Design, Development and Implementation of Automatic Transplanting based on Embedded System for use in Seedling Transplanters

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Abstract

Hand transplanting of vegetable seedlings is always been a time consuming and labourious activity which often leads to muscular fatigue. Use of hitech instrumentation increased to achieve precision and automation in agricultural operations. At present the transplanting is done manually which accounts for large amount of hand labour and time. To ensure precision and timeliness in operation, an automatic transplanting based on embedded system for use in seedling transplanters was developed. The developed system consists of feed roller, pro-tray belt, a pair of L-shaped rotating fingers, embedded system, DC and stepper motor. The pro-tray on the belt moves by DC motor whereas, the stepper motor was used to actuate the metering shaft to and from. The ground wheel used to rotate the rotating fingers which eject the seedling from the pro-tray into the delivery box. The performances of the developed system was tested rigorously at four different operating speeds (vf) (1.0, 1.5, 2.0 and 2.5 km/h) and three angles of pro-tray feed roller (00, 300, 450) for attaining optimum plant to plant spacing in soil bin. The result indicated that percent transplanting and plant to plant spacing was found optimum when speed of operation was 2.0 km/h and angle of pro-tray feed roller was 300. The average plant spacing, transplanting efficiency, furrow closer, angle of inclination and miss planting was 600 mm, 91.7%, 90.3%, 18.30 and 2.1%, respectively. The developed system ensures the precision by sigulating the placement of seedlings at optimum spacing. It also enabled the optimum transplanting rate, the ability to transplant at higher speeds and maintaining proper plant to plant spacing.

1. Introduction

Precision is very important criteria for transplanting of vegetable seedlings at right time, at right moisture content and at equal interval to facilitate other intercultural operations. Also, the crop yield increases per unit area when plant to plant spacing in the field is optimum [1-3]. In other words, using automatic vegetable transplanters (AVTs) cut down the production cost as well as permit timeliness in operation, as vegetable seedlings are very sensitive to climatic conditions. However, labour shortage during peak season causes delay in transplanting, leading to drastic reduction in yields [4]. The major constraints in increasing vegetable productivity are the low level of mechanization and quality of seedlings. Mechanized cultivation, along with other improved crop production practices, can increase crop yield and quality. Manual transplanting on a large commercial scale is labour intensive, expensive, and often does not result in uniform distribution of plants compared with mechanical transplanters [5]. Also, feeding of seedlings to the delivery unit in semi-automatic transplanters were difficult due to singulation, selection, alignment and manual transfer of seedlings that depends on the skill of the operator.

The performance of transplanters during planting is very important for attaining uniform plant spacing. The most important component that directly affects the performance of transplanter is metering mechanism [2,6-8]. Metering mechanism has generally been the component that has been worked the most during the development period of transplanters. Studies have been carried out mostly on the development of metering mechanism used in the transplanters for seedling pick-up from pro-tray and delivery into the furrow. The most advance type of vegetable transplanter uses application of robotics where the pick-up mechanism is mostly controlled with electronics in AVTs. This type of mechanism is gaining attention for efficient planting of seedlings, maintaining the accuracy, precision and effectiveness in planting seedlings with minimum human intervention. Here, the seedling pick-up is an important concept, where a single seedling is extracted automatically from the tray with the help of a pair of pin or fork, then discharged into the furrow and again retracting back to its starting position. Developing a robotic transplanter requires specialized mechanism. This type of mechanism uses computer graphics or machine vision system and end-effector mechanism for extracting the seedling [9,10]; gripper and a manipulator [11-13]; indexing drum type seedling removal device with ejector [14,15]; or a pick-up system, a planting system and a feeding system [16-20].

Simonton [21] developed an end-effector for controlling the position, velocity and force to minimize damage to the petioles and main stem of geranium cuttings. A rack and pinion type end-effector was developed that convert rotational motion of the stepping motor to the clipping motion of the finger [22]. A machine vision system was used to detect the unsuccessful transplanting [23]. A robotic transplanter developed by Tai et al. [10] uses machine vision system to locate empty cubes and also guides re-transplant healthy plugs into empty cubes.

Ryu et al. [17] developed an end-effector using a pneumatic system which can grip, hold and release a seedling plug during transplanting. This system uses microcomputer to control the slide actuators in the manipulator. The moving distance and the speed of the slide actuators were calculated and the results were transferred to a control unit to operate the slide actuator driver units. The performance of the vision system was evaluated by identifying empty cells in 72-cell trays and 128-cell trays with 16 days old cucumber seedlings.

Working with robotic transplanters that uses electronic system has specific requirements (micro-controller based system, stepper and DC motors, data interface system, complex calibration processes, plant to plant spacing, etc.) and there is no scientific study that compares their performance. Furthermore, these developed AVTs with different metering mechanism were either very expensive or not meeting the farmer’s expectations. In addition to these, experimental studies to overcome the constraints mentioned in developed transplanters and to provide a solution that can singulate and precisely deliver the seedling into the furrow at specified interval are still under progress. This paper describes the design, development and implementation of an innovative Embedded System based Automatic Transplanting of plug-type vegetable seedlings used in seedling transplanter and also to investigate its performance.

2. Structure And Working Principle

2.1 Transplanting object

The vegetable seedlings of chilli (Variety-Pusa Jwala) are used as transplanting object. The seedling tray is a conical tray of 104 pots. The depth of the pot is 30 mm. The spacing between the consecutive pots is about 4 mm. Each pot section has a top and bottom diameter of 32 mm and 20 mm, respectively. Generally, the seedling substrate i.e. coco peat, vermiculite and perilite were used in desired proportion of

3:1:1, respectively for raising vegetable nursery in pro-trays. The 30 days old seedlings having 4-5 leaf are suitable for transplanting in field (Figure 1a). Since, the testing of the developed transplanter requires lots of seedlings, so dummy seedling of similar dimension i.e. height and weight was prepared (Figure 1b). The average stem diameter, height and weight of the seedling were 0.1 mm, 96 mm and 14.7 gm. To add some weight, the mixture used for growing nursery includes coco-peat, vermiculite, perilite and soil in proportion of 2:1:1:1, respectively. The soil of the farm was black cotton soil (plasticity index 20–65%) with 95% of clay and silt, and 5% sand. Average bulk density of soil was 1.63 g/cm3 at 14.6% moisture content (db). The soil used had an average pH = 6.2, EC = 0.045 mhos/cm2 with nutrient contents of N = 0.012%, P = 4 ppm, K = 85 ppm and organic C = 0.38%. The sand was the other component mixed with soil in equal proportion to add air space and weight to the potting mixture. Cleaned and washed medium sand with particles in the range of 0.425–2 mm was used.

2.2 Structure of seedling transplanter

To avoid shattering of plug and damage to the seedling, the seedling should be released as close as possible to the ground from the pro-tray in the direction of forward travel of the transplanter. The transplanting system mainly consists of a feed roller, pro-tray belt, a pair of L-shaped rotating fingers, embedded system, DC and stepper motor (Figure 2). The "L-shaped" rotating fingers are mounted on the metering shaft which is connected with the ground wheel as well as stepper motor. The ground wheel is used to rotate the shaft at a specified forward speed whereas the stepper motor is used to move the metering shaft to and fro with the help of micro-controller. The electronic switches are connected to change the direction as the switch was pressed. The DC motor was used to actuate the feed rollers so that the next row comes to the striking position when switch was pressed. The ground wheel used to rotate the rotating fingers which eject the seedling from the pro-tray into the delivery box.

2.3 Working principle of seedling transplanter

For automatic control and functioning of the system, embedded system was developed. The working principle of the seedling transplanter is shown in the Figure 3. The developed system was driven through a ground wheel, stepper motor and DC motor. The ground wheel was provided on one side of seedling transplanter, which is used to rotate the metering shaft in the forward direction whereas the stepper motor was used to move the metering shaft to and fro. The DC motor was used to rotate the feed roller shaft as per programme. The metering mechanism was controlled by a micro-controlled based system by actuating the stepper motor and DC motor as per the programme. The feed roller has to feed one pro-tray of seedlings at a time to the metering system. The sprocket of the ground wheel has 28 teeth and 14 teeth sprocket on the idler shaft. The increase in speed is in a ratio of 2:1.

Again, the idler shaft has sprocket with 20 teeth and sprocket on metering shaft with 12 teeth. The increase in speed is about 1.7 times. This rotational speed is used to eject out the plug seedling from the pro-tray into the delivery box. The velocity ratio between ground wheel shaft of the feeding mechanism and metering shaft is taken as 3.4:1.

2.4 Design of embedded system for automatic transplanting

To release seedling at optimum spacing, a novel transplanting mechanism was developed which is controlled by electro-mechanic system to automate the operation. In this system ArduinoUno microcontroller is used for operating the driver of DC motor and stepper motor (Figure 4). Microcontroller generates PWM signals of different pulse width for both dc and stepper motor. Here, two leaf switches are used for changing the direction of stepper motor attached on MS sheet at 120 mm apart. Both the switches were pressed with the help of special bush attached on the metering shaft. When stepper motor moves and its presses the right switch, then controller receive signal from switch digital pin and it gives digital output at direction pin of stepper motor driver. Thus, motor rotates in clockwise direction and when left switch is pressed stepper motor moves in anti-clockwise direction. As the direction of stepper motor changes, DC motor turn ON with delay of 1 second and after 75 milliseconds DC motor becomes off. The DC motor makes to moves only in anticlockwise direction so that the feed roller rotates in forward direction. The microcontroller provides 5V DC voltage as power supply for both drivers. A 12 V DC battery is used as power supply for both motors and microcontroller.

2.5 Design requirement of the seedling transplanter

The vegetable transplanter developed for plug-type seedlings are generally semi-automatic type which consists of either pocket-type, cup or bucket-type or conveyor-type metering mechanism that uses bare root, plug or pot type seedlings for transplanting. Also, it was observed that the existing system is costly, labour intensive and has low field efficiency. The developed seedling transplanter should perform the following functions:

i. Open the soil in form of narrow furrow section
ii. Extract/eject single seedling at a time in the delivery box
iii. Place seedlings vertically upright in the furrow and
iv. Cover and compact the soil around seedling

3. Design And Development Of Experimental Transplanting System For Plug-type Seedling

The experimental setup was designed and run in soil bin. The different components of the setup were as follows:

i. Experimental transplanting system
ii. Embedded system

3.1 Experimental transplanting system for seedling transplanter

To avoid shattering of plug and damage to the seedling, the seedling should be released as close as possible to the ground in the direction of forward travel. To achieve this, a seedling transplanter was designed and developed which consists of a pair of “L-shaped” rotating fingers, pro-tray feed rollers, belt, metering shaft, pro-tray guides, delivery unit and embedded system. The developed experimental setup in soil bin laboratory is shown in the Figure 5. To address the two rows, pair of “L-shaped” rotating fingers was mounted on the metering shaft at distance of 120 mm. The metering shaft is connected with the ground wheel as well as stepper motor. The rotating fingers ejects out the seedling from the pro-tray while rotating on the metering shaft. The ground wheel was used to rotate the shaft at a specified forward speed whereas the stepper motor was used to move the metering shaft to and fro.

A single seedling was pushed out from the pro-tray into the delivery unit and placed in the furrow through the delivery tube. For more effective delivery of single seedling, pro-tray guide and pro-tray press assembly were provided. The pro-tray guide was used to guide the pro-tray in the specified path whereas, pro-tray press assembly “1” was used to press the pro-tray horizontally and pro-tray press assembly “2” was used to press the pro-tray vertically. The length of rotating finger was adjustable and kept just enough to eject out the seedling out of the pro-tray with ease. The seedlings spacing between them can be adjusted by increasing/decreasing the forward speed of the machine. The spacing can also be changed by changing the ratio between forward speed and rpm of the metering shaft. The complete specification of the developed two-row seedling transplanter is given in Table 1.

Table 1. Specifications of developed two row seedling transplanter

Sl. No.	Particulates	Specifications
1	Processor	ATmega328
2	Power supply mode	12 V Battery
3	Digital I/O pins	6
4	DC current per I/O pin	40 mA
5	SRAM	2 kB
6	EEPROM	1 kB
7	Typical light running current, A	3 A
8	Rated torque, Nm	50 Nm (feed roller unit); 2.2 Nm (metering unit)
9	Normal speed, rpm	72 (feed roller unit); 82 (metering unit)
10	Overall dimension (l x b x h)	2030 x 1295 x 1015 mm
11	Weight of seedling transplanter	210 kg

3.2 Embedded system

An embedded system for seedling transplanter comprised of microcontroller board (Arduino Uno), DC motor, stepper motor and button switch. Arduino board has 2 kB SRAM and 1 kB EEPROM, it have 14 digital input/output (I/O) pins (of which 6 can be used as PWM outputs), 6 analog inputs, a USB port, a 16 MHz crystal oscillator, a power jack, an in-circuit serial programming (ICSP) header, and a reset switch. The micro-controller was configured by using open source Arduino software to upload new code without use of an external hardware programmer. The micro-controller board can be powered via USB cable from laptop as well as external power supply adapter. The programming of microcontroller based system was done in C language.

3.2.1. DC motor actuating unit

DC motor driver was used to operate the DC motor. Since this driver provides Pulse Width Modulation (PWM) signal generated by microcontroller to motor, the microcontroller able to control the switching action of dc motor. It comes with a simple Transistor –Transistor- Logic (TTL) or Complementary Metal oxide semiconductor (CMOS) based interface that can connect directly to the IOs of an MCU. It has a breaking feature that can immediate halt the shaft of motors in most high power applications and also includes protection circuitry to avoid any electrical fluctuations affecting the normal operation of Microcontroller Control Unit (MCU). This driver can move the motor in both directions. DC motor was operated at 12V and 5V was providing to DC motor driver by Arduino for operating the motor at constant speed. Controller generates PWM for controlling the speed of motor and it also set the direction of motor clockwise or anticlockwise. DC motor was used for controlling the longitudinal movement of feed roller.

3.2.2. Stepper motor actuating unit

TB6560 stepper motor driver was used for controlling the direction and switching action of stepper motor. This driver receive PWM and direction signal from digital pins of microcontroller. Microcontroller controls the operation of stepper motor. The stepping motor driver uses hybrid IC power MOSFETs in the output stage. It includes a built-in micro-stepping controller and is based on a bipolar constant-current PWM system. Stepper motor move the shaft in which L type rotating fingers are attach used for striking the pro-tray so that seedling comes out from the tray.

4. Design Of Seedling Transplanter

4.1 System working principle

The complete system works on the combine effect of both mechanical as well as electronic system. The working principle of the developed system is shown in the block diagram (Figure 6). The system mainly consists of pro-tray feed roller unit, metering unit, delivery unit and corresponding embedded system.

The embedded system developed is used to drive the metering mechanism and the mechanical system used to drive the system at optimum rotational speed at 3.4:1 transmission ratio to obtain recommended plant to plant spacing. At the same time, the seedling pro-tray feed rollers and metering shaft is driven by DC motor and stepper motor to supply the seedlings transversely and longitudinally, respectively, so as to eject the seedling from the pro-tray and planting the seedlings into the furrow. The entire operation was controlled by embedded system. The pro-trays are fed longitudinally and metering shaft moves transversely. The seedlings are ejected by rotating fingers mounted on the metering shaft.

4.2 Design of control system

(1) Component for control system

In this system Arduino Uno microcontroller is used for operating the driver of dc motor and stepper motor. Microcontroller generates PWM signals of different pulse width for both dc and stepper motor. Here, two leaf switches are used for changing the direction of stepper motor attached on MS sheet at 120 mm apart. Both the switches were pressed with the help of special bush attached on the metering shaft. When stepper motor moves and its presses the right switch, then controller receive signal from switch digital pin and it gives digital output at direction pin of stepper motor driver. Thus, motor rotates in clockwise direction and when left switch is pressed stepper motor moves in anti-clockwise direction. When the direction of stepper motor changes and the DC motor turn ON with delay of 1 s and after 75 ms DC motor becomes off. The flow chart of the embedded system for developed seedling transplanter is shown in Figure 7. The DC motor makes to moves only in anticlockwise direction so that the feed roller rotates in forward direction. The microcontroller provides 5V DC voltage as power supply for both drivers. A 12V DC battery is used as power supply for both motors and microcontroller.

(2) Complete circuit and software interface of the system

CNC Router Single Axis 3A Stepper Motor driver board was used for axis control with Input signal high-speed opto-coupler isolation, large heat sink to ensure good heat dissipation. Coding of embedded system had been done in Arduino software in C language, snapshot of the program and complete circuit is shown in Figure 8 & 9. Stepper motor driver is Semi-flow mode adjustable, semi-flow current adjustable, with a variety of semi-flow model and semi-flow current setting functions.

5. Performance Evaluation Of Developed Seedling Transplanter

5.1 Experimental protocol

The developed seedling transplanter unit was fixed to the carriage mounted on soil bin rails. This unit consisted of developed transplanter with metering mechanism, ground wheel and the power transmission. The soil bin experiments were conducted to check the working of the developed AMM. They were operated simultaneously at factorial combinations of four levels of forward speed of transplanter (S1=1.0, S2=1.5, S3=2.0 and S4=2.5 km/h) and three levels of angle inclination of feed roller (A1=0^0, A2=30^0 and A3=45^0), respectively with three replications. The experimental design of laboratory tests was given in Table 2. Soil bin experiments were conducted on transplanting mechanism to study the effect of machine parameters viz. speed of operation on furrow closure, uniformity in spacing and success of transplanting plug seedlings. Observations for angle of inclination of stem with vertical, proper furrow closure and plant spacing were recorded at different forward speed.

The performance of the system was indicated by measure of plant to plant spacing, planting depth, transplanting efficiency, percent furrow closer, angle of inclination of seedling and miss planting.

Table 2. Experimental design for laboratory tests

Sl. No.	Parameters	Levels	Details
1	Forward speed (0.5 – 2.5 km/h), (S)	4	S1=1.0, S2=1.5, S3=2.0 and S4=2.5 km/h
2	Angle inclination of feed roller (0^0 to 45^0), (A)	3	A1=0^0, A2=30^0 and A3=45^0

5.2 Test parameters

The important performance parameters required to evaluate the transplanting system are plant to plant spacing, planting depth, transplanting efficiency, furrow closer, angle of inclination and miss planting. The equations for calculation of above parameters are given below:

Plant to plant spacing: The plant to plant spacing along the 20 m row length was measured with the help of steel tape during the field operation.

Planting depth: The planting depth was measured with the help of steel tape. The planting depth was measured by uprooting seedlings at five different locations randomly in the field.

Transplanting efficiency: The transplanting efficiency was determined by the ratio of seedlings inclined less than 30° from the vertical and proper soil compaction around roots to the total number of seedlings transplanted. The angle of root plug axis of seedling with vertical was taken if the stem of seedling was not straight.

$$\text{Transplanting efficiency, Et} = \left(\frac{\text{Nt}}{\text{N}}\right) \times 100$$

Where, Nt = Number of seedlings successfully transplanted with angle of inclination less than 30° from the vertical and proper soil compaction around roots

N = Total number of seedlings transplanted

Furrow closer: For a seedling to be counted as successfully transplanted, the plug of the seedling must be covered and compacted properly with soil. The furrow was said to be properly closed if the root plug of the seedling was not visible and covered completely with soil. Visual observations for furrow closure were recorded as “1” for proper furrow closure and “0” for the rest.

Angle of Inclination: For a seedling to be counted as successfully transplanted, in addition to furrow closer of stem from vertical, the transplanted seedling must be having angle of inclination < 30^0 from the vertical.

Miss planting: The seedling that were missed to transplant, results in wide spacing's between consecutive transplanted plug seedlings and was expressed as the percent miss transplanting. Per cent miss transplanting was calculated using formula:

$$\text{Miss planting, Mp} = \left(\frac{N1}{N2}\right) \times 100$$

Where, N1 = Number of seedlings missed to plant

N2 = Number of seedlings to be planted

5.3 Results and Discussion

The experiment were carried on soil bin at four forward speed of operation and at three different inclination of feed roller to get the best combination of result on the basis of performance (Fig. 5). The effect of speed of operation and angle of pro-tray feed roller on different performance parameters were given in Table 3.

Table 3. Performance parameters with respect to speed and angle of protray feed roller

	Plant spacing (mm)	Planting depth (mm)	Transplant-ing efficiency (%)	Furrow Closer (%)	Angle of inclination (^{0})	Miss Planting (%)
S1=1.0 km/h						
A1=0^0	749.2	52.7	73.6	77.8	19.5	4.2
A2=30^0	710.4	52.4	77.1	79.2	21.8	4.2
A3=45^0	636.7	52.4	67.4	69.4	23.5	8.3
S2=1.5 km/h						
A1=0^0	681.5	51.5	75.0	82.6	20.4	4.2
A2=30^0	622.9	51.2	76.4	79.9	22.1	2.1
A3=45^0	618.7	51.2	69.4	74.3	25.6	10.4
S3=2.0 km/h						
A1=0^0	603.2	47.1	81.3	77.1	18.4	2.1
A2=30^0	**600.6**	**46.4**	**91.7**	**90.3**	**18.3**	**2.1**
A3=45^0	546.3	46.2	70.1	77.8	26.2	8.3
S4=2.5 km/h						
A1=0^0	508.6	44.8	68.8	69.4	29.0	8.3
A2=30^0	520.2	44.7	70.8	68.1	26.9	6.3
A3=45^0	451.5	43.5	61.1	60.4	31.8	20.8

(1) Plant to plant spacing

The results of plant to plant spacing for different forward speed and angle of pro-tray feed roller are shown in Table 3 and Figure 10. The result indicated that the developed transplanter transplants seedling at optimum spacing when the speed of operation is 2.0 km/h. The developed mechanism was driven by wheels which rolled over soil bin rails without skid. Therefore, there was less chance of variations to be observed in uniformity of spacing in soil bin. However, higher variation in spacing may be expected in actual field conditions due to high skid values of ground wheel.

(2) Planting depth

The observed depth of planting for different forward speed and angle of pro-tray feed roller are shown in Figure 11. The result indicated that depth of planting decreases with speed of operation irrespective of angle of the pro-tray feed roller. The best results were obtained for S3 and A2 combination.

(3) Transplanting efficiency

The average percentage of seedlings transplanted irrespective of proper furrow closure for selected forward speed and angle of pro-tray feed roller are shown in Figure 12. In order to achieve higher field capacity, it is desirable to transplant the seedling at higher speeds i.e. 2.0 km/h beyond which the transplanting efficiency reduces. At this speed, the transplanting efficiency was 90.3 % which is considered very good (Khadatkar et al., 2018). It was observed from the result that transplanting percentage increases with increase in speed of operation and then reduces afterwards, which may be due to the reason that at higher speed the soil covering was not proper.

(4) Furrow closure

Proper furrow closure with sufficient compaction around the vegetable seedlings is critical criteria for establishment of seedlings after transplanting and also to uphold the seedlings at a transplanted position during early growth stage. The average values of furrow closure out of total seedling transplanted for different forward speed and angle of feed roller are shown in Figure 13. The result indicated that the percentage furrow closer increases with increase in speed of operation and angle of pro-tray feed roller upto S3 and then decreases which may be due to bending of seedling at higher speed.

(5) Angle of inclination

For proper transplanting, it was necessary that the angle on inclination of seedling should be less than 30^0 from the vertical. The average values of angle on inclination out of total seedling transplanted for different forward speed and angle of feed roller are shown in Figure 14. The result indicated that angle of inclination of seedling increases with increase in speed of operation as well as increase in angle of feed roller. The result indicated that angle of inclination increases with increase in speed of operation as well as angle of the pro-tray feed roller.

(6) Miss planting

The percent missing of seedlings transplanted at selected forward speed of operation and angle of pro-tray feed roller are shown in Figure 15. The result indicated that missing per cent decreases with increase in speed of operation as well as increase in angle of feed roller. At S3=2.0 km/h speed and A2= 30^0, the miss planting was 2.1 % which is considered very good [24].

6. Conclusion

The developed seedling transplanter with automatic transplanting system that would enable the singulation and optimum plant to plant spacing was developed and tested. An embedded system based software programme was developed, the hardware design was fabricated and it was integrated with seedling transplanter. The developed system was tested under laboratory condition and their performances parameters were recorded. The average values of performance parameters obtained with the ESAM was found to be closer to the recommended values. The result indicated that average values of plant to plant spacing, planting depth, transplanting efficiency, percent furrow closer, angle of inclination and miss planting was 600 mm, 46 mm, 90.0 %, 84.2 %, 18^0 and 3 %, respectively. The developed system ensures the optimum transplanting rate, the ability to transplant at higher speeds, singulation of seedlings and maintaining proper plant to plant spacing.

The study indicated that speed of operation and angle of pro-tray feed roller is the most important factor in improving the efficiency of the transplanter. Therefore, speed of operation and angle of pro-tray feed roller should be optimized in the newly to-be-developed systems for industrial application.

Declarations

Authors' Contributions

SMM was in charge of the whole project; AK and SMM done the analysis and wrote the manuscript. Both the authors read and approved the final manuscript.

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Competing Interests

The authors declare that they have no competing interests.

Availability of data and materials

NA

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Conflict of interest

The authors declare that there are no conflicts of interest.

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Figures

Figure 1

A. Seedlings at 30 days old for transplanting. B. Dummy seedlings developed for prior testing.

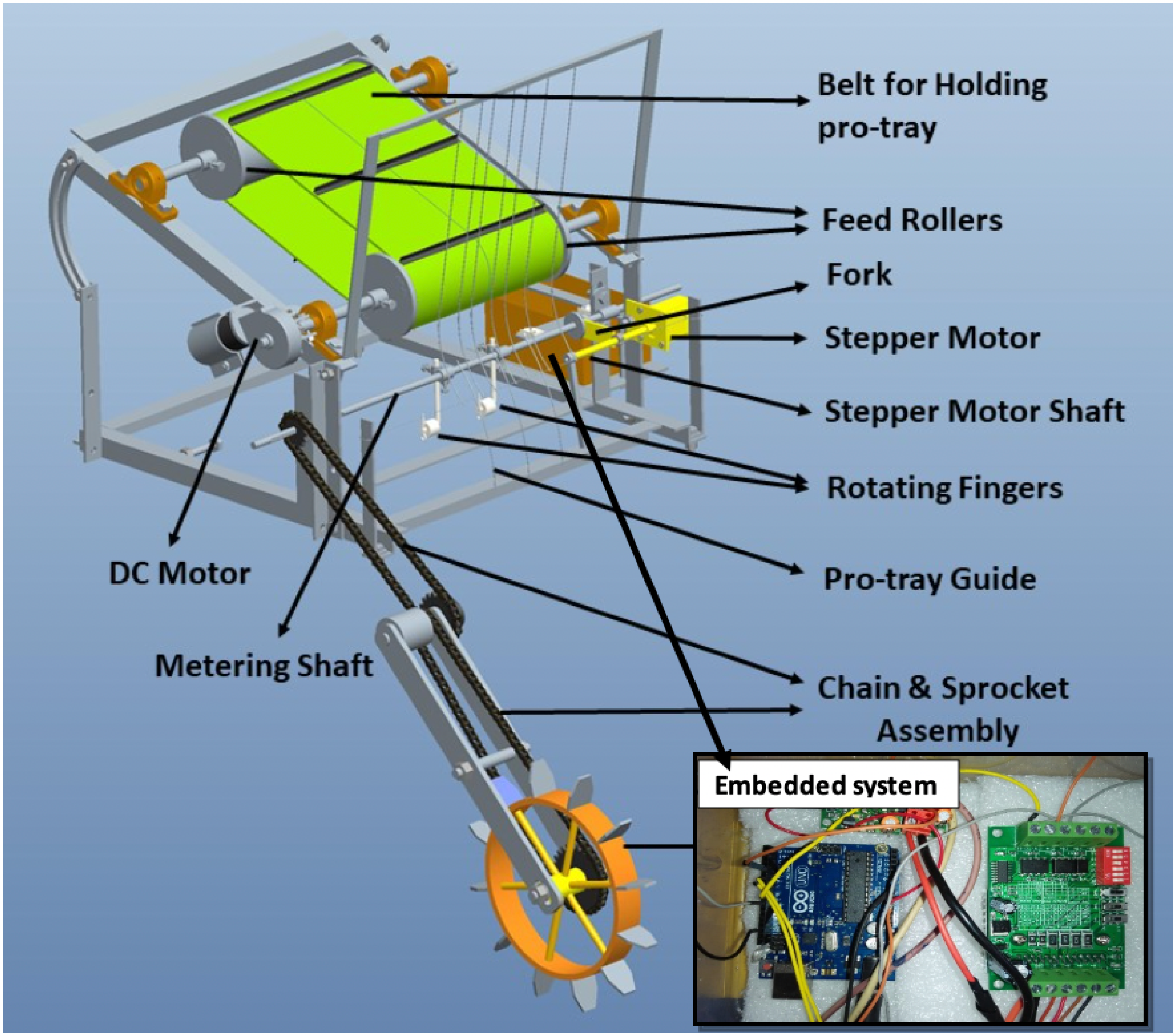

Figure 2

Schematic diagram of automatic precision seedling transplanting

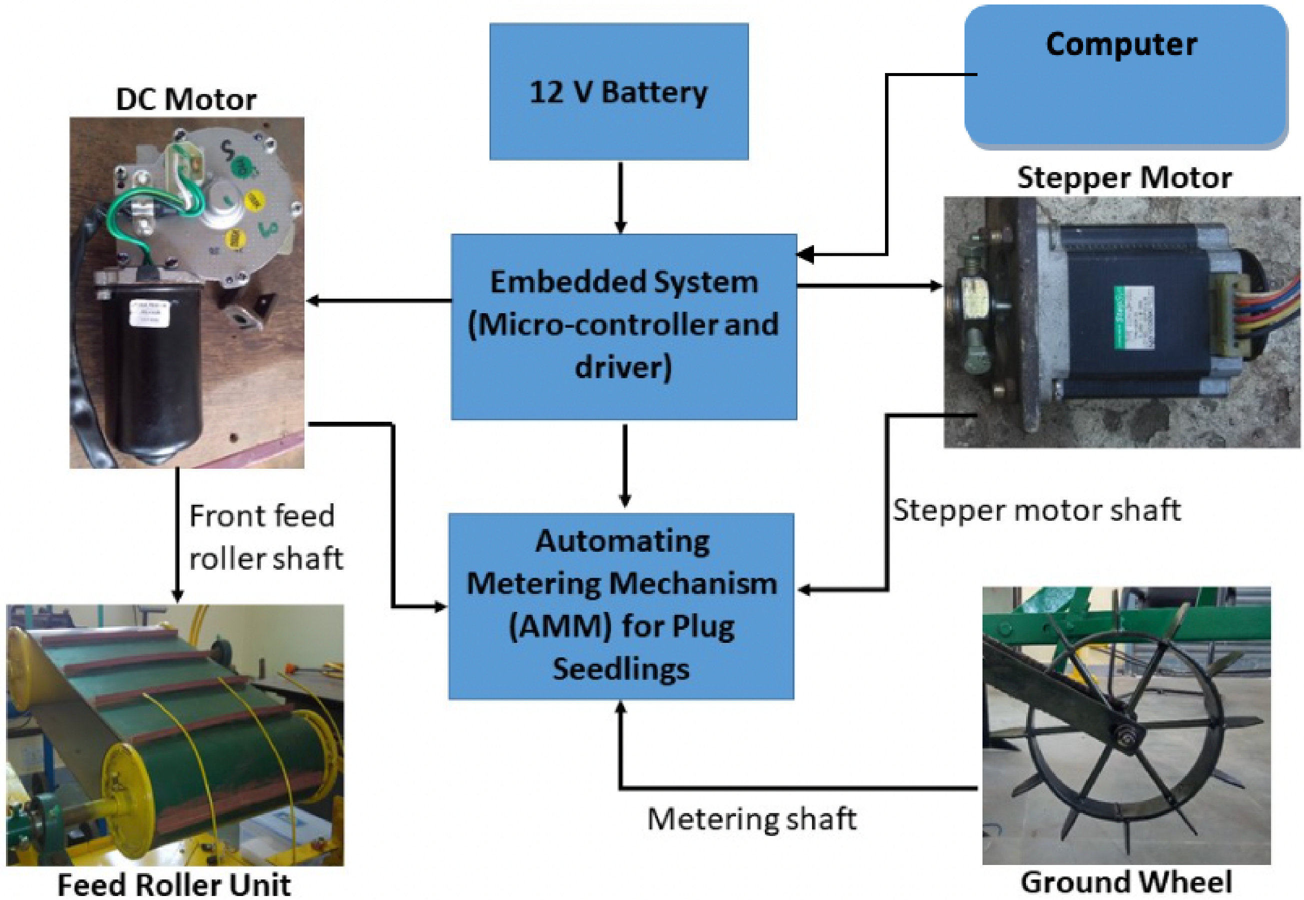

Figure 3

Working principle of the developed transplanter

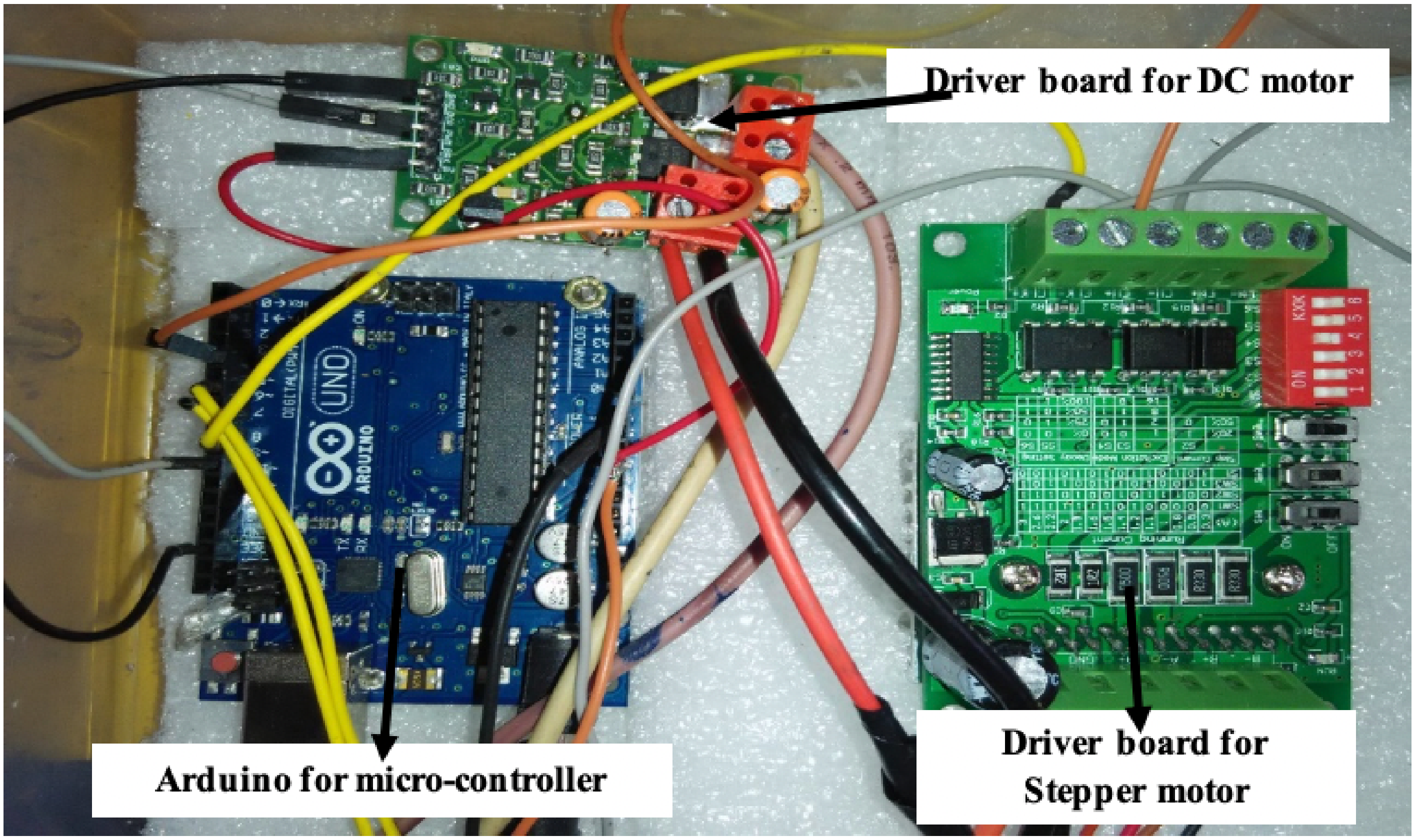

Figure 4

Electronic components for the developed Embedded System

Figure 5

Developed experimental setup in soil bin laboratory

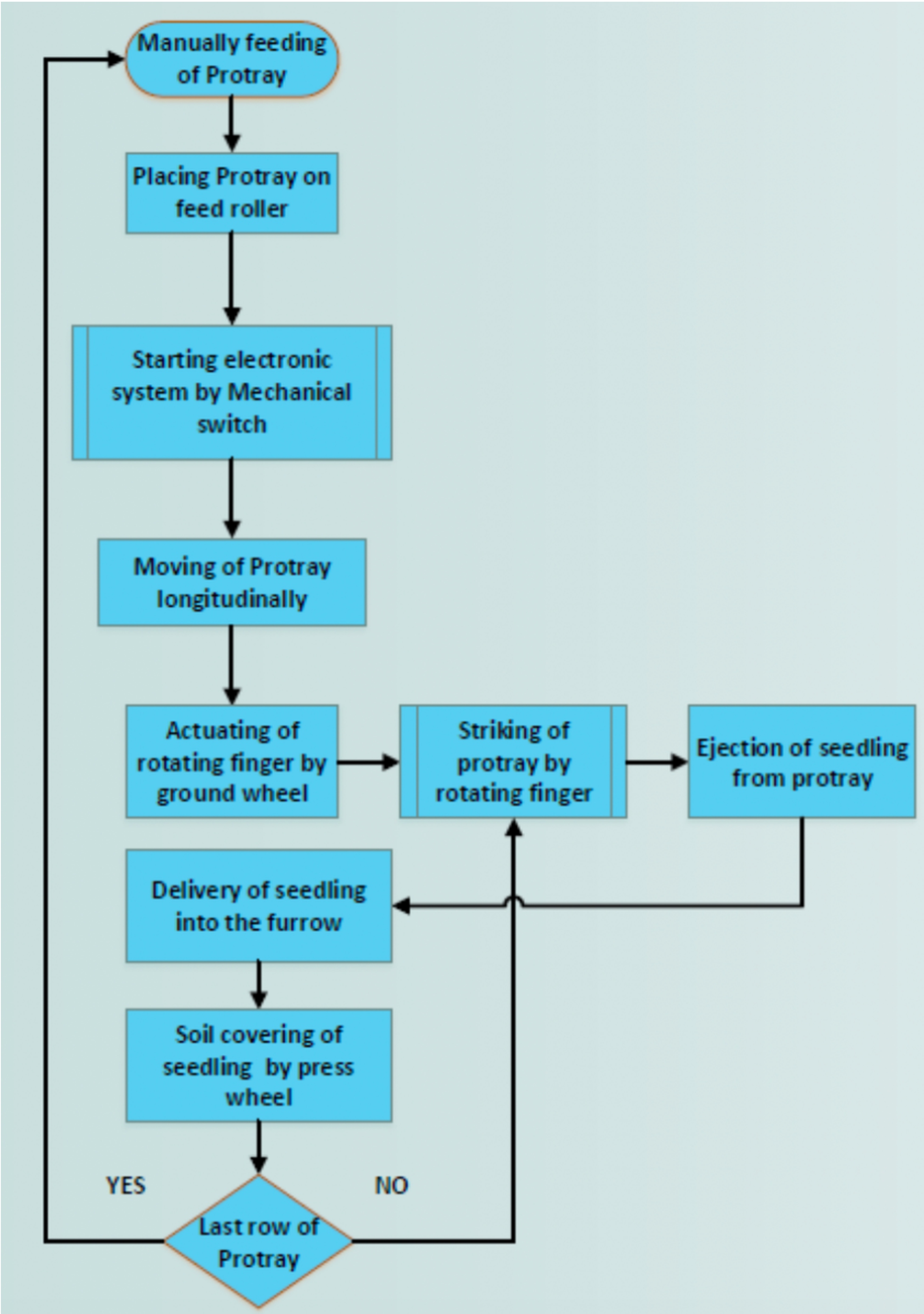

Figure 6

Block diagram of working principle of the automatic transplanting system

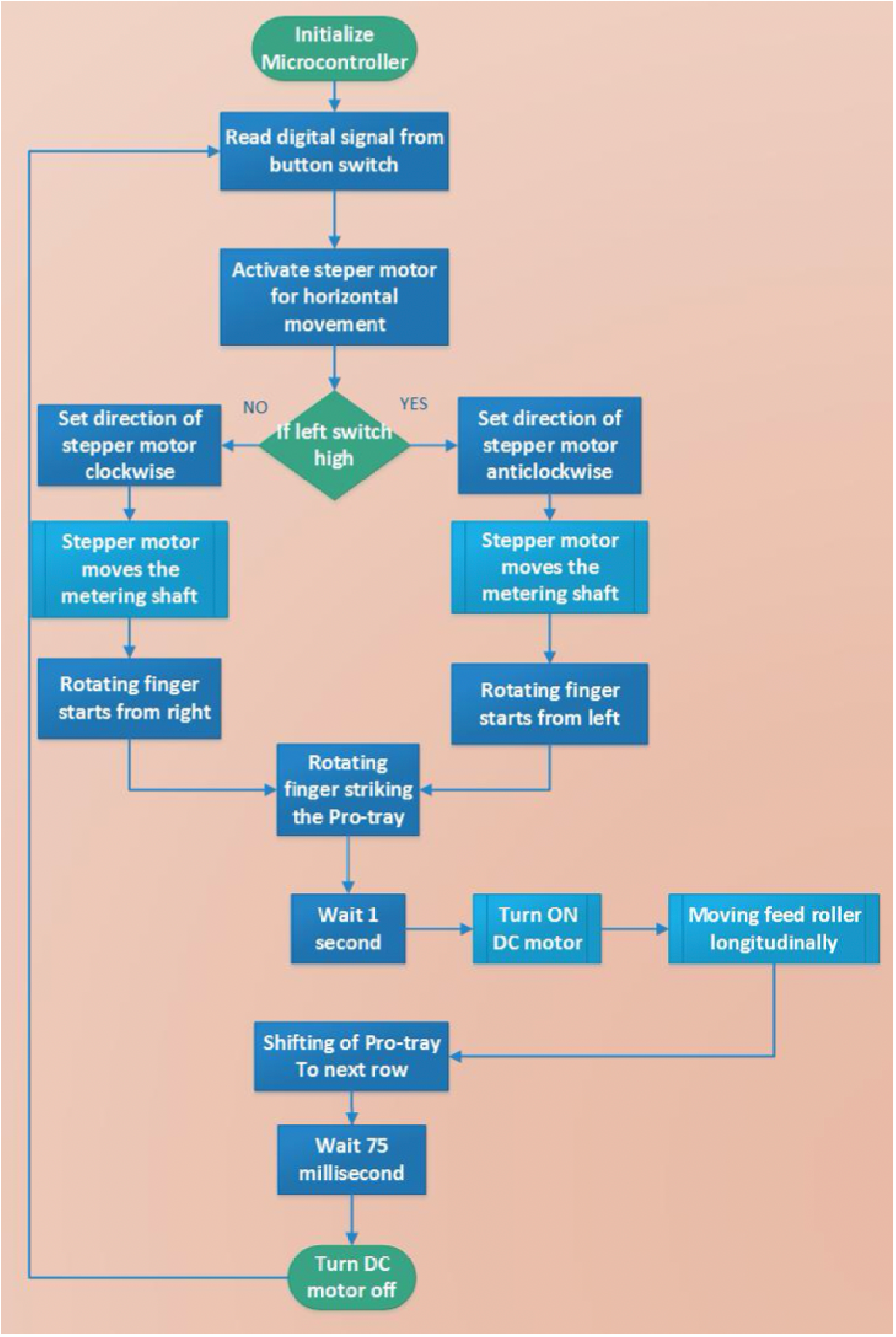

Figure 7

Flow chart of the embedded system for developed PST

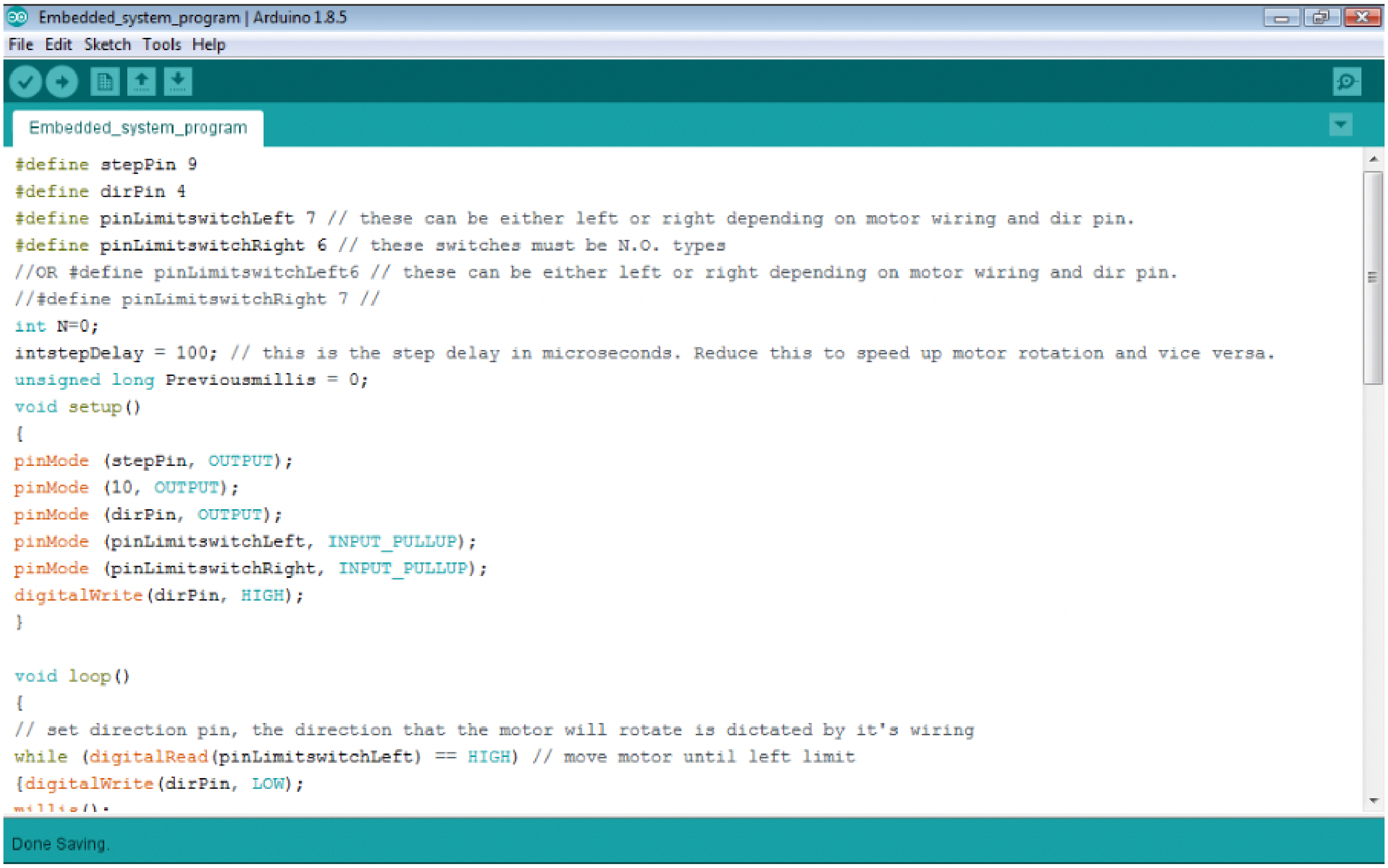

Figure 8

Control System interface

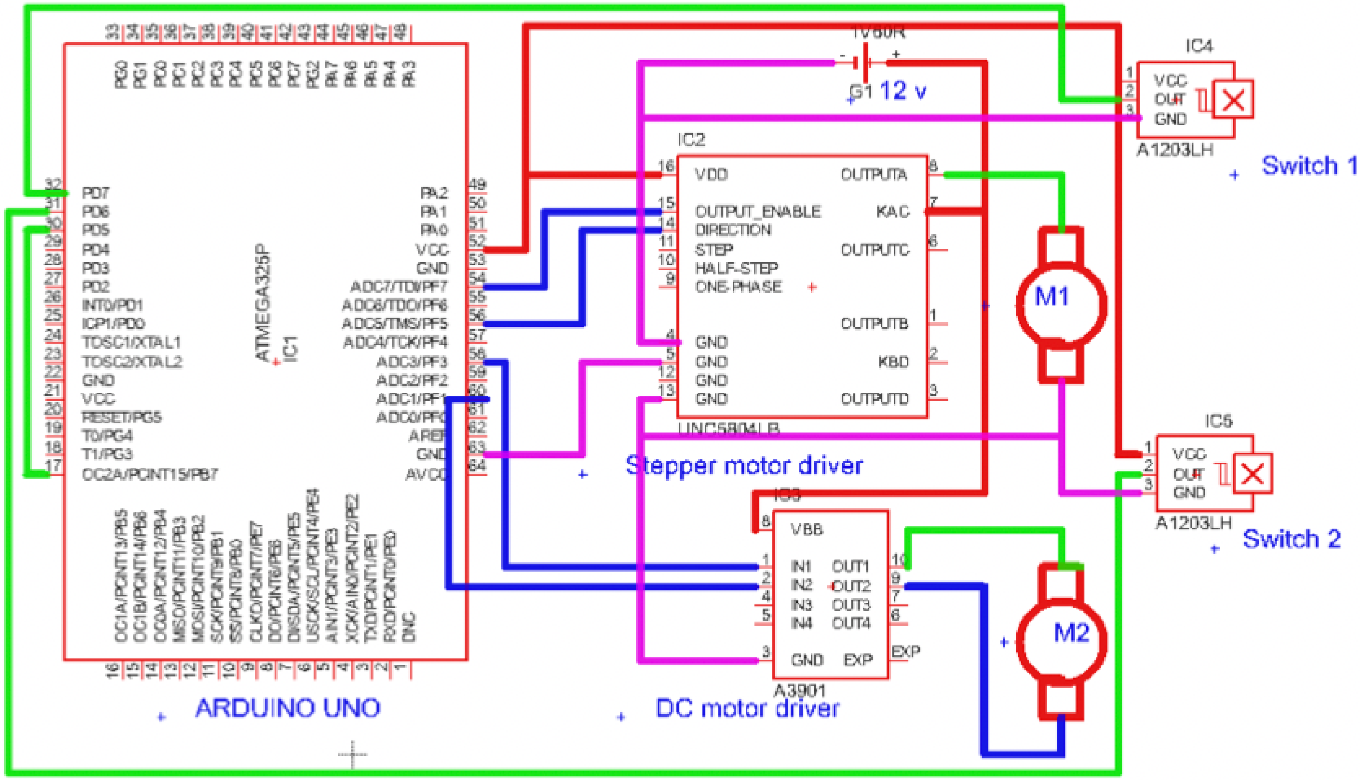

Figure 9

Circuit diagram used for embedded based system

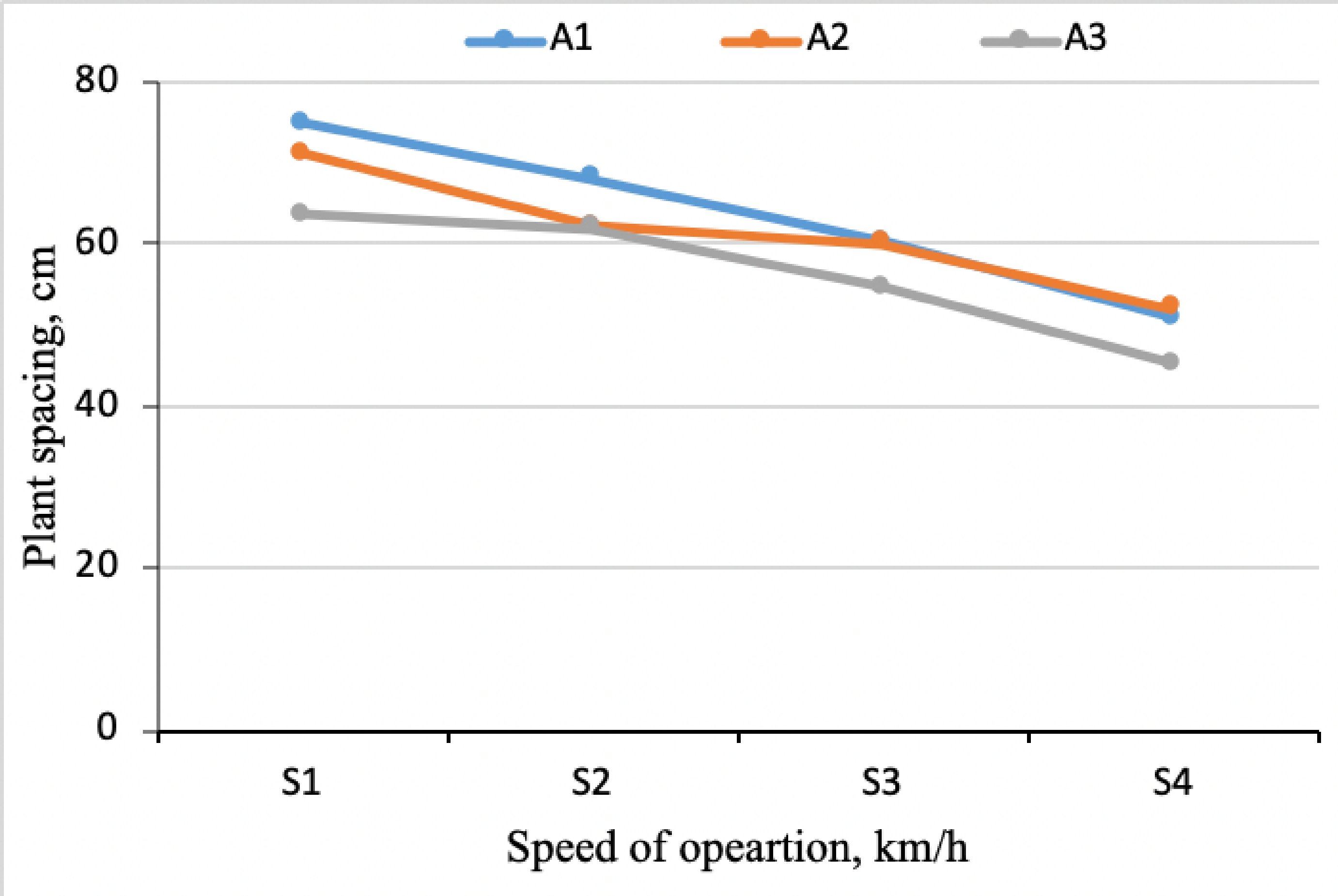

Figure 10

Average plant spacing at different forward speed and angle of portray feed roller

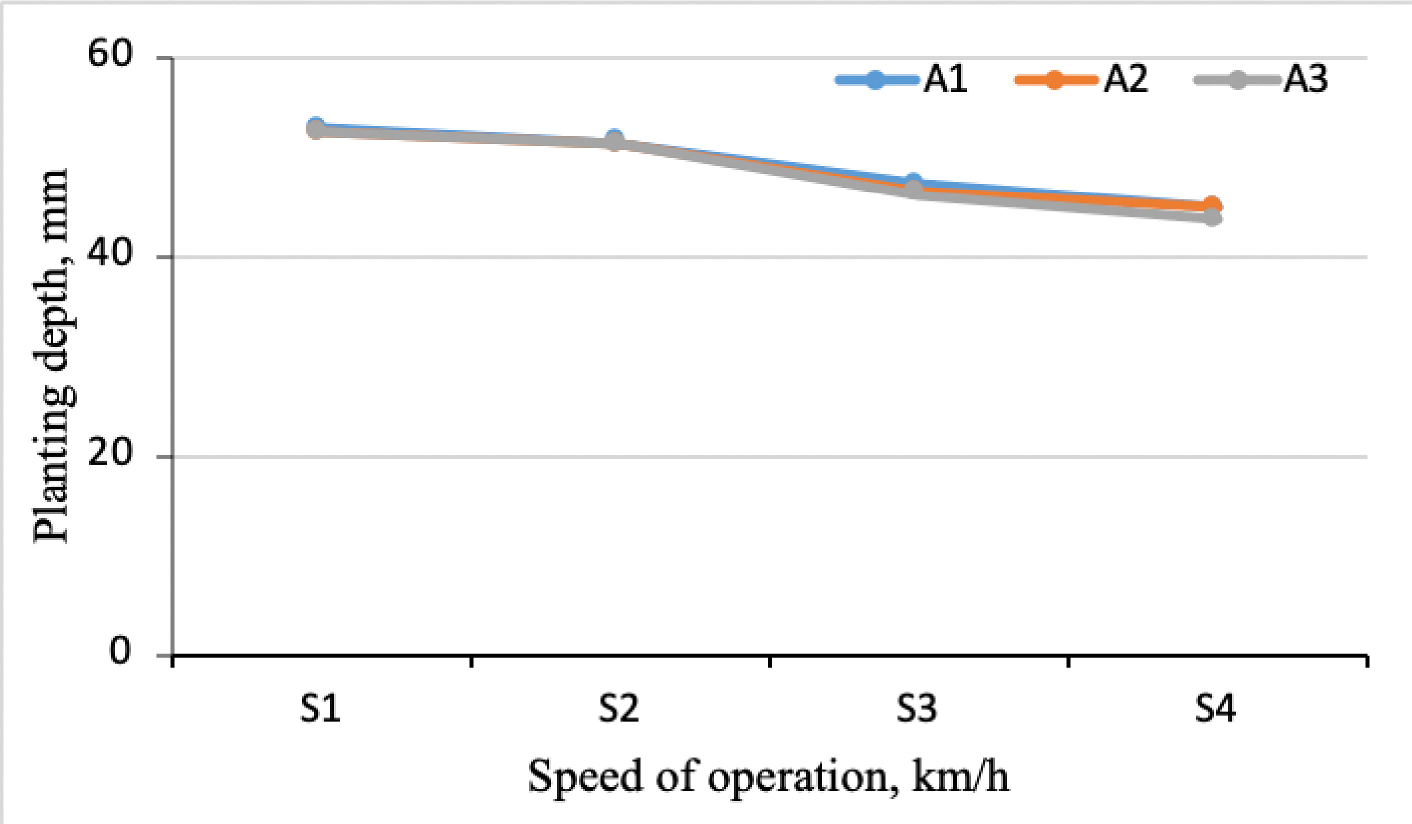

Figure 11

Average planting depth at different forward speed and angle of portray feed roller

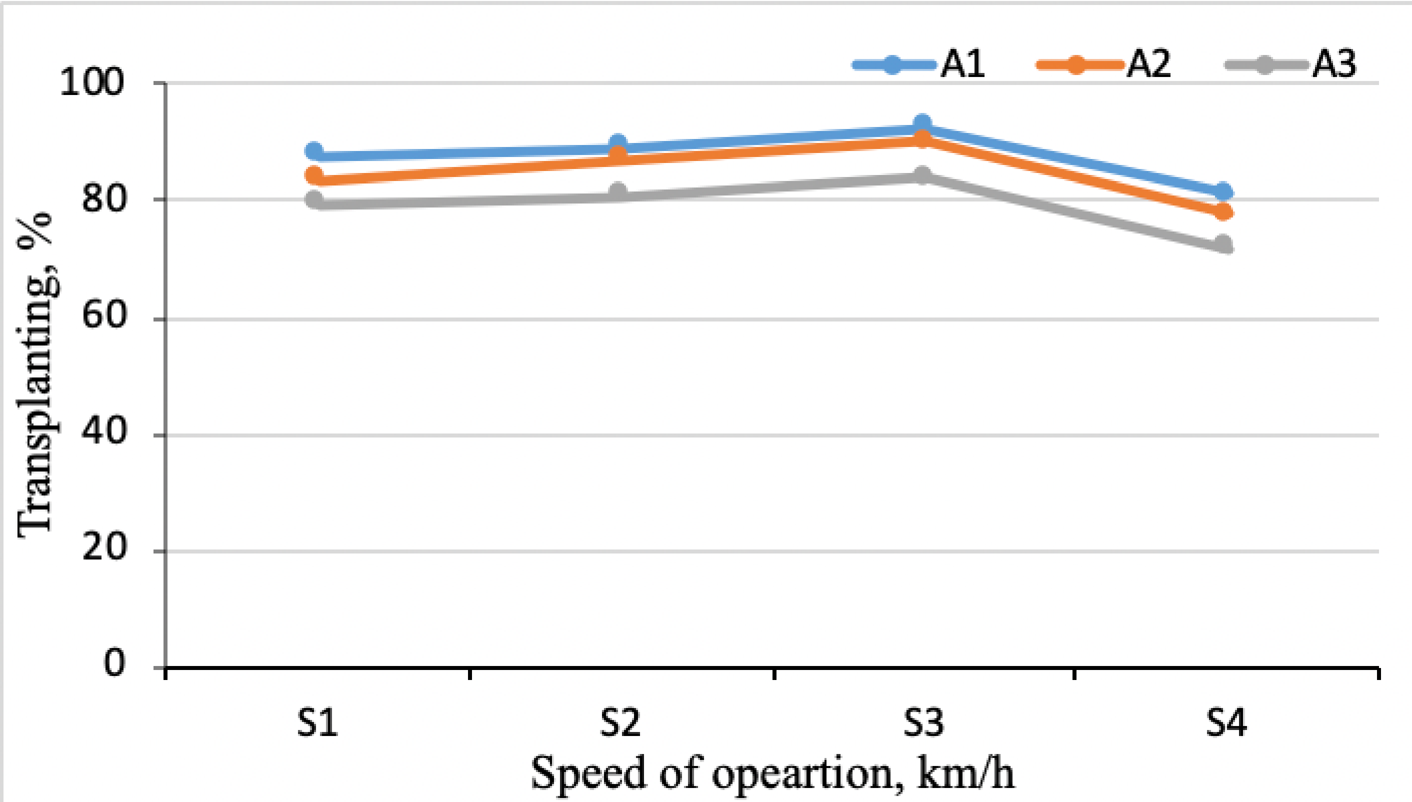

Figure 12

Average per cent transplanting at different forward speed and angle of portray feed roller

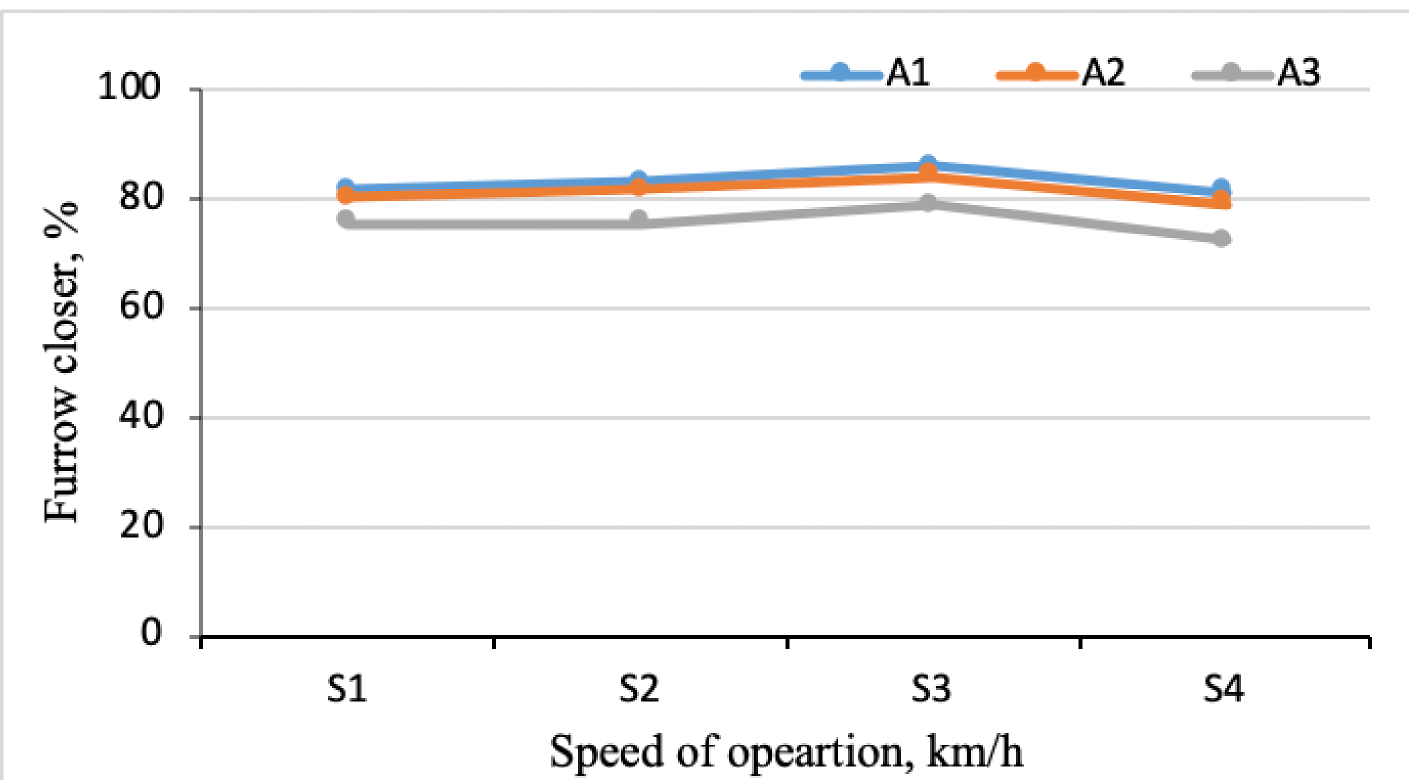

Figure 13

Average per cent furrow closer at different forward speed and angle of portray feed roller

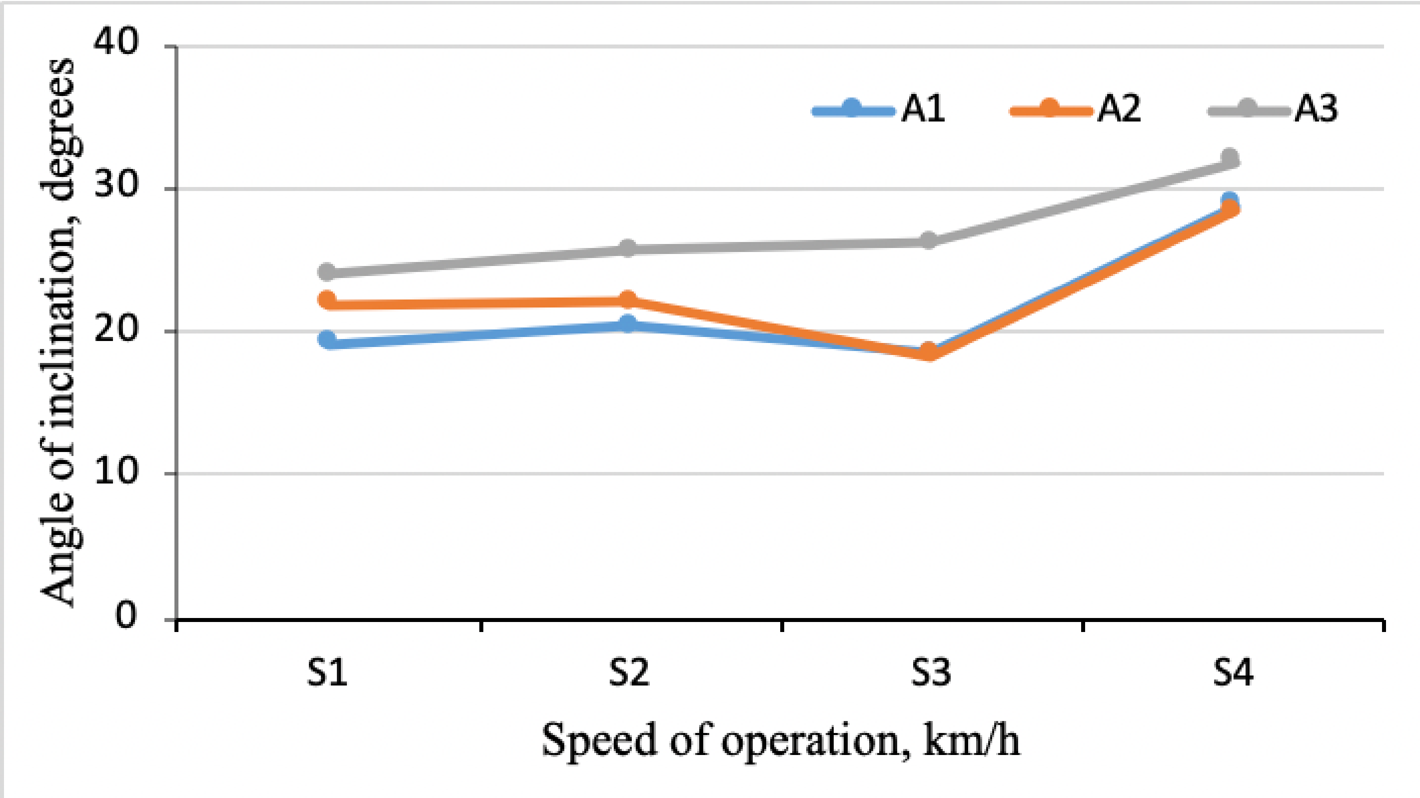

Figure 14

Average angle of inclination at different forward speed and angle of portray feed roller

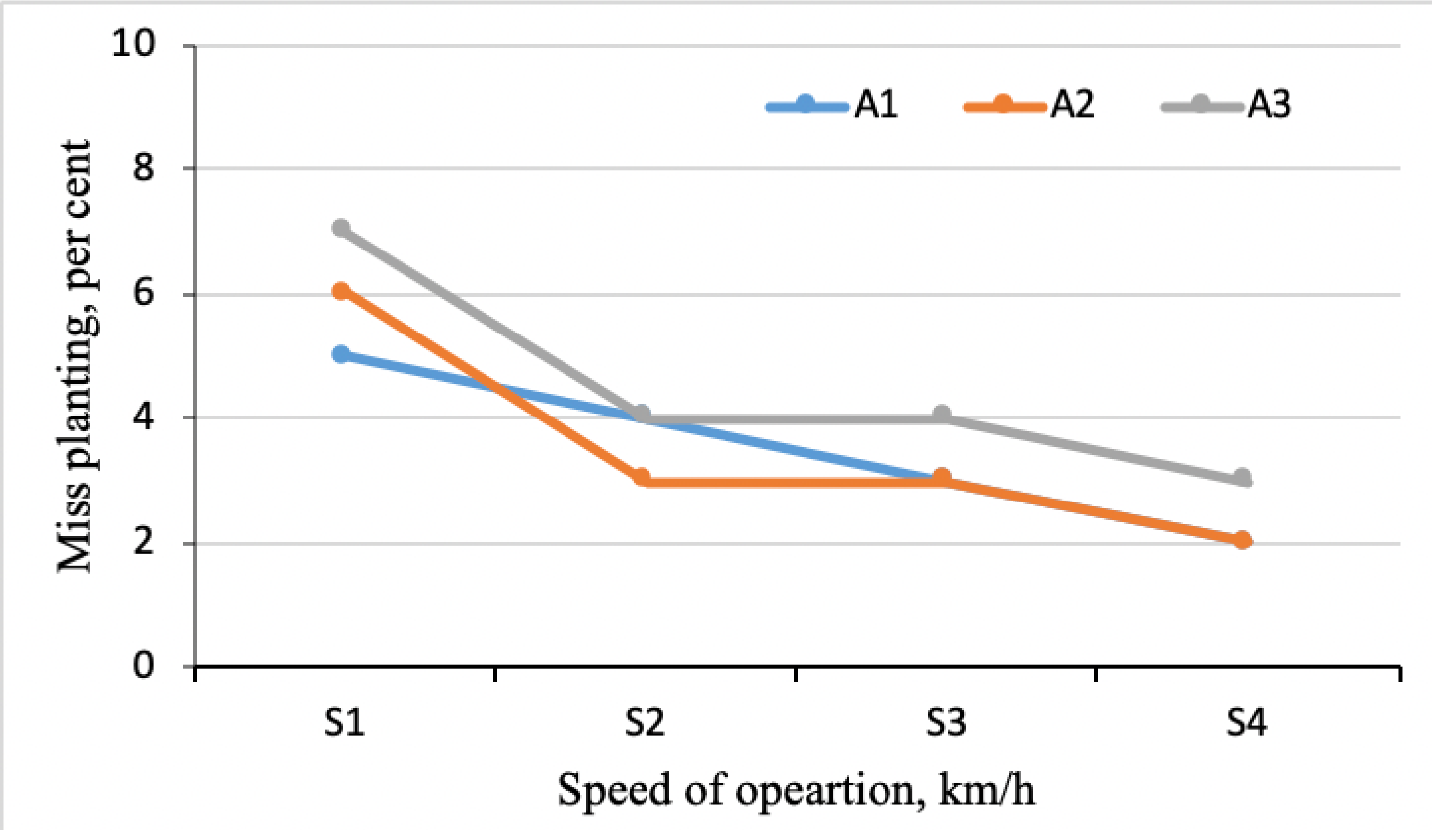

Figure 15

Average miss planting at different forward speed and angle of portray feed roller