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Design and Implementation of Low-Cost Field Crop Sprayer Electronic Flow Control System

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Highlights

- An ergonomic system prototype produced in which chemicals do not harm the operator.
- Step by step electronic system creation details were presented.
- Compared to existing systems, the newly developed system is 40% more economic.

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Automation
Flow control
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Physical tests

Abstract

The purpose of this research is to present the designs required and methodology of prototype production to control electronically a mechanical-controllable system on a case study. The system under consideration is a field crop sprayer. The reason for the investigation of this system is operator exposure to the harmful chemical and inefficiency of flow control. It is necessary to precisely start and end the chemical flow at the requested location, to close a certain part of the spraying line, and to prevent overdosing during the pulverization. An Arduino system was designed to control a precise electronic flow system. In this regard, Mechanical flow-control valves are equipped with 16 bar pressure-resistant and chemical resistant solenoid valves. Designs were produced and prototypes were presented. Low-cost sprayer control systems (SCS) chemical losses were reduced by 6% to 20%. The ergonomic design increased the productivity of the operator. Moreover, this system reduced fuel consumption by 2% to 6%. It is 40% more economical than existing systems. As a result, productive electronic control was achieved in the field crop sprayer.

1. INTRODUCTION

The purpose of today's technology is to control and monitor many systems with electronic systems, and to increase comfort and standardization. For this reason, electrically and electronically controlled systems replace mechanical control levers and drive elements in the control of machines developed to increase the comfort of people [1,2]. Today, adaptive control system applications can be made without changing the mechanical structure of existing systems. However, this is possible with the design of a control system suitable for the existing system. A good design is only possible with capaciousness, evaluating all parameters interactively, and determining the design criteria. Design criteria are generally used to specify what the system should do and evaluate how it does. Determining the criteria in the design of automation systems is revealed by the correct analysis of the working mechanism of the system. Agricultural machinery is a mobile system. Therefore, the design contains many parameters [3]. Factors such as geometric information, cost, material, safety, energy, assembly, security, environment, strength, sustainability, recycling, modification, manufacturability, ergonomics, time, and maintenance of the automation system should be evaluated in the system under consideration. By evaluating these factors within a system, optimum automation system design is achieved. In this study, the control system adapted to a mechanically controlled system is handled with the systematic control design, which is a versatile evaluation method [4]. In today's agriculture, chemicals are used in the struggle against weeds, in plant nutrition operations with agricultural chemicals and micro elements, and in activities such as soil adjustment and enrichment [5]. Agricultural applications and researches have been focused on the application of these chemicals in liquid form. Many types of fertilizers and chemicals applied in solid form in the past have been applied today through spraying activities in liquid form. Liquid chemicals are sprayed in a pulverized state on soil, plants or pests together with a little water through agricultural pesticide machines [6].

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The use of chemicals in agriculture is beneficial and necessary in terms of high yields and food supply. However, the widespread use of chemicals causes human exposure to chemicals, potential environmental pollution and financial losses. One of the problems is that the operator is exposed to concentrated chemicals when preparing the tank mix and applying the mix in the field. Especially in field applications, the operator through respiratory and skin contact takes pulverized chemicals. These chemicals cause skin irritation, eye irritation, cough, dizziness, nausea and diarrhea. The effect is particularly high among those who do not take the protective measure. These effects are shown to be effective in cancer, Parkinson's and Alzheimer's diseases as well as in various disorders of the respiratory and reproductive tracts [7,8]. The biggest drawback of agrochemicals for weed and pest control is that they are very harmful to the environment and population that thereby makes their over-utilization a menace. Most of the farmers in Pakistan face health issues because of exposure to the agrochemicals while they are applied to crops/weeds [9]. Arielly F.B. de Oliveira et al. [10] detected that pesticides used in soybean farming can cause DNA damage. The other problem is that overused chemicals may be harmful to the environment. Only 30% of the pulverized chemical adheres to the crop or soil, while the remaining 70% pollutes the environment. This means a great threat to the ecosystem. The other problem is that unnecessarily overused pesticide leads to financial loss. The financial loss caused only by chemical loss in Europe is $ 30 billion [11]. Velandia et al. [12] saved $4 per ha to $26 per ha by adopting the technology that they have developed and reducing double-planted areas depending on the distribution of field types in a farming operation. Overlaying causes a great amount of financial losses at all agricultural operations and these losses increase every year. The desired amount of spraying of the drug or chemical to the target area depends on the precision of the sprayer controlled by the operator [13]. As a result, this system is a need for the operator who is exposed to the chemicals at first degree. In addition to this, overlaid and overdosed pesticides harm the environment and human health. Moreover, the chemicals that are used in fields are expensive. For this reason, there is a need for an economical sprayer flow control system to minimize financial loss.

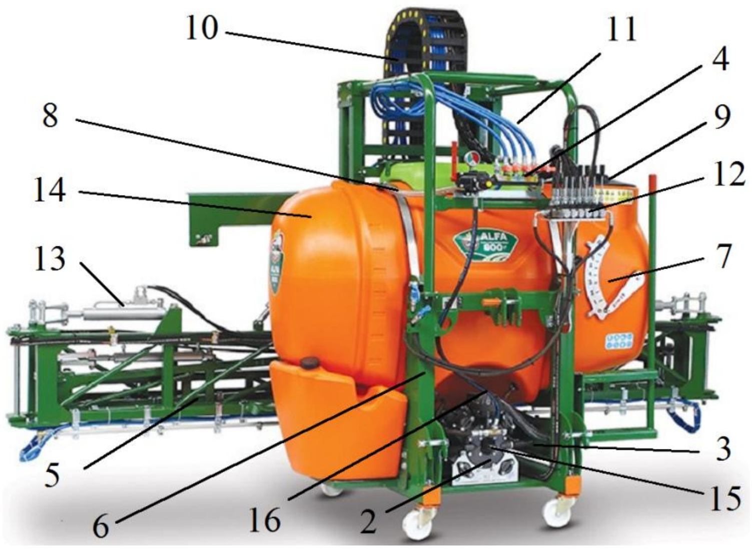
Sprayer control systems have been researched, and developed over the last few decades. Putra et al. [14] found that advanced, cost-effective technologies can rapidly increase the effectiveness of the expenses, labor, and time use. Andrade et al. developed a virtual calibration module for temperature, pressure, and flow sensors in the spraying system using an Arduino that can read CAN protocol. In 2012, R. Gonzalez et al. [6] developed a low-cost, and valid solution by controlling the embedded automatic pressure control system that works in greenhouses with a microprocessor. With the pressure-based sprayer control system, [15] Dickey-John SC1000 performed the operation with an application error of less than 5% at ground speeds ranging from 3.2 to 9.7 km / h. Chemical, fuel, and timesavings in spraying application were provided with precise guiding, and precise control of spraying. M.E.R. Paice et al. [16] conducted a study to determine whether the drug should be sprayed or not and which dose to apply with average weed density information in the field. In this study (2015), Hossein Maghsoudi [17] examined the machine walking speed, spray flow rate, and the neatness of droplet distribution. The study provided a reduction of about 34.5% in the use of variable rate chemicals. Zhihong Zhang et al. [18] enabled the dosing pump in variable rate garden sprayers to control chemicals below 5% error for desired speeds (up to 300 mL). Many agricultural applications have been done with Arduino [14,19-24]. In this study, an Arduino based flow control system prototype was developed for the electronic control of manually controlled sprayers. The innovations of this research can be summarized as follows: with this prototype, an industrial circuit board design was actualized, and produced in which the low-cost Arduino microprocessor can be assembled. A durable, stable, economic, and ergonomic system without heating problems was produced.

The main objective of this study is to create a simple, low-cost electronic system able to be utilized by farmers, able to be adapted to the existing manually controlled field crop sprayers. Within this context, the systems of the existing field crop sprayers were scrutinized in the first place. The flow chart of the electronic system was created. The appropriate Arduino model was selected, and the required components were determined. A compact design appropriate for buttons and LEDs, encompassing information for the operator was created through CATIA. The panel with IP65 protection class for the operator panel was produced out of ABS material by being processed with CNC. The electronic circuit board was created and produced via the online PCB design software EASYEDA. In the flow system of the field crop sprayer, solenoid valves were installed and the cable assembly was produced. Arduino software was produced. The current drawn by the control system was measured. The drawing current optimization was done for the sprayer control system not to harm the electrical system of the tractor and the valves were powered respectively. The temperature rising test for the board was implemented for the case where all solenoids were energized.

2. MATERIAL METHOD

2.1. System Functions of Existing Manually Controlled Field Crop Sprayers

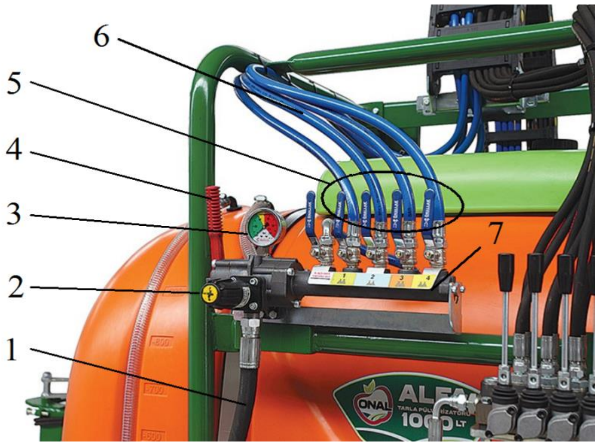
Spraying machines are propelled by power take-off (PTO). This energy is activated by the booster pump of the spraying machine. The pressurized fluid is pulverized by passing through filters, manually controlled valves, the pressure regulator and nozzles with micron-sized holes respectively. It can be seen in Figure 1 a manually controlled suspended field crop sprayer. Their pump pressure generally ranges between 0-50 bars.



1-Tank
2- Pump
3-Filter
4-Pressure-regulating regulators and valves
5- Booms and nozzles
6-Chassis
7-Level indicator
8- The return and hydraulic, mixer hose
9-Fuel lid
10-Hose assembly
11-Compressed flow lines
12-Hydraulic manual controls of the boom
13-Boom cylinder actuators
14-Tank
15-PTO connection
16-Pressure line

Figure 1. *Field crop sprayer of the suspended type, with hydraulic boom, with a manual flow control*

The return-to-tank pressure of the pressurized fluid reaching the regulator is adjusted via the pressure-regulating valve located on the regulator. Figure 2 demonstrates the settings for manual control and the flow. The pressure is adjusted by swerving the regulating valve numbered 2 after reading the pressure on the manometer. If all valves are closed, the system pressure rises to the pressure having been adjusted via the pressure regulating valve, and the fluid returns to the tank and does its part as hydraulic mixing. If all or a number of valves are open, flow from the nozzles commences and pressure builds up in the system. The focal point of this study was to control the flow electronically via the solenoid valves inside the cabin instead of using manually controlled valves numbered 5 and 4 in Figure 2.



1-Pump pressure line
2-Pressure regulating valve
3-Manometer
4-Manual control (all lines)
5- Manually controlled valves
6-Pressure flow lines (4 pcs)
7-Regulator

Figure 2. *Manually controlled valves and field crop sprayer flow system*

2.2. Problems and Losses Caused by Manually Controlled Flow Control Valves

To control the valves, the window of the tractor cabin should be open. When this window is opened, the operator is exposed to toxic and deleterious chemicals. When the operator closes this window again during the operation, he creates for himself a room full of poison. This creates an important health problem (Figure 3).

Stimulating the manual valves causes uncontrolled movement of the tractor for approximately 15 secs. This is a serious problem in terms of job security.

A duration of 15 secs is too long for the control of valves. This causes loss of chemicals at significant amounts.

Especially because active flow control cannot be implemented in non-rectangular, triangular, and curved areas, application of overdose occurs as a result of double spraying. This harms nature, crops and productivity, the soil and causes financial loss.

Even in wheat cultivation where there is the least amount of need for pesticides and for plant nutrition, the minimum number of pesticide operations has risen to 4, over the last 10 years in particular. As these operations are implemented continually, the number of errors is multiplied.

If manually controlled valves are controlled after the tractor has been stopped rather than when the tractor is moving, spraying at an overdose transpires at the place where the tractor has stopped in this case. This means loss of chemicals and of fuel.

Figure 3. *The use of manually controlled valves by the operator*

2.3. Design of A Low-Cost Electronic Flow System

Without hindering the manual use of the current agricultural sprayers, the design of a low-cost electronic flow system that can be adapted into the system and was produced. The operator panel was designed in a suitable size for the hand-use of a farmer and for the use in a vibrant and resonant environment. The system comprises seven buttons, 14 LEDs, an operator panel with IP65 protection class, an Arduino-based electronic circuit board, a cable assembly and 6 solenoid valves that were shown in Figure 4.

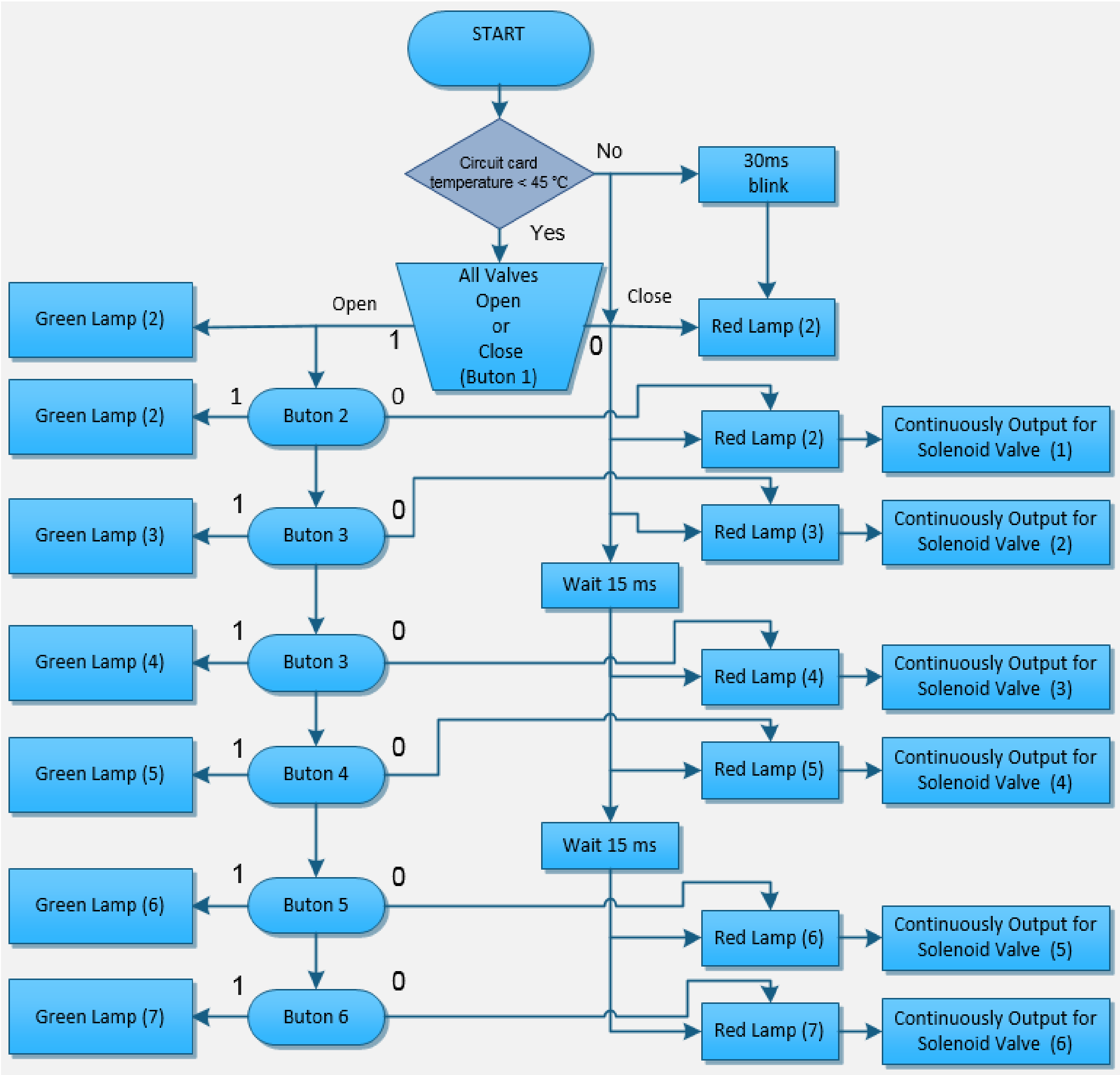


Figure 4. *Flowchart of sprayer control system*

2.4. Low- Cost Microcontroller: Arduino Nano

There are 8 inputs and 14 outputs in the control system. Arduino nano was considered appropriate due to the count of inputs and outputs and because it has a small size.

The system was designed as two PCBs that are the main board and led board. The mainboard was supplied with 12V provided by the electrical system of the tractor. The mainboard was designed in the manner that Arduino nano could be assembled by headers without being soldered.

Normally open solenoid valves were chosen for the flow control. Red and green LEDs were used to define if the solenoid/solenoids are open or not. In a case, that the heat of the mainboard was over 50 °C. a security control system that gives a warning and turns the valves off was created.

2.5. Operator Panel Design

An ergonomic design at optimum dimensions was achieved through CATIA V5 R20, a three-dimensional, advanced solid modeling software (222 x 146 x 75). 7 buttons, 1 switch,1 safety fuse, 7 green and 7 red led sockets were placed on the project box. Moreover, geometries identifying the system and the relationship of buttons with LEDs were produced (Figure 5). Penetration of dust was prevented in full measure; damage likely to be exerted by the entry of low-pressure water that can reach from any direction was prevented thanks to IP65 protection [25].

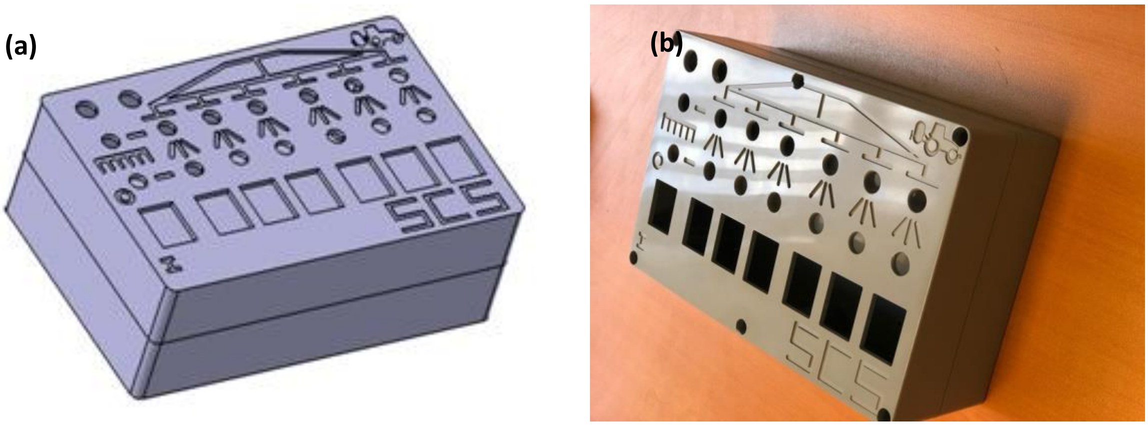


Figure 5. *a) 3D solid model of the Operator Panel b) The operator panel was processed via CNC*

2.6. Solenoid Valve Selection

Solenoid valves (Figure 6) utilize electricity in order to open and close a hole (an orifice) on the valve body. In this study, a normally open valve at the power of 12 volts and 17 watts and resistant against 16 bars pressure, corrosion and chemicals were used. By using normally open valves, the system was adapted for manual use in case of a power cut (Table 1).

Figure 6. *Solenoid valve*

Table 1. *Technical specifications of the solenoid valve*

The count of pathways: 2/2
Position: Normally open
Manner of Operation: Pilot-operated
Sealing element: Viton diaphragm
Connection line size: 1/2"
Orifice: 12 mms
Max flow rate: 65 l/min
P_{max}: 16 bars
T_{min} / T_{max} : -10 ºC / 80 ºC
Weight: 640 g

2.7. The PCB Design of Sprayer Electronic Control System

To obtain successful results in the industrial and experimental studies, circuit cards must be used. Several parameters are efficient in the design of PCB, and minimum space is aimed. The PCB design is achieved through the identification of the field, algorithm, components and the functionality of the board. There are goals, calculations and rules for the board design. For the operator panel to be in a suitable size, PCB was designed as double-layered, and no coolant was needed. The calculation of the board track width must be done in such a way that the temperature rise will be at 10 ºC. Calculation of line width is implemented in PCB design based on copper foil thickness, the amount of the current, and the permissible temperature rise.

A solenoid draws a current at the amount of 1.43 A. 6 solenoids draw a current of 8.58 A. In this study, because the board had IP65 protection, board bed widths were implemented in accordance with inner layer calculation. Calculation of inner and outer layers was carried out via Equations (1) and (2) (https://www.4pcb.com). A: Area ($mils^2$), I: Current (A), Δt: Temp. Rise (°C), W: width (mils), t:thickness (oz).

$$A = \left(I/k * \Delta t^{b}\right)^{(1/c)} \tag{1}$$

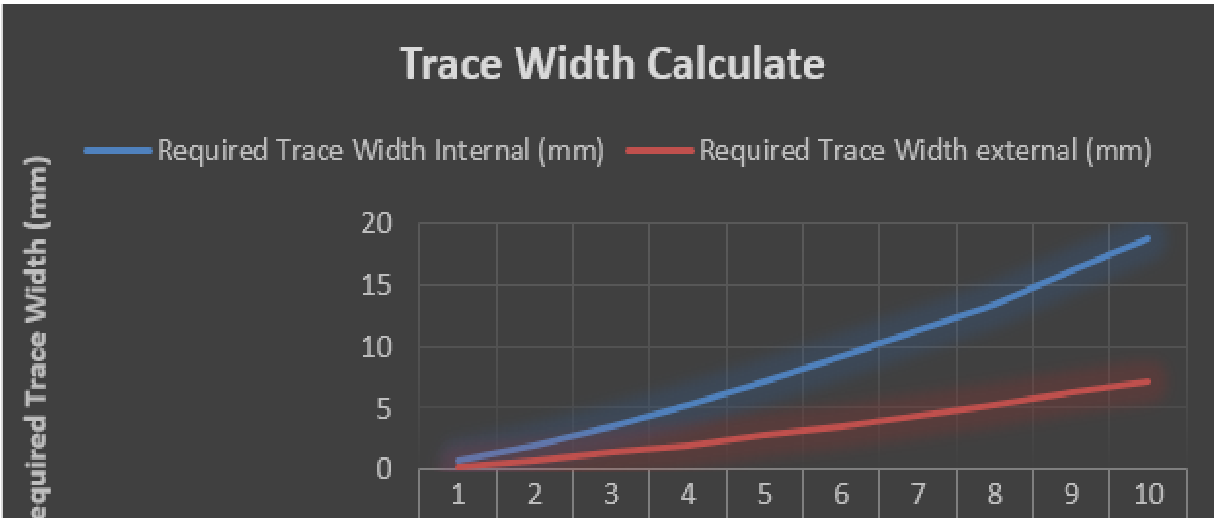
Then, the Width was calculated:

$$W = A/(t * 1.378) \tag{2}$$

For IPC-2221 internal layers: k = 0.024, b = 0.44, c = 0.725

For IPC-2221 external layers: k = 0.048, b = 0.44, c = 0.725.

The change in the trace width in accordance with the current value was able to be seen in Figure 7.



Current (A)	1	2	3	4	5	6	7	8	9	10
Required Trace Width Internal (mm)	0,781	2,03	3,56	5,29	7,19	9,25	11,4	13,4	16,2	18,7
Required Trace Width external (mm)	0,3	0,781	1,37	2,03	2,77	3,56	4,4	5,29	6,22	7,19

Figure 7. *Trace widths for a temperature rise of 10 °C in accordance with the current value*

The system consists of 14 MOSFETs, 6 relays, xt60, 12V-5V dc-dc converter, 10k and 1k resistances, connectors, Arduino nano, 6 diodes, 2 condensers and 14 LEDs.

The board design was conducted via the online EASYEDA software by considering Arduino nano as at the center of the style of design. The drawing of the board including the limits of the card size and the holes were imported. The electronic components on the board area were utilized from the library and were placed. The paths of the components were dimensioned according to current and heat calculation. Thus, the design of the card was completed by considering many parameters. The Gerber file of the board was produced and hence, was prepared for printing Figure 8 (a). The mainboard and the led board were produced in one piece. The top view of the produced board was shown in Figure 8 (b).

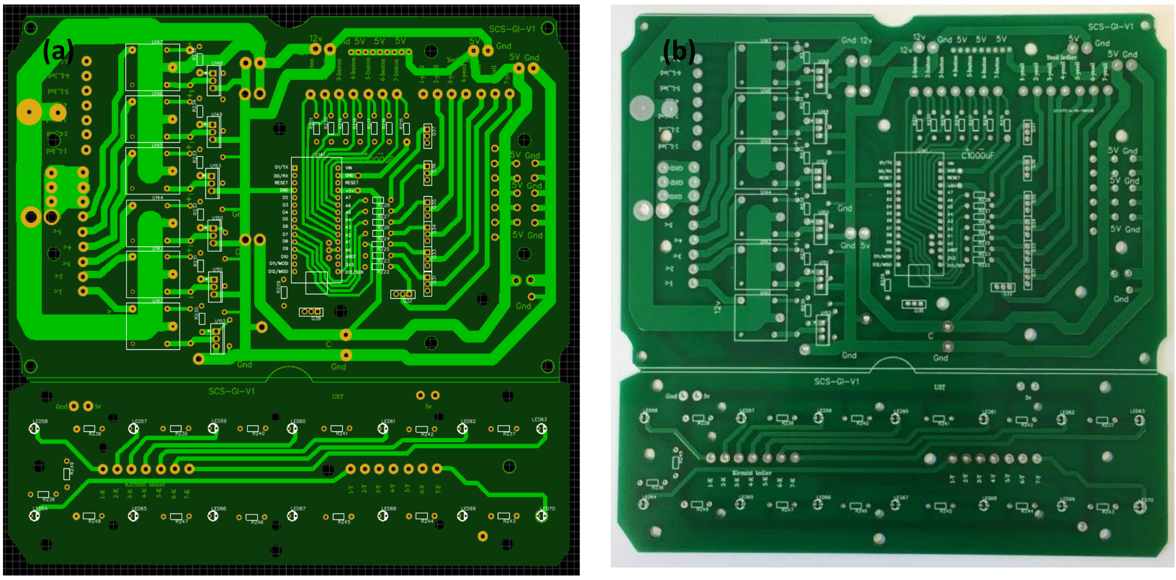


Figure 8. *a) Drawing of a double-layer circuit board (b) The produced form of the circuit board*

The integrated board and the LED board were cut out of the lines seen in Figure 9. Red and green LEDs, resistors, 2 7-pin connectors, one power connector were soldered on the led board. Since the upper surface of the board will be installed onto the bottom part of the upper lid of the box, there are only LEDs on the upper surface. They were soldered onto the bottom surface of the board.

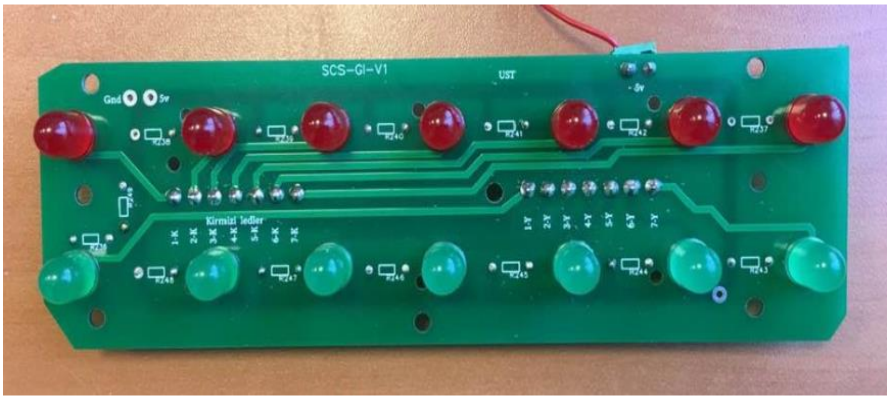


Figure 9. *Led board installation*

The motherboard and its components were shown in Figure 10. Lm35 temperature sensor installation was implemented underneath Arduino headers in the center. The Dc-Dc converter implements 12V-5V conversion. 9 pin output connectors, 7 pin red led connectors, Relays, diodes, MOSFETs, button input connectors, the green led connector, resistors, capacitors, energy socket xt60, energy pin and 5v energy connector were seen in Figure 10. Via open-source Arduino Software (IDE), the software was created for the algorithm seen in Figure 4 and was loaded into the Arduino nano.

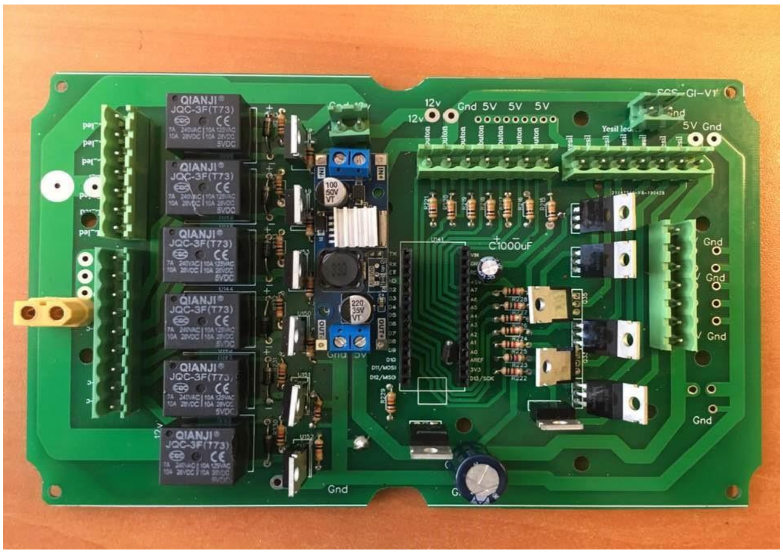


Figure 10. *Installation of circuit board elements on the motherboard*

The operator panel, LEDs, buttons, the energy switch, and the safety fuse were seen in Figure 11. On the left is the energy connector; on the right is the signal connector. The operator panel is at the size of 222 x 146 x 75mm. Solenoid valves were installed at the filter inlet connection point without any mechanical modification implemented on the manually controlled field crop sprayer used for testing. Six valves were shown in Figure 12.

Figure 11. *Sprayer control system operator panel*

Figure 12. *The installation of the valves*

The panel was installed in such a way that it could be used ergonomically (Figure 13 a) and supply was provided through a 12V cabinet socket (Figure 13 b).

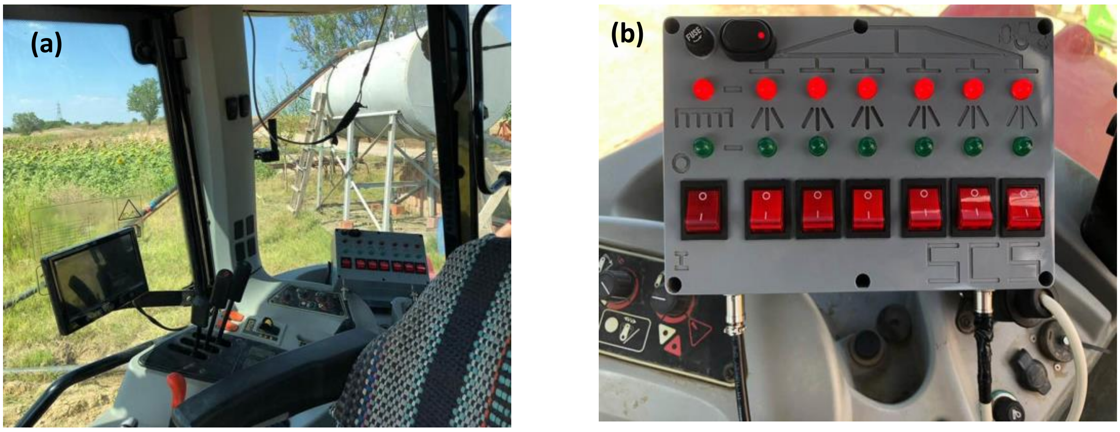


Figure 13. a) Position of the tractor cabin and of the operator panel b) The operator panel inside the tractor cabin

In this way, the cable assembly was formed between the panel and the valves by only one cable; the system and its creation were completed.

3. RESULT AND DISCUSSION

3.1. Low-Cost Electronic Field Crop Sprayer Control System

Today's economic conditions increase the cost of agricultural production in all aspects. This situation restricts farmers working on small and medium sized land in terms of purchasing new equipment. Therefore, this system, which provides the farmer with time and cost savings in production as well as protecting its health, has been reduced at an economically accessible cost. Similar products produced in the market have superior features in some ways. However, low-income farmers cannot purchase these systems. The prices of similar control systems were shown in Table 2. The developed system (SCS V1) was 40% cheaper than the closest control system.

Table 2. *Comparison of control system price*

Brand	SCS	TeeJet	Raven	Micro-trak
Model	V1	744A	Scs450	Spraymate II
Description	6 sections	3 sections	6 sections	3 sections
Price	$348	$580	$1410	$1104

3.2. Field Tests of The Sprayer Control System

Installation of the system was completed and the test through the field crop sprayer was carried out. 200 liters of water mixed with red powder paint was put into the field crop sprayer whose boom was unfolded, which was seen in Figure 14. Luck et. al [26] examined how the rise in the number of sections affect reducing the losses and they found that when compared to one section control, three control section made a reduction in overlapped areas ranged from 8% to 8.5%, five control section made a reduction ranged from 11.2% to 11.5%. In this study, 6 section control was used which was seen in Figure 14. The field crop sprayer pump was propelled through PTO. Each compartment was separate from the other and all the system opening and closing were tested through the operator panel.

Figure 14. *A general field crop sprayer, boom partitions and SCS-V1 system tests*

The test of the system was presented in video 1 through the use of the operator panel. The leftmost button numbered 1 close and opens the flow for the entire system. It controls 6 valves connected to 6 sections of a triad of machines that are 2 in the count. Red LEDs indicate that the flow is off for the entire system. The simultaneous shooting was implemented in video 2 with two cameras. The flow control in buttons and the field crop sprayer was seen. Starting from compartment 1, the flow was commenced in each compartment respectively. The flow was cut off and recommenced in all sections. The system successfully worked.

Video 1. *System operator panel*

Video 2. *System test*

An ergonomic system was produced for the operator. It was sufficient for the operator to use his fingers to control the system. Tractor control was thus made safer. When the flow was completely closed, the machine switched to the hydraulic mixer. The operator is not exposed to chemicals. The connection of the machine to the operator panel was quickly realized with a single cable installation. Moreover, as the open-center valves were used during the spraying activity, they were energized even in off position at approximately 10% of the machine's operating time. This provided a considerable amount of energy savings. Cutting off some parts of the flow did not change the sprayer pressure. This feature stabilized the amount of dose (video 3).

Video 3. *System pressure*

To examine the geometry of agricultural lands in central Edirne, aerial photographs from Google earth were taken. Nearly 70% of the lands were not in a square or rectangular shape. Also, the lands did not have straight edges in general (Figure 15).

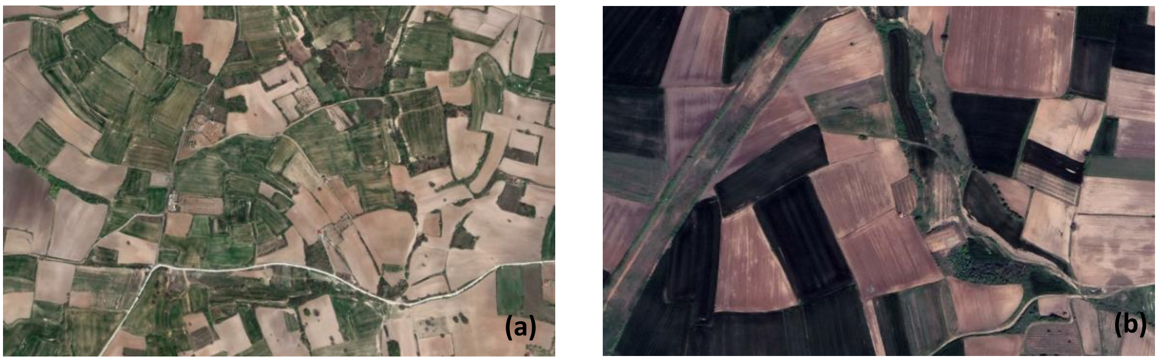


Figure 15. a) Google earth aerial pictures of fields in Edirne b) Google earth aerial pictures of fields in Sazlidere

The advantages of the flow control system and section control for 15m. Wide sprayer was explained in the figures that consider the aerial geometrical shape samples (Figure 16).

In Figure 17 (a), it was seen that the sprayer overlapped and it applied the pesticide outside the required field. This problem was solved by section control. In Figure 17 (b), an agricultural spraying operation was simulated. When the electronic control system was not put into practice in the spraying operation, the cabin window had to be opened 8 times for manual control. When flow control was not used in the system, the percentage of overlapping is 45.5%. Also, 1% uncontrolled spraying occurred outside the required field. When the electronic control system was used, the percentage of overlapping was approximately 3.2% thanks to the six separated sections. In addition, the tractor did not move uncontrollably.

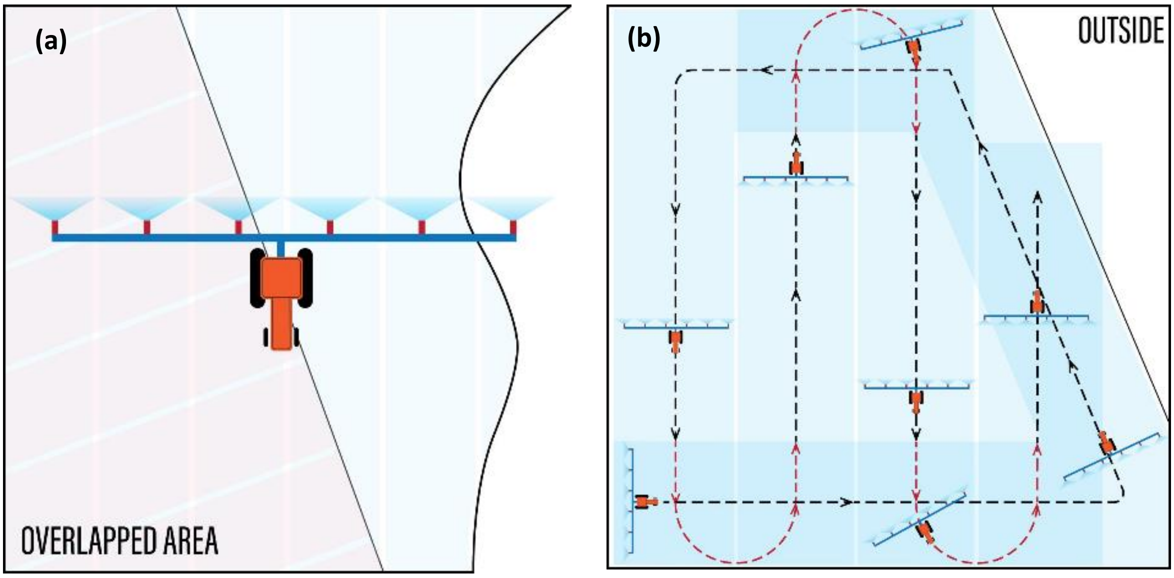


Figure 16. *a) Spraying misapplication b) The simulation of spraying operation*

Chemical losses were reduced from 6% to 20% depending on the geometry of the land. This calculation was made considering the work of the machine on field geometry. The system reduced fuel consumption by 2% to 6%. Because during the spraying process it was not necessary to stop for control.

3.3. Impact of The System on Agriculture, The Environment, and on Chemical Loss

For sustainable agriculture, it is important to develop methods that protect the soil, plants and human health, and feed the growing population. Machine flow control was performed ergonomically via buttons by the operator. In this way, fuel and pesticide losses were prevented. Loss of pesticides due to reasons such as superposition, etc. was prevented and financial gains were guaranteed. It is important to increase the technological level of electronic and electrical systems and agricultural mechanization, through efficient use of the machine. Within this context, the use of electronic systems in field crop sprayers rather than their use with manually controlled valves is more beneficial. Precision agriculture is recognized as the provider of efficient and sustainable agriculture in the future.

Video 1- https://youtu.be/eIBLckHtxtE

Video 2- https://youtu.be/e--T1V0XMNY

Video 3- https://youtu.be/4c6namCgHtU

4. CONCLUSION

The design procedure of an Arduino based electronic sprayer control system was presented in details. The electronic circuit board was designed and produced as a prototype. After that, it was tested for the operator panel. Following conclusions could be drawn:

A technological flow system, which can be adapted to existing sprayers, is low-cost, ergonomic, and does not harm the operator with toxic chemicals.

Six flowlines of the sprayer can be closed at the same time or individually with a button. Closing some of the sections does not change the sprayer pressure.

Impulse voltage drop in the tractor electrical system was prevented with the software. Efficient sprayer flow control was provided.

Valves were tested in operation for approximately 200 hours in 2 years of use. A long-lasting system was created with economical Viton valves resistant to chemicals and 16 bar pressure. With these open-center valves, the system can be used with manual valves in case of any electrical failure.

In the spraying process, starting and ending the chemical flow precisely at the requested location, closing a certain part of the spraying line and preventing overdosing are provided with this control system. Overdose spraying was prevented, especially on lands with triangular and curvilinear geometry.

Low-cost sprayer control system (SCS) chemical losses were reduced by 6% to 20%. The ergonomic design increased the productivity of the operator. Moreover, this system reduced fuel consumption by 2% to 6%. It is 40% more economical than existing systems and as a result, efficient electronic control was achieved in the field crop sprayer.

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CONFLICTS OF INTEREST

The author declared no conflict of interest.

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