Design of 3 Axis Automation System for Analysis of Spray Nozzle Performance in Precision Pesticide Applications

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ABSTRACT: *New spraying techniques developed in agricultural have brought new test methods to test these techniques. Within the scope of this project, a 3-axis test stand and software have been developed to test and develop systems that can make spot spraying instead of uniform spraying.*
The spray nozzles used in agricultural spraying are tested with their pulverization characteristics and their performance is determined. The successes of these analyzes are compared. The tests carried out in the scientific studies on this subject are collected in separate groups as field studies or laboratory studies. Laboratory studies are required to simulate field tests. However, it is very difficult to use tractors in the laboratory environment and control of them.
A test system and control automation software have been developed within the scope of this project. The purpose of design is automating tests of new precision spraying systems. This design consists of a 3-axis movable chassis, three-step motors, a step motor driver, a control mechanism and a spraying system. With the help of the control mechanism, the system can move at a certain speed along the x-axis and can move to the specified point along the y-axis at a certain speed and its height can be adjusted in the z-axis. With the developed software, the spraying system nozzle which moves at a constant speed to the defined point of the control system can take its position and spray it at this point. Also, it can be controlled by spraying with a solenoid valve placed on the spraying system and the pressure and flow in the system can be monitored by the flow meter.

KEYWORDS: A*griculture, spraying, 3D, control, precision*

I. INTRODUCTION

One of the most important issues for researchers and farmers working in the field of agriculture is to increase the amount of agricultural production while using environmentally friendly techniques. Pesticides are the leading inputs used to increase agricultural production. However, it is not possible to achieve the desired success without spraying. The success of the application is closely related to the type of sprayer used and the settings of this sprayer. Regardless of the type and amount of pesticide used, the most important factors that determine the success of the application together with the operator are the characteristics of the sprayer and the correct use of this machine.
At least that area of the development of applications in agricultural production in Turkey is pesticide application. However, pesticides have great damages both on the environment and on human health. Although it is not possible to eliminate these damages at the point where pesticide application technology is in the world today, it is possible to reduce losses as much as possible and at the same time achieve the expected success of spraying.
In agricultural production, when plant protection machines are used in inappropriate spraying conditions and the technical features of the equipment on spraying machines are inadequate or defective, it increases the input costs of agricultural enterprises. Although many machines are used in plant protection applications, field and garden sprayers are used for spraying large areas. The elements of the machines used are the same. Since these machines have been used by farmers for many

years, the equipment found in the sprayers is worn out or deteriorated.

In the licensing of plant protection machines, spraying machine test reports are introduced in terms of structural and operational characteristics. General dimensions, motion transmission, power supply, pump, air bell/tube, medicine tank, mixer, spray group, nozzle and guns, strainers, tank filler, pressure regulator, manometer, hose and connections, for traction type; chassis, drawbar arrow, drawbar ring, axle assembly and wheels, for hanging type; chassis and three-point suspension arrangement, for those carried on the back; basic features such as suspension belt. In addition to these technical properties, the amount of fluid sprayed per unit time (flow rate) and distribution uniformity, spraying distances and angles, drop sizes, machine noise levels and atomizer, ULV machine and fogger air velocity of spraying machines are also determined. However, institutions or organizations engaged in the manipulation of the sprayer testing center in Turkey or elsewhere in use have not been established. After prolonged use of sprayers, there may be deterioration of distribution uniformity, cracks in hoses, clogging of filters and leaks. Such problems adversely affect the success of spraying and threaten human and environmental health. Therefore, periodic inspections of spraying machines at certain time intervals and to certain standards will increase the success of spraying and reduce the negative effects on the environment. Many countries in the European Union have been performing some periodic tests of sprayers for years.

However, sprayers with almost automation systems have not been evaluated. Experiments are carried out with fixed systems in a laboratory environment. They do mobile applications in the field of agriculture. However, the error rate is high due to environmental effects.

Agriculture is one of the strategic sectors where information and communication technologies are rapidly used. Agricultural production, marketing of agricultural inputs and outputs, agricultural extension in areas such as software and hardware products on scientific studies and as a result of the company's R & D studies are commercially offered to the market. Agricultural Spraying and machines used for this purpose are among the important tools used in agricultural production. Information technologies (sensors, dosage, GPS, etc.) are very successful in delivering the right amount of medicine to the right place. Precision farming has achieved this success in two ways: (1) accurately identifying pathways and eliminating untreated or re-sprayed areas;

With the help of the adaptation of ultrasonic and laser technologies to spraying machines, a direct application can be made on the target plant or tree to be applied. The spray nozzles can be switched on and off using sensors on the machine, depending on the shape and position of the plant. These systems also allow the solenoid valves to open and close after a while to compensate for the effect of the wind. The pesticides may be administered intermittently instead of continuous application in the form of a cloud beam. As a result, drift is reduced, in other words, controlled pesticides are applied to prevent off-target spraying. Ultrasonic sensors use sound waves to determine the presence or absence of a plant or tree. With the help of sensors mounted on both sides of the machine, the application can be made to the areas where the tree canopy is detected. The spraying machine equipped with sensors activates only the nozzles corresponding to the region where the plant is detected, and the mapping of the weed distribution pattern (density) with the help of digital cameras is one of the priority subjects in the fight against weed. Weed distribution can be determined by high platforms (airplanes, etc.) or satellite images and the amount of medication is sprayed according to the location and density of the weed.

In these systems, the position is determined with high resolution. Field boundaries are mapped and virtual paths are created for the sprayer to follow in the field. In this way, the covering is kept to a minimum during application and thus no re-application can be made in the same place or there are no gaps between the application patterns. Depending on these reasons, there is a need for stands for the project, which can test the spray system and spray nozzles used in automation in spray system test laboratories. Also, to develop spray systems, their performance must be tested in laboratories as well as in real applications.

Besides, the spray nozzle is the most important element determining the success in agricultural pesticide applications. This should be designed correctly, as well as the tests should be done correctly. Particularly in sensitive applications, accurate simulation of the spraying system affects the results obtained in the laboratory. That is why there is a need for systems in laboratories that can simulate automation in the field.

Most of the pesticides applied in plant protection applications cannot reach the target due to drift, application error and technical deficiencies [1,2]. Therefore, both operators and application techniques need to be developed. Many researchers in the world are working on these problems [1,2,3,4]. The most important topics are spray nozzles and the distribution of pesticides from them. Nozzles are distributed on patternator in laboratories and different types of sampling surfaces (water-sensitive papers, filter papers, oil sensitive papers, etc.) are determined in the field [5,6,7].

Drop sizes and distributions of spray nozzles are also among the subjects of the researchers [8]. Drops produced by different spray nozzles under different application conditions and their distribution also affect the application success [9]. Since the tractor speed is an important parameter in determining drop distributions, it is not possible to make measurements in a stable environment in the laboratory because it is not a suitable test unit [10]. Therefore, the tests are mostly in the form of field applications. In these tests, different problems (weather conditions, time, etc.) are encountered.

Also, moving spray nozzles are used in precision agriculture and especially in image processing techniques. Commonly, systems that allow fixed spray nozzles to spray only on specific coordinates are used [11,12]. Today, these applications are made with tractors mounted on the automation system in agricultural lands [13]. However, there are problems in the accuracy of the results due to the variability of the outdoor conditions. To test these nozzles, mobile systems capable of simulating the agricultural area are needed.

II. MATERIALS AND METHOD

The test stand created in the project was connected to a spray system. The spraying system of the patternator in the workshop of the Biosystem Engineering Department of the Faculty of Agriculture of NKU was used as the spraying system. Spray system consists of 400 lt tank, TAR30 pump, and an electric motor. The system is operated between the electric motor and the pump using a belt-pulley mechanism. It is connected to the boom on the test stand by the hose through the regulator. There are a flow meter and a spray nozzle connected to the solenoid valve on the boom.

Chassis;

The main body is made of an aluminum frame. It consists of two profiles (B) on which it will move, a car with two legs (C) movable on this profile and another car (H) which can move on the column of the car. Movements and transmission are provided by stepper motors (E-D-F) and timing belt system. As shown in Fig. 1, the movement of the motor F on the System B rails is moved in the z-direction and the movement of the tractor in the direction of travel is represented. The movement of the spray nozzle in the y-direction, indicated by G connected to beam B connected to beam H, ie the height of the spray nozzle is provided by motor D along column A. By the movement of motor E on beam H, the spray nozzle (G) can move in the x-axis direction. Thus, the spray nozzle position can be adjusted with the help of the automation system. The spray nozzle G is connected to the solenoid valve. These values can be read during operation using a pressure-flow meter connected to the spray pipe B. Since all motors will be connected to the motor driver, the software on the computer can be controlled (it can also be controlled manually via the control panel without being connected to the computer) and movement is provided in the x-y-z-direction of the spray nozzle. The on/off command via the solenoid valve performs the spray function in the spray nozzle.

Linear bearing bearings and induction chrome-plated, CK 45 material standard shafts, which are the innovations of today's technology, are used in the bearing of the motion systems of X, Y and Z axes in the system. Since linear ball bearings operate with the logic of continuous recirculation of the ball system within them, it has been tried to minimize the friction and to minimize the itching and stresses that may occur in the system.

In the X-Y-Z stand, the stepper motor (E-D-F) and the chrome-plated shaft system are used to transmit this movement to the axes. Stepper motors have been selected because they produce high torque at low speeds and are easy to control. Three, step motors are used in the system: X, Y, Z axes. These stepper motors have 4.5 Nm torque of X and Z axis and draw 4 A current. The stepper motor used in the Y-axis has a torque of 3 Nm and draws 4 A current.

Control System and Software;

Two NEMA 34 bipolar stepper motors are used in the system. These stepper motors have 4.5 Nm torque and 1.8 degrees step angle. The motors operate at 24 V and draw 4 A current. Nema 24 bipolar stepper motor will be used in the system. This stepper motor has a torque of 3 Nm and a step angle of 1.8 degrees. The motor runs at 24 V and draws 4 A current.

Stepper Motor and driver;

The stepper motor driver is a current amplifier. It controls the high current signals that will start the motor by taking the low current control signals. In the project, CWD556 4-wire bipolar stepper motor driver was used as stepper motor driver. This motor drive can operate up to 5 A current.

This stepper motor drive is a 2-phase drive with a 32bit DSP processor. It has anti-resonance, low noise, micro step and low operating temperature. In this way, the motor driver can operate stepper motors with low noise and less vibration. Thanks to its adaptive PID method, it provides precise control. The operating voltage range is 24-50 VDC. The number of steps can be set to a maximum of 51200 steps / turns.

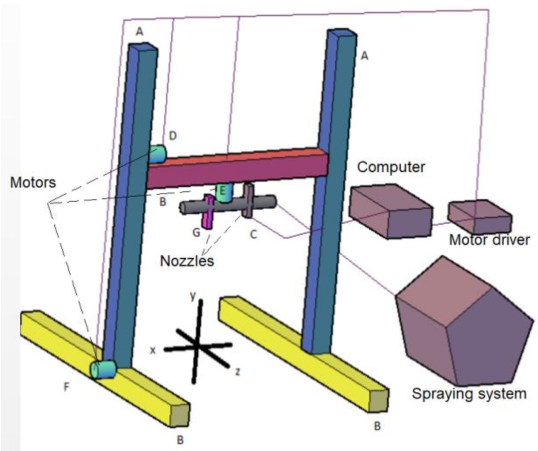

Figure 1. Chassis

For programming of the system, G-code used for position control in CNC machines was used. The 3 step motors for controlling the X, Y and Z axes can be controlled independently of each other. Arduino UNO module is used to send G-code commands to stepper motor drives. This module is connected to the computer via USB cable.

Arduino Microcontroller;

Arduino is an open source microcontroller platform. It consists of a microcontroller and a print circuit including all the equipment to support this microcontroller. This microcontroller can be programmed with a programming language and interface, which is a simplified version of the C ++ programming language. The Arduino UNO model uses an 8 bit Atmel ATMEGA328 microcontroller.

System Block Diagram;

GRBL is an open source CNC control software developed using C and C ++. Thanks to this software library, it is possible to send gcode axis control commands to the stepper motor controllers via Arduino UNO (Fig. 2).

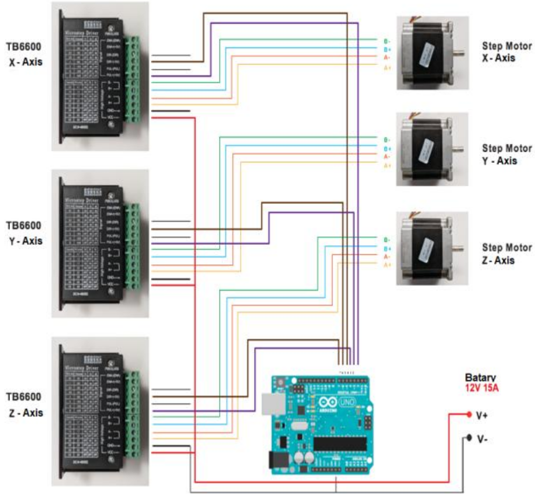

Figure 2. Electrical connection diagram of the test system

Universal Gcode Sender;

In GRBL three axis control, UGS (Universal Gcode Sender) will be used as machine-human interface. 3 axis movement on the UGS can be operated as prepared gcode code or stepper motors can be controlled manually (Fig. 3).

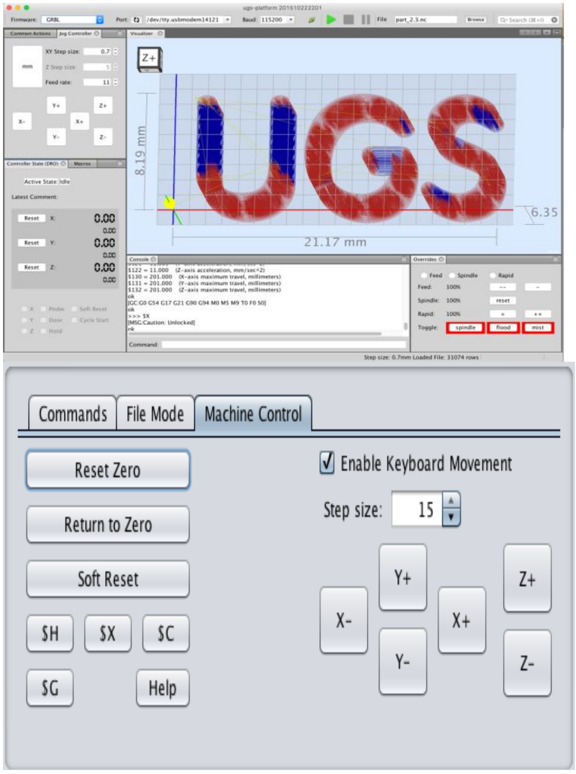

Figure 3. UGS interface and UGS manual control interface

G-Code

G-Code (Geometric code) is the generic control language used in the control of CNC machines. Allows step motors to control at desired speed. Numerical control units use basic blocks to achieve the desired motion. The various g-code blocks that can be used are:

* G00: Fast positioning
This code allows the machine to run at high speed
* G01: Linear interpolation
System moves on a straight line
* G02: Circular / Helical interpolation
The system follows a clockwise circular or helical pattern
* G03: Circular / Helical interpolation
The system follows a circular or helical pattern counterclockwise
* G17: X-Y plane selection
* G18: X-Z plane selection
* G19: Y-Z plane selection
* G20: programming in inches
* G21: Programming in mm

III. RESULTS AND DISCUSSION

Within the scope of this project, a 3-axis test stand and software was developed to test and develop systems that can throw pesticides only on weeds instead of throwing peticides to the whole field in classical applications (Fig. 4).

Software has been developed to design a test setup and automation of this booth, which has a spraying system where we can test the spraying characteristics of spray nozzles used in agricultural plant protection applications, adjust speed, pressure and position, and develop software for its automation.

It is widely used in industry to use CNC (Computer Numerical Control) technology for testing spray nozzles. Stepper motors are used in this system which provides three-axis control of the spray nozzles and the control of the motors is provided by the CWD556 stepper motor driver which provides adaptive PID control.

Figure 4. Prototype

The commands to be performed by the stepper motor driver were created with a software developed for the Arduino UNO microcontroller unit and the electric motors were made to perform the desired movements.

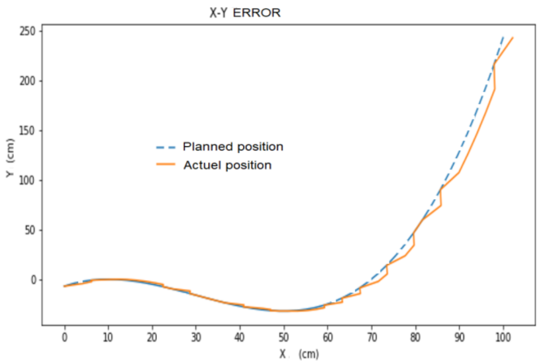

Figure 5. The relationship between the planned subject and the position actually followed (X-Y: 250-100)

During the tests, the motion on the X-Y and Y-Z axes was compared for axis error.

In the graph of Fig. 5, the blue (dashed) line indicates the planned position and the orange line indicates the actual tracked position. 250 cm movement on the Y axis and 100 cm movement on the X axis. The mean axis error in the X-Y plane was 0.07cm, and the standard deviation was 0.17cm.

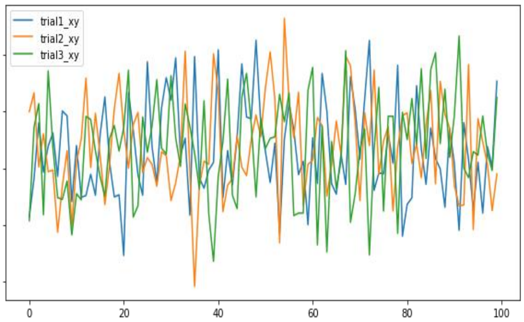

Figure 6. Position Errors for X-Y Plane Trials

Trials on the X-Y plane were performed in 3 replicates. The error values obtained in each trial are shown in the Fig. 6. When the histogram graphs of the error values obtained in each trial were examined, it was observed that they exhibited normal distribution (Fig. 7).

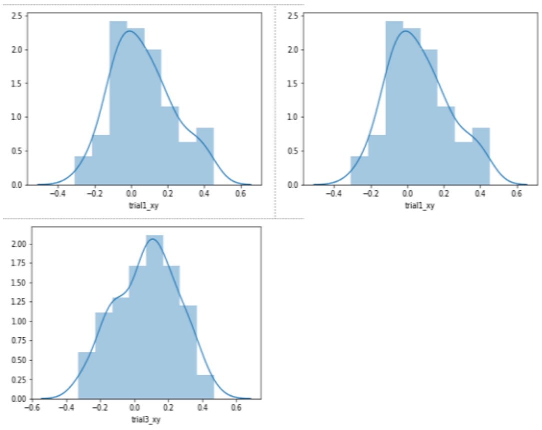

Figure 7. Position Errors Histograms for X-Y Plane Trials

In addition, when the trial position errors compared by box-plot, there was no significant difference between the error values obtained in the experiments Saphiro-Wilk test was used to verify the normal distribution of the errors in the X-Y plane. This test yielded a p-value of 0.09 for Trial 1, 0.75 for Trial 2, and 0.28 for Trial 3. Since all these values were greater than 0.05, it was found that these 3 groups had normal distribution (Fig. 9).

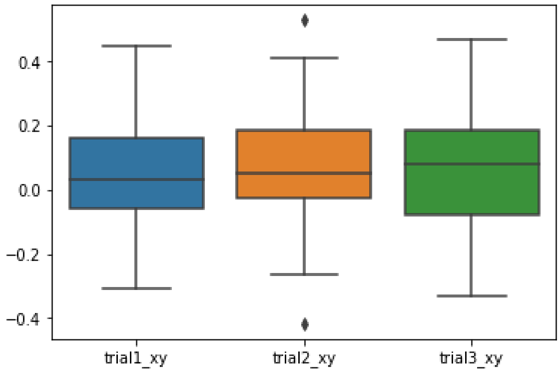

Figure 8. Position Errors Comparison for X-Y Plane Trials

After the normality check, ANOVA test was used to determine whether there was a significant difference between the experiments and 0.82 p-value was obtained. Since the p-value obtained was greater than 0.05, it was concluded that there was no statistically significant difference between the groups.

In the graph of Fig.9, the blue (dashed) line indicates the planned position and the orange line indicates the actual position. 250 cm movement in the Y axis and 100 cm movement in the Z axis. The mean axis error in the Y-Z plane was 0.09 cm, and the standard deviation was 0.18 cm. More deviations in the Y-Z axis than in the X-Y axis are due to the resistance to gravitational force during movement on the Z-axis.

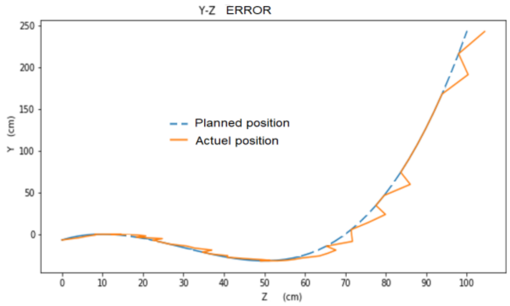

Figure 9. The relationship between the planned subject and the position actually followed (Y-Z: 250-100)

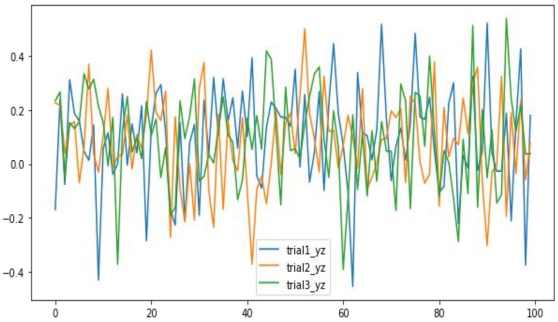

Figure 10. Position Errors for Y-Z Plane Trials

Trials on the Y-Z plane were performed in 3 replicates. The error values obtained in each trial are shown in the Fig.10. When the histogram graphs of the error values obtained in each trial were examined, it was observed that they exhibited normal distribution (Fig.11).

In addition, when the trial position errors compared by box-plot, there was no significant difference between the error values obtained in the experiments (Fig.12).

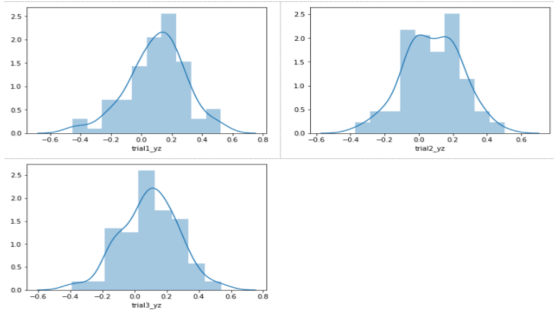

Figure 11. Position Errors Histograms for Y-Z Plane Trials

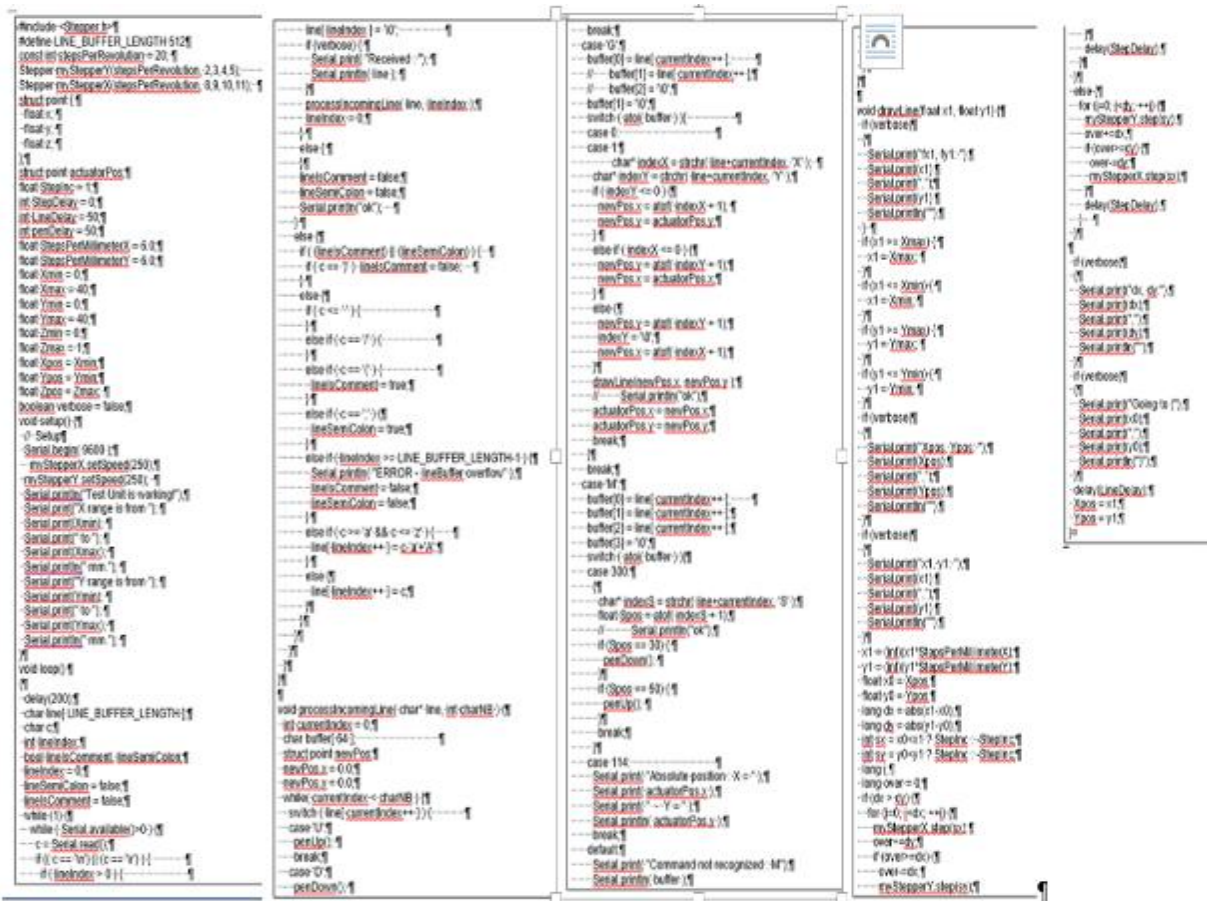

Figure 13.The program developed for Arduino

Saphiro-Wilk test was used to verify the normal distribution of the errors in the Y-Z plane. This test yielded a p-value of 0.18 for Trial 1, 0.93 for Trial 2, and 0.74for Trial 3. Since all these values were greater than 0.05, it was found that these 3 groups had normal distribution.

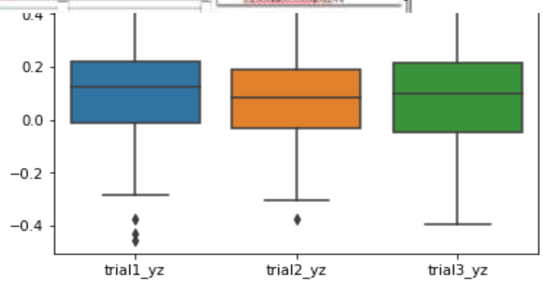

Figure 12. Position Errors Comparison for Y-Z Plane Trials

After the normality check, ANOVA test was used to determine whether there was a significant difference between the experiments and 0.75 p-value was obtained. Since the p-value obtained was greater than 0.05, it was concluded that there was no statistically significant difference between the groups.

The t-test was used to determine whether there was a statistical difference between the experiments for X-Y and Y-Z planes. As a result of this test, 0.17 p-value was obtained and it was concluded that there was no statistically significant difference between them.

The program developed for Arduino during the design phase is shown Fig.13. The given G-code (x-y-z position data to be monitored) is processed by this program and the stepper motor drives are controlled so that the system works.

IV.CONCLUSION

This designed test system will allow spray nozzles to be controlled at desired speeds without the use of tractors in the laboratory environment. It will also provide the infrastructure for various academic studies on sensitive agricultural pesticides. It can be used for testing of agricultural spraying machines with spot spraying with automation.

In later studies, this test system can be controlled more accurately than stepper motors by using servo motor, or a more secure operation can be provided by limit switches to be added at the end of plane.

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