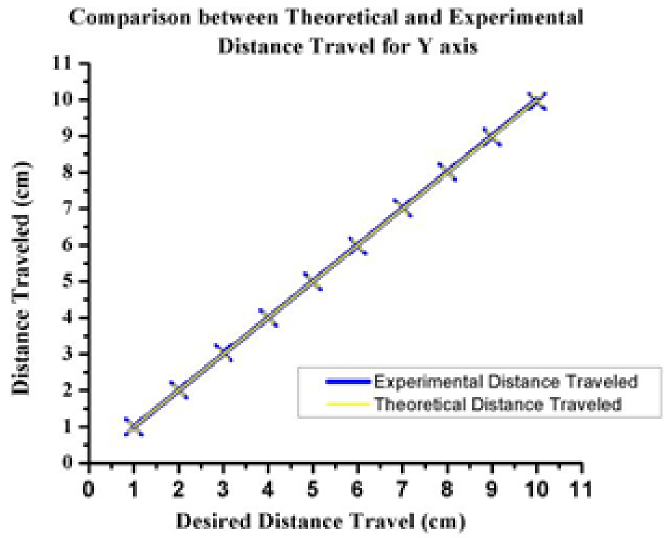


Fig. 7 - Performance of Y-axis

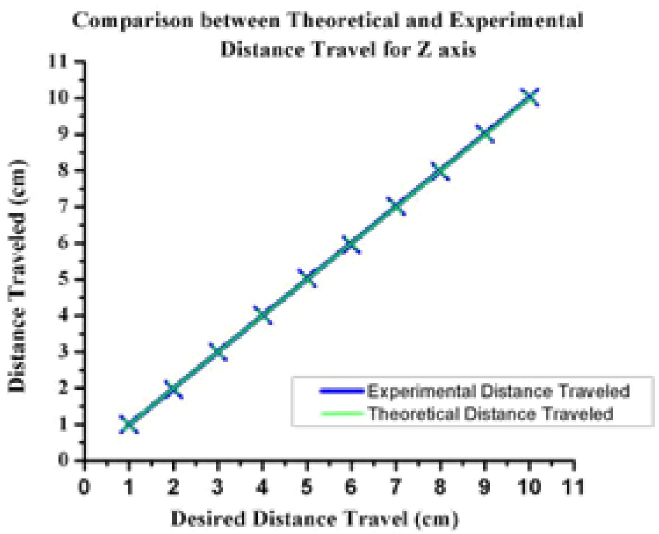


Fig. 8 - Performance of Z-axis

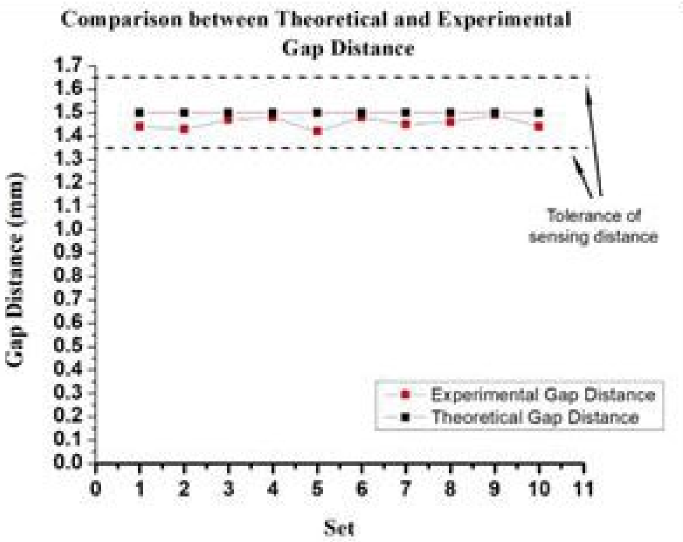


Fig. 9 - Performance of inductive proximity sensor

4. Conclusion

In conclusion, design and develop the movement control system for EDM machine was conducted successfully and the results were indeed promising. In this study, the design of the hardware layout and the software program about the axis movement by using LabVIEW had been done which achieved the first objective. The hardware system had developed by using NI MyRIO and other electrical boards to drive three DC servo motor of EDM machine. The desired movement for each axis had their own control panel that developed by LabVIEW and control by using laptop. This fulfils the second objective which was integrate and analyse the CNC movement control system with machine hardware. Based on the experiment results, the movement control system was stable and functions properly. The relationship between traveling time with distance travelled was determined by experimental method due to absent of encoder as position sensor. Calibration and adjustment had made for the accuracy of the movement control system. The average percentage of error of distance travel for X, Y and Z axis was 0.36%, 0.37%, and 0.49% respectively. The percentage of error able to maintain below 1% which meet the precision machining criteria. Therefore, this analysis had accomplished the last objective which was analyse the performance of the developed movement control system with respect to the CNC movement system. Other than that, the gap between Z-axis and work piece had created successfully by implemented an inductive proximity sensor. The sensor controlled by using NI MyRIO and hold by a 3D printed slot that installed at the Z-axis. The gap distance was measured by using Vernier calliper and the average gap distance was 1.46mm. The average percentage of error was 2.9% which was within the range of tolerance that stated in the datasheet. The task was accomplished and the outcome was similar with expectation. On the whole of this project, the three objectives were achieved with reasonable results. This movement control system able to function in a long period of time and it has great potential to develop more features in future. The control system fulfilled the sustainability.

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