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Design and Development of a Low-cost Wireless Control Kit for Field Sprayers

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ABSTRACT

In recent years, agricultural machinery for precision agriculture has made extensive use of information and communication technologies. An Android-based module was developed in this study to allow the nozzles on the field sprayer booms to be opened and closed as a group. The developed module was tested on a 24 m working width field sprayer, controlling 48 pairs of nozzles in 4-8 groups based on GPS position data. For control, an electronic control unit and an application developed in the Android operating system were used. Wireless communication between the electronic control card and the developed software is provided via Bluetooth. The module, which was created through laboratory and field trials, was successfully tested.

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Introduction

One of the most important aspects of precision agriculture is its ability to be used as a map-based application. In applications with large working width sprayers, it is critical that the nozzles to be controlled individually or in groups based on GPS position data to avoid spraying the incorrect position or overlapping applications (Tellaeche et al., 2008; Blackmore et al., 2005; Kempenaar et al., 2017). Field sprayers with a wide working width are manufactured as tractor power and technology improve. It is extremely difficult to apply without losing position on the target field as the working width of the field sprayers increases. This problem can be solved by watching a small amount of operators, but it is insufficient. The use of sensitive GPS data in agricultural activities is now advantageous. However, when nozzles are not controlled individually or as a group, problems such as overflowing or overlapping of field boundaries occur in studies with field sprayers with large working widths.

ISOBUS-based agricultural applications can now be created precisely using location data on a virtual terminal (Kortenbruck et al., 2017). The use of an ISOBUS-based field sprayer, on the other hand, necessitates very expensive machinery and operating costs. ISOBUS is only widely available on tractors built with cutting-edge technology (Fountas et al., 2015). In field sprayer applications, researchers or farmers employ a variety of techniques to keep spraying nozzles from overlapping or overlapping in neighboring fields. The automatic section control system is one of the most important features for field spraying (Christensen et al., 2009; Miller et al., 2007). Variable rate application in the field is possible with the automatic section control system (Luck et al., 2010).

It is extremely difficult and expensive to apply undamaged, small, or slanted fields. Section controlled practices in such fields can help reduce the cost of medicines while also avoiding legal ramifications (Diekmann and Batte, 2014). Spraying machines with automatic section control can save a significant amount of money (Guan et al., 2015). Automatic section control mechanisms provide far more benefits than large-scale plantations, especially in deformed or small-scale fields (Carmona et al., 2018).

In recent years, mobile phone applications have become increasingly used in agricultural activities. Mobile phone applications, particularly for remote monitoring and control, are finding a home in a variety of fields, ranging from irrigation system operation to image detection systems. The Android operating system is used in mobile applications because it allows for simple programming and software (McDougall, 2001).

In this study, nozzles on a field sprayer with a working width of 24 m were controlled in four groups based on GPS map data using an Android-based mobile phone application and an electronic control circuit. Furthermore, laboratory and field tests of the developed system were conducted.

Materials and Methods

Material

For the control system developed in this study, a suspended type field sprayer with a working width of 24 m and a conic nozzle with 50 cm intervals on the boom was designed and manufactured. An electronic control card, a mobile tablet with GPS, software developed in the Android operating system, solenoid valves, and related fasteners are used to control the group. Bluetooth was used to communicate between the electronic control board and the mobile device.

Electronic Control Circuit Design

In the electronic circuit design program, the electronic control circuit that will control the entire system in the developed prototype machine was designed and developed. The developed circuit includes three sensor inputs, a Bluetooth kit, and control valves. The circuit can receive, read, evaluate, and transmit signals to the smartphone and tablet. The ATmega 328 P (Digi-Key Electronics, 701 Brooks Avenue South Thief River Falls, MN 56701 USA) microprocessor was used in the development of the electronic control card. The processor used has a working frequency of 20 MHz, which allows it to exchange data approximately four times faster than a microcontroller.

Bluetooth Block (B) and Voltage Level Translator Block (V)

Bluetooth is used to connect the designed prototype to a tablet, computer, or smart phone. The voltage level translator block performs voltage matching between the microprocessor and the Bluetooth module.

Led Block (D)

It is the block that allows you to see the instantaneous states of the solenoid on the designed prototype that is controlled by the microprocessor. When the solenoid valve is turned on, its LED lamps light up.

Microcontroller Block (M)

ATMEL's ATMEGA328P microprocessor was used in the prototype. This microprocessor runs at 16MHz. It performs the timing / control tasks of the entire circuit based on the embedded software (Figure 1).

Power Block (P)

It performs all of the necessary feeding and voltage conversion for all of the blocks in the prototype.

Selenoid Power Block (S)

The prototype can control 13 different solenoid valves (Figure 2)

RS232 Block (R)

The designed prototype can also be controlled using the RS232 protocol. This connection is used to simultaneously transfer developed software to the microprocessor and to simulate mobile applications.

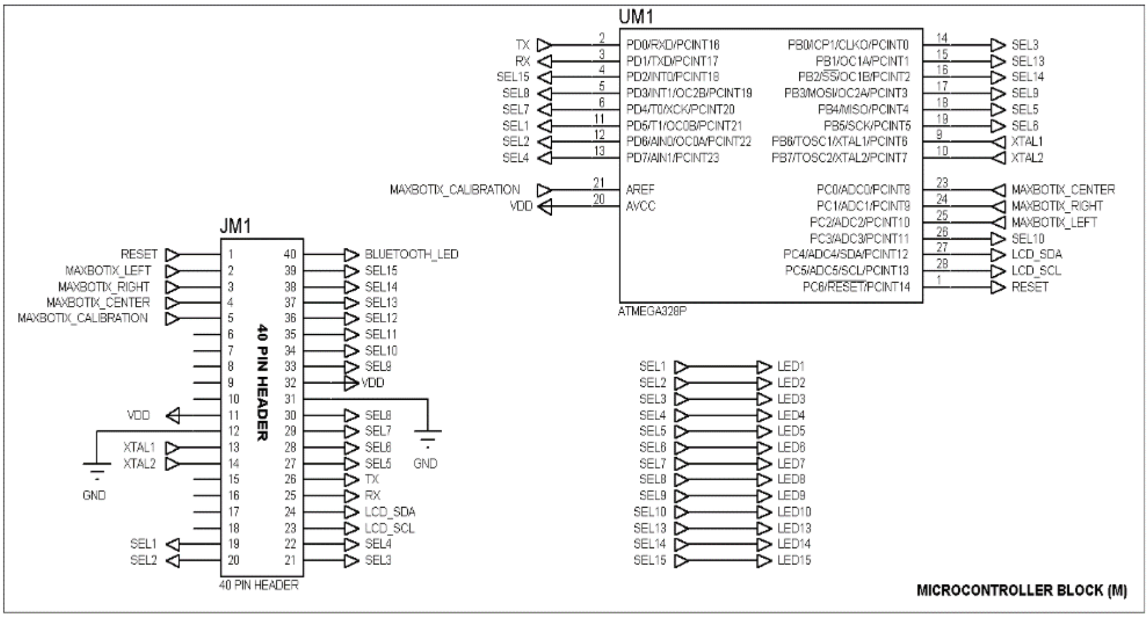


Figure 1. Microprocessor circuit diagram.

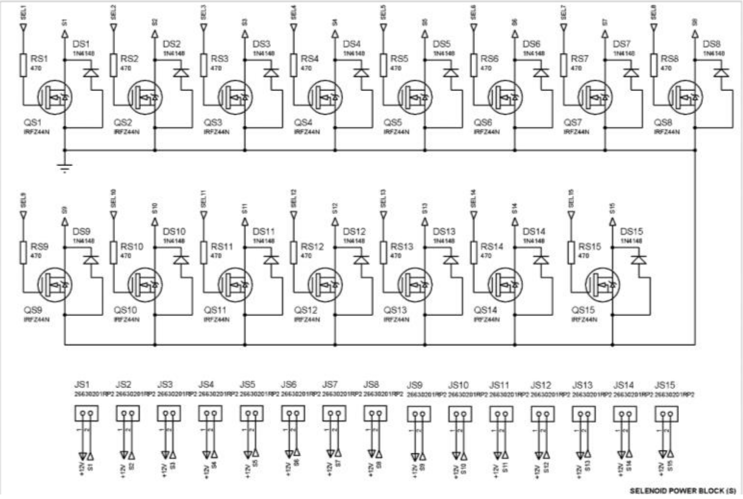
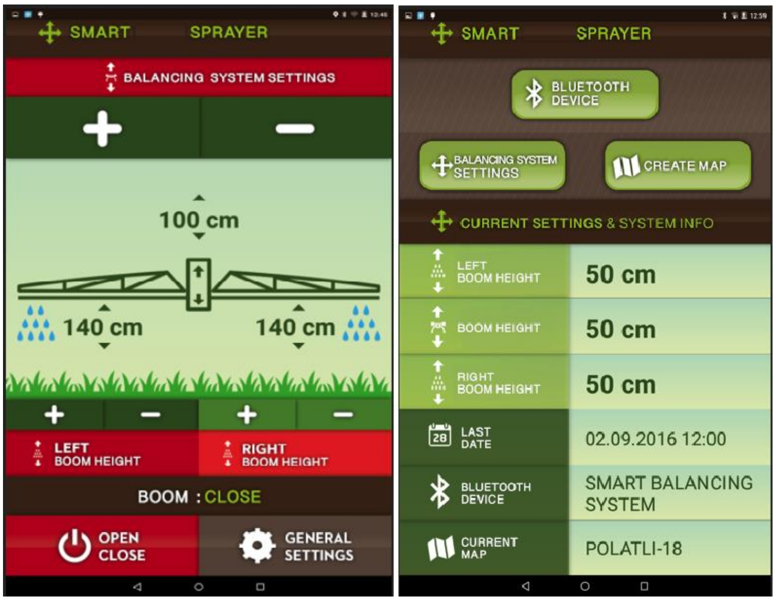


Figure 2. Solenoid valve connection circuit.



100 cm

140 cm

140 cm

LEFT BOOM HEIGHT

RIGHT BOOM HEIGHT

BOOM : CLOSE

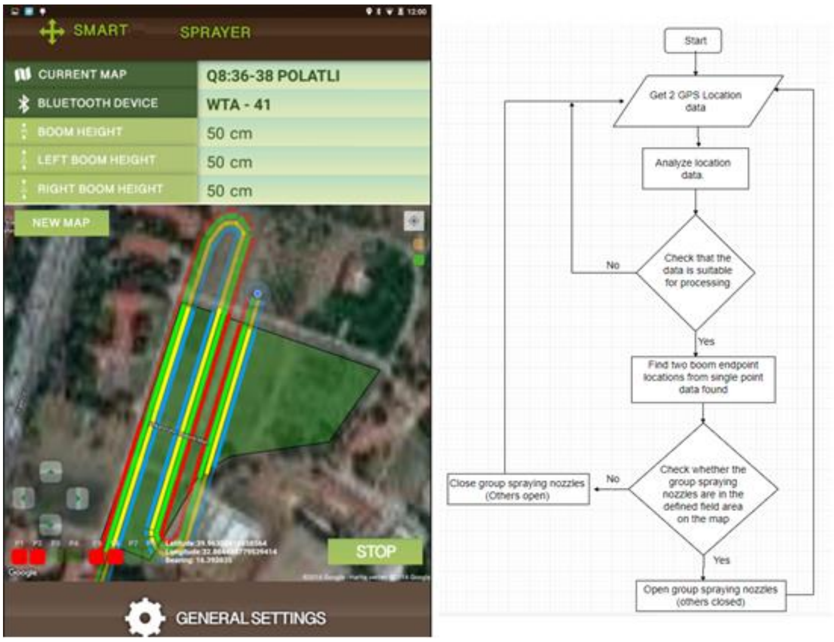
LEFT BOOM HEIGHT	50 cm
BOOM HEIGHT	50 cm
RIGHT BOOM HEIGHT	50 cm
LAST DATE	02.09.2016 12:00
BLUETOOTH DEVICE	SMART BALANCING SYSTEM
CURRENT MAP	POLATLI-18

Figure 3. Mobile phone application view.

CURRENT MAP	Q8:36-38 POLATLI
BLUETOOTH DEVICE	WTA - 41
BOOM HEIGHT	50 cm
LEFT BOOM HEIGHT	50 cm
RIGHT BOOM HEIGHT	50 cm

Latitude:39.962043889698904
Longitude:32.86410911763781
Bearing: 97.987144

Figure 4. Field position creation and flow diagram.



CURRENT MAP	Q8:36-38 POLATLI
BLUETOOTH DEVICE	WTA - 41
BOOM HEIGHT	50 cm
LEFT BOOM HEIGHT	50 cm
RIGHT BOOM HEIGHT	50 cm

Figure 5. Interface and flow diagram of the state of active operation and group-operated solenoid valves.

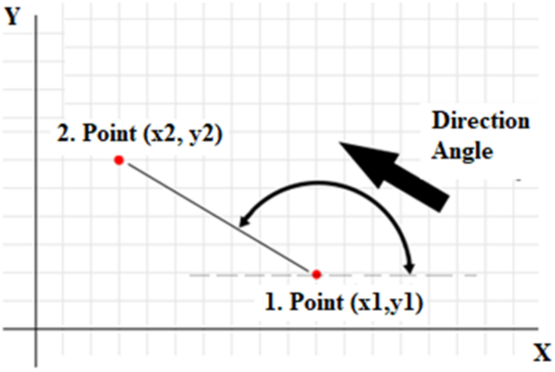


Figure 6. Schematic representation of finding location data between two points (Kahveci and Yıldız,2009).

Android-Based Mobile Phone Application

One of the most important aspects of the study was the implementation of a mobile phone application in the Android operating system. The application communicates with the electronic control circuit via Bluetooth, allowing all data to be monitored and saved from any location with internet access. The developed application allows the operator to monitor all data related to machine operation and adjust the required set values. Furthermore, the operator can follow the marker path and display it on the interface in its processed and unprocessed areas using the developed mobile phone application. Brief information about the most recent operation is displayed in the application opening screen, and buttons for switching to other menus are added to the interface of the software that serves as the intelligent field sprayer's brain.

The interface on the left in Figure 3 represents the program's first application page. The sprayer's arms' height can be adjusted using the (+) and (-) buttons on this screen, as well as the heights of the right, left, and middle sections. The communication between the electronic circuit and the booms can be started with the Open / Close-button for automatic control of the booms with electronic circuit.

In Figure 4, the buttons for switching to other menus are placed with the most recent operations on the second interface page on the right. It is possible to provide access to and registration of the desired information regarding data exchange and location data in this manner. The interface to the field location in Figure 4 is determined by clicking the Create Map button. This interface uses Google Earth map data to select the field location to be used in uneven field conditions. The position can be precisely determined using the field's position and the desired number of point data.

After the operation on the developed interface, the control option for the solenoid valve arrays is added to the software in the control section of the solenoid valves if the spraying nozzles are to be checked in how many groups (2 + 2, 3 + 3, and 4 + 4). Furthermore, the valves controlling the arm groups are determined to be more sensitive if they are independently within the selected area. It is thus possible for undesirable conditions to emerge for selective pesticide applications or variable rate applications. In addition, tools for map creation and display ease of use for group-controlled valves have been added. To improve the accuracy of GPS data, software filters have been developed. Positional deviations are significantly reduced in this manner.

Position data for selectively controlled nozzles can be seen with different colors from the mobile phone or tablet in Figure 5.

a b c

Figure 7. Parcels specified in Google maps.

When you exit the field, the position data on the screen turns a pale color to close the nozzles as a group. This component can function independently of the electronic control board. In other words, by entering work widths, different machines can be used.

The speed data can be seen on the screen depending on the GPS position on the same screen. When speed limits are exceeded, a color warning is displayed.

Determination of GPS Location

GPS requires at least four satellites (pseudorange) from four satellites in order to determine position. By multiplying the time and light velocity of the signal from the satellite to the receiver, the distance between the satellite and the receiver on Earth is calculated. The position can be precisely determined by arranging the formula with respect to the satellite clock and receiver clock deviations (Blewitt, 1997).

$$c.\ x(t_a - t^u) = P + c\ .x\ (\Delta t^u - \Delta t_a) + I + T$$

Where;

t_a and t^u: The GPS time the signal arrives at the receiver and the GPS time the satellite departs,

Δt^u and Δt_a: Satellite clock time as well as the difference between receiver and GPS time

I and T: The ionospheric and tropospheric effects between the satellite and the measurement point

c: light speed (m. s^{-1}),

P: The distance between the satellite and the receiver at the time when the signal is separated from the satellite and received by the receiver.

The coordinates of the satellite antenna installation point are found in the top synthetic length P (Kahveci and Yıldız, 2009).

$$P = \| U - A \| = x = \sqrt{(X^u - X_a)^2 + (Y^u - Y_a)^2 + (Z^u - Z_a)^2}\ 2$$

Where;

U: X^u, Y^u, Z^u : Satellite coordinates,

A: Xa, Ya, Za: Receiver antenna refers to the coordinates of the established point.

Because GPS equipment in devices varies in quality, it is not possible to obtain consistent GPS data on all devices. In particular, determining the orientation, or the position of the posture on the map, is critical for determining the right and left boom positions.

Devices lacking compass hardware cannot obtain orientation information. As a result, it can be discovered by performing mathematical correction procedures on point data. In this study, the direction of the mobile device was determined by comparing the data obtained from successive GPS data. Simple geometric formulas were used for this purpose. The angle formed by two points is illustrated below (Figure 6).

The java.lang.Math.atan2 (double y, double x) code was used to find the angle between these two points. This code,

java.lang.Math.atan2 (double y, double x) Converts rectangular coordinates. This method computes the phase of computing.

```
double X = dX2– dX1;
double Y= dY2 - dY1;

double directional Angle = Math.atan2 (X, Y) * 180 / Math.PI.
```

There are also filters for equipment that cannot receive consistent data. In case of receiving incorrect data, for example, filtering was made for the maximum change distance and maximum angle change amounts. However, since sequential data must be close to each other, data less than 10 meters apart are also eliminated for precise positioning. Furthermore, for the subsequent data, the maximum angle (orientation) change amount was determined to be 120 degrees. As a result, even devices with limited hardware can generate stable and processable data.

Field Experiments

Field trials were carried out at Ankara University's Faculty of Agriculture in Ankara. In the trials, both the GPS location data selective controlled spraying mechanism and map-based spraying were successful. During the trials, the system was tested at a speed of 3.5 km/h-1 in three different areas, and the coordinate data were recorded. The tests were carried out on parcels identified on Google Maps (Figure 7).

Results and Discussion

At the end of the experiments, there was a deviation of about 2 m from the test conditions prepared according to the field sprayer with a working width of 24 m. To save money, tablet computer GPS was used in the experiments. Despite the use of filtering software, the GPS deviation could not be reduced below 1-2 m. There were significant deviations of about 2 m in the rounded areas of Figure 7. RTK GPS system should be used to minimize the deviations in the location data or to reduce it to centimeter precision. To avoid large deviations in position data, McDougall et al. (2001) suggested the use of automatic steering system and precision (RTK) GPS. The same researchers emphasized that the Lightbar system can be used in this system, but its success is dependent on the operator's ability (Carmona,2018). The use of map-based selective control systems can aid in the reduction of agricultural activities (Ehsani et al., 2002). According to Luck et al. (2010), the costs are approximately 15-17% higher due to overlapping applications (Luck et al. 2010). The same researchers have concluded that section-controlled pesticide application can reduce overlapping application from 12.4% to 6.2%. In addition to GPS error, it is well known that the speed of movement and deviations caused by the operator are two of the most significant causes of deviation from targets. To prevent operator-induced deviations, automatic steering systems can be used. Automatic steering systems are a technique for reducing position deviations caused by the operator. Several researchers have also suggested that successful applications can be made using progression speed and precise GPS location data (Schueller et al., 1994; Gan-Mor et al., 2007; Garcia-Ramos et al., 2011). Furthermore, position deviations from GPS can be reduced further using automatic steering systems.

Conclusion

Within the scope of this research, an electronic control circuit and Android application were created for a spraying machine with a working width of 24 m. The nozzles of the sprayer were independently controlled in groups of 4 to 8 based on GPS location data. Based on Google map data, designs were made in the mobile application interface to display the processed and unprocessed areas as stripes in different colors. Embedded software developed in trials has proven to be functional. However, the position deviations did not fall below 1-2 m due to the low accuracy of the GPS used. In addition, deviations caused by the operator have also occurred. As a result, it can be said that the application created with a sensitive GPS and automatic steering system can be used much more sensitively and cost-effectively.

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