Development of a manually drawn single row onion set planter using a 2 DOF robotic arm

Pranay Sarkar*, Hifjur Raheman

(1. Agricultural and Food Engineering Department, Indian Institute of Technology, Kharagpur, West Bengal, 721302, India)

Abstract: To obtain precise planting of onion sets, a manually drawn planter with a two degrees of freedom (DOF) robotic arm was developed. The key idea was to reduce multiple set droppings to single set dropping per hill. The developed three-wheeled planter consisted of a suitable hopper for onion sets, conveying system, robotic arm, seed tube, furrow opener and closer, and necessary electronics circuits. The rotation of the DC motor of the conveyor belt was dependent on the output of the LDR circuit. Onions coming to the workspace of the robotic arm, interrupted the laser light from falling over the LDR hence stopped the belt movement. The robotic arm, programmed in the Arduino platform, approached, picked, carried, and released the onion sets into the seed tube. Furrow opener and furrow closer were there for planting onions at the proper depth and covering them with soil, respectively. Average hill spacing was found to be 160.2 mm with a standard deviation of 4.64 mm at the operating speed of 0.582 $km.h^{-1}$ as compared to 237.1 mm and 10.65 mm for operating speed of 0.85 $km.h^{-1}$. The average missed planting of onion sets was 7.8% at the operating speed of 0.582 $km.h^{-1}$ as compared to 17.45% at 0.85 $km.h^{-1}$.

Keywords: precision, robotic arm, degrees of freedom, light-dependent resistor, onion sets planting

Citation: Sarkar, P., and H. Raheman. 2021. Development of a manually drawn single row onion set planter using a 2 DOF robotic arm. Agricultural Engineering International: CIGR Journal, 23(2):181-194.

1 Introduction

Onion dry bulbs are commonly established in the field either by direct sowing of seeds to the field or by transplanting seedlings from a seedbed or sets depending on the growing conditions of the specific region (Ketema et al, 2013). Planting of onion sets can be used for both onion production and seed production. Sets produce heavier crops than either seeds or seedlings. The importance of mechanically planting sets is since this is one of the surest and easiest methods of producing green onions or large bulbs at a minimum planting cost. The method is a short time process, applicable in a wider range of agro-climatic conditions, and very appropriate to maintain the variety identity. A bulb can produce several stalks hence it has a higher seed yield. Sets are probably the most convenient and safest type of planting material for either small scale or commercial onion production as the emerging plant will be very strong, vigorous, and easily established under stressed conditions. These were important especially to catch the early market (O'connor, 1994). Some researchers showed that the agronomical parameters played a major role in the yield of the onion, which should be taken into consideration while designing a planter. The yields of onion tubers were maximum when sets were ranged from 0.5 inches to 0.75 inches (12.7 mm to 19 mm) in diameter and spaced 2.25 inches to 2.5 inches (57.1 mm to 63.5 mm) apart in 13 inches to 14 inches (330.2 mm to 355.6 mm) row widths (Colby et al., 1945). Vandermark (1977) suggested that onion-sets should be planted 25.4 mm deep in rows about 304.8 mm to 355.6 mm apart,

Received date: 2020-02-08 **Accepted date:**2020-09-11

***Corresponding author:** Pranay Sarkar, Research Scholar, Agricultural and Food Engineering Department, Indian Institute of Technology, Kharagpur. Tel: +91-8906256642. Email: pranayfmp@iitkgp.ac.in

with the sets 50.8 mm apart. It was found in another study that a planting depth of 1.5 to 2 times the diameter of the sets was best for onion bulbs and onion-sets should be planted 25.4 mm deep in rows between 304.8-355.6 mm apart, with the sets 50 mm apart. Effect of bulb size on yield, maturity, and bolting response in five cultivars was studied by Khokhar et al. (2001) and they suggested that medium size sets were suitable for higher yield and a small amount of set was required for planting. Onion planters can reduce manpower requirement and help to plant the onion sets precisely which in turn increased the yield. Sadhu (1982) developed an onion set planter which was a tractor-mounted two-row planter with a horizontal plate metering mechanism. A vertical cylindrical hopper was mounted over the frame providing free gravity flow for the sets. A cone agitator was provided for agitating the sets inside the hopper for proper metering. Pandharinath (2000) developed a tractor-drawn eight-row semi-automatic onion transplanter. Three functions such as onion transplanting, fertilizer application, and making the irrigation channels were performed at the same time. The transplanter consisted of a frame, fertilizer box, and fertilizer conveying tubes, seedling trays, two ground wheels, furrow openers, seedling delivery chutes, and seating arrangement of up to four people. Turbatmath et al. (2011) developed a semi-automatic tractor operating onion transplanter with plug type metering unit. Four metering mechanisms, each covering two rows, covered 8 rows. The field trials of semi-automatic transplanter revealed that with the plug type metering mechanism the row to row spacing of 20.4 cm to 21.20 cm, plant to plant spacing of 11.00 cm to 11.6 cm, and depth of placement were observed as 2.8 cm to 4.00 cm. The missing percentage, the capacity of the machine, and field efficiency were 9.00% to 10.95%, 0.1088 $hm^2.h^{-1}$ to 0.1174 $hm^2.h^{-1}$, and 70.49% to 71.60%, respectively. Madan (2013) developed a semi-circular cup type metering mechanism for onion bulblet planter. The mechanism was tested on a manually powered single row planter. With an increase in travel speed and peripheral speed of the rotor, bulblets damage increased for all hopper fills. Bulblets damage and elevating error were less at a travel speed of 0.78 $km.h^{-1}$ and peripheral speed of 5.37 $m.min^{-1}$, for all hopper fills. For half hopper fill, bulblets damage was minimum (2% and 1%) at a minimum travel speed of 0.78 $km.h^{-1}$ and a minimum peripheral speed of 5.37 $m.min^{-1}$, respectively. Ranthikumari and Jesudas (2015) developed a tractor operating onion set planter with a sloped bottom rectangular hopper. The concept of the unit planter was adopted and each unit had a seed hopper and a pair of metering discs. A precision of 0.27 was obtained in this planter. The performance indices namely multiple indexes, miss index, quality of feed index, precision, the mean and standard deviation of onion set planter were reported as 0.05, 0.18, 0.77, 0.27, 11.71, and 5.22 cm, respectively. The field capacity of the onion set planter was 0.15 $hm^2.h^{-1}$.

Nowadays, robotics can play an important role in increasing the efficiency of agriculture productivity given limited land, water, and labor resources. It can increase the production rate in the agriculture sector (Megalingam et al., 2017). But the outdoor agricultural field had an uncontrolled environment (Bechar and Vigneault, 2016) and uneven soil surface which caused vibrations on the propelling vehicle. Researchers are working on developing an autonomous robotic system for field applications (Bechar and Vigneault, 2016). Hwang and Sistler (1986) used a 5 DOF serial robot arm in a commercial mechanical vegetable transplanter for pepper plant and achieved a transplantation rate of 6 seedlings per minute with a transplanting cycle time of 10 s. Gantry-type stationary robotic transplanter for bedding plants was developed by Ryu et al. (2001), which utilized a machine vision system and a pneumatic pickup unit to assist the manipulation of the gripper for the use of stationary plug seedling transplantation in a greenhouse at an average cycle time of 2 s per seedling. Cho et al. (2002) developed a three-degrees-of-freedom robot for harvesting lettuce using machine vision and fuzzy logic control. Fuzzy logic control was applied to determine appropriate grip force on the lettuce plant. The success rate of lettuce harvesting was 94.12%, and the average harvesting time was approximately 5 s per lettuce plant. Foglia and Reina (2006) introduced a cost-effective robotic arm for the harvesting of radicchio. It was composed of a manipulator with a double four-bar linkage and a suitable gripper that could cut a plant approximately 10 mm underground. Zhao et al. (2011) developed 5 degrees of freedom apple harvesting robotic arm mounted on a mobile vehicle. All the rotary joints were actuated with servo motors. The last DOF was made flexible so that the end effector could reach easily the target according to the robot control command. Zion et al. (2014) proposed a multi-arm robotic system for harvesting melons. Four 3 DOF Cartesian manipulators were used in a rectangular frame. Zhao et al. (2016) developed a dual-arm robotic system to harvest tomatoes. Both the arms were of 3 DOF (two rotational and one prismatic type joint). Xiong et al. (2019) developed a robotic arm with a special type of cable-driven gripper to harvest strawberries in polytunnels. Rahul et al. (2019) designed and developed a robotic arm with two degrees of freedom (DOF), five revolute joints (5R) with a parallel arm structure for handling paper pot seedlings in a vegetable transplanter. The robot arm took 2.1 s to 2.4 s to pick and drop a pot seedling from a distance of 116.6mm with a maximum power consumption of 20.47 W.

The aim was to develop an onion set planter for small scale farmers. A robotic arm was used as a metering unit for less damaging, proper planting, and less missing hill percentage of onion sets. This paper presents the development of a single row manual drawn onion set planter in which a robotic arm with two degrees of freedom is used as a metering device.

2 Materials and methods

2.1 Physical and geometric properties of onion sets

Size, weight, bulk density, and angle of friction were important parameters for designing hopper, gripper, conveying system. Thirty samples of onion sets were taken for measuring these properties. The size of the onion sets can be represented by the geometric mean diameter.

Shape index and sphericity were calculated as follows:

$$Shape\ index = \frac{D_e}{\sqrt{D_p \times T}} \quad (1)$$

$$Sphericity = \frac{\sqrt[3]{D_e \times D_p \times T}}{max\ (D_e, D_p, T)} \quad (2)$$

Where, D_p was the cube root of the product of linear dimensions polar diameter (mm), D_e was equilateral diameter (mm), T was thickness (mm).

2.2 Theoretical considerations of robotic arm

The arm consists of two rotating joints. One is the revolute joint (axis of the joint and that of output link are perpendicular to one another) and the other one is the twisting joint (the axis of output link becomes either parallel to or coincident with the joint axis). The schematic diagram of the robotic arm is shown in Figure 1. The Denavit-Hartenberg notations are given in Table 1.

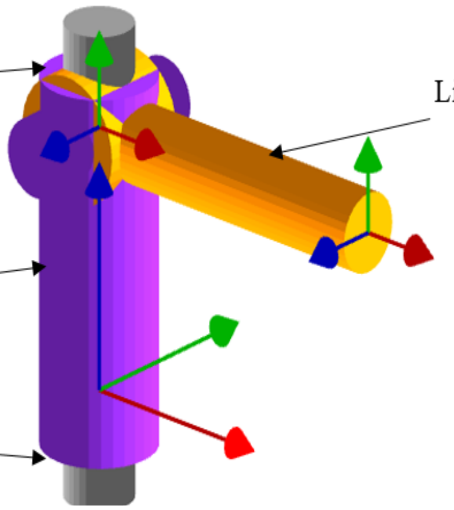


Figure 1 Schematic diagram of the robotic arm

Table 1 Denavit-Hartenberg parameters of the robotic arm

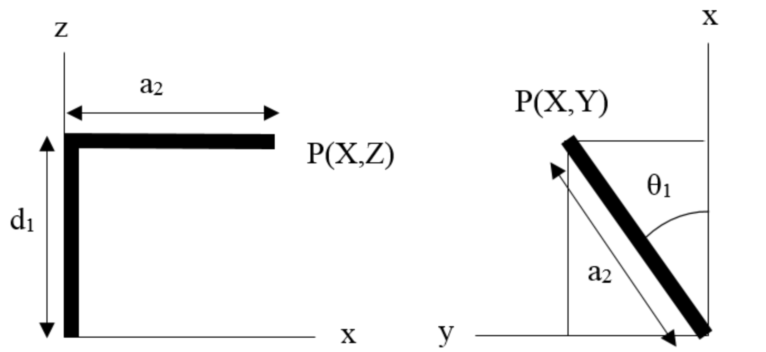
Link	θ_i	d_i	α_i	a_i
1	θ_1	d_1	90°	0
2	θ_2	0	0	a_2

The position of the end effector of the robotic arm can be determined using simple geometry. When there is no rotation of revolute joint (Figure 2), the coordinates of the end effector will be as follows:

$$x = a_2 cos\theta_2 \quad (3)$$

$$y = a_2 sin\theta_2 \quad (4)$$

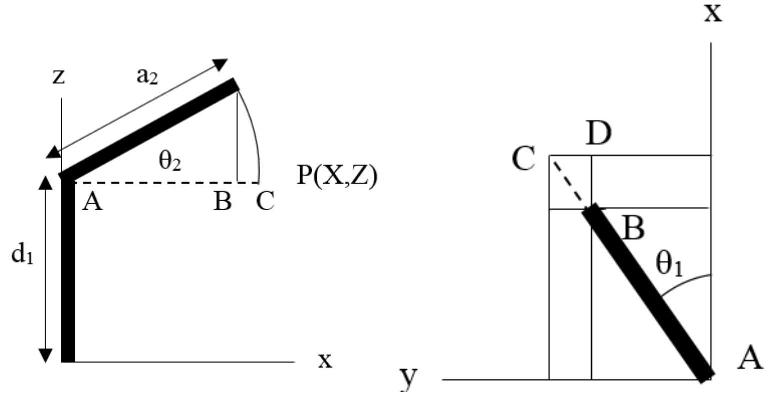
$$z = d_1 \quad (5)$$



(a) Side view (b) Top view

Figure 2 Schematic diagram of the robotic arm with no rotation of revolute joint

Figure 3 shows the position of the robotic arm when there is rotation of the revolute joint along with the twisting joint.



(a) Side view (b) Top view

Figure 3 Schematic diagram of robotic arm with rotation of revolute joint

$$z = d_1 + a_2\sin\theta_2 \quad (6)$$

$$x = a_2\cos\theta_1 - BD \quad y = a_2\sin\theta_2 - DC$$

$$BD = BC\cos\theta_1 = a_2(1 - \cos\theta_2)\cos\theta_1 \quad x = a_2\cos\theta_1\cos\theta_2 \quad (7)$$

$$DC = BC\sin\theta_1 = a_2(1 - \cos\theta_2)\sin\theta_1$$

$$y = a_2\sin\theta_1\cos\theta_2 \quad (8)$$

The coordinate position of the seed tube was fixed at x = 180 mm, y = 55 mm, z = 200 mm. The required rotation of twist joint and revolute joint were calculated as $\theta_1 = 17^\circ$ and $\theta_2 = 20^\circ$, respectively.

2.3 Gripper of the robotic arm

A three-finger gripper was developed to pick, carry, and release onion sets. A servo motor (model: Tower Pro MG995, Torque: 12 kg.cm, Operating voltage: 5 V, Current: 2.5 A) was used to control the gripper. Servo motors consisted of a motor (DC or AC), a potentiometer, gear assembly, and a controlling circuit. At the initial position of the servo motor shaft, the position of the potentiometer knob was such that there was no electrical signal generated at the output port of the potentiometer. When an electrical signal was given to another input terminal of the error detector amplifier, one came from the potentiometer and the other came from the source. The signals would be processed in a feedback mechanism and output would be provided in terms of the error signal. The error signal acted as the input for the motor and it started rotating.

Two fingers were driven by the servo motor and were attached to a long U servo bracket. One of the both was stationary and extended part of the base of the servo motor as shown in Figure 4. The inclination of the rotating finger was made based on the angle of friction between the onion tuber surface and the finger material (PLA). When the finger pushed the onion to slid along the finger surface rather than getting compressed in between stationary and rotating fingers and occupied the wider space. 30° rotation of rotating finger was found to be enough for picking and releasing of onion sets.

2.4 Development of robotic arm

The base set up of the robotic arm was made strong and robust to resist the vibration in the actual field. It consisted of four main parts called a base plate, supporting frame, bearing holder, and rotating platform. A rotating platform was placed over the bearing holder platform. A servo motor (model: Tower Pro MG995) was fixed on the rotating platform with the help of a servo universal bracket to rotate the arm about the horizontal axis. The hollow shaft of the rotating platform coming through the bearing was coupled with a coupler which in turn was attached to the base servo motor shaft. Base servo motor (model: Tower Pro MG995) was there to rotate the arm about the vertical axis. A long U bracket was used to attach the servo on the rotating platform to provide rotation of the arm about the horizontal axis. Gripper assembly was connected to this bracket with a 3D printed L shaped joint. The isometric view of the CAD model of the robotic arm with a gripper is shown in Figure 4.

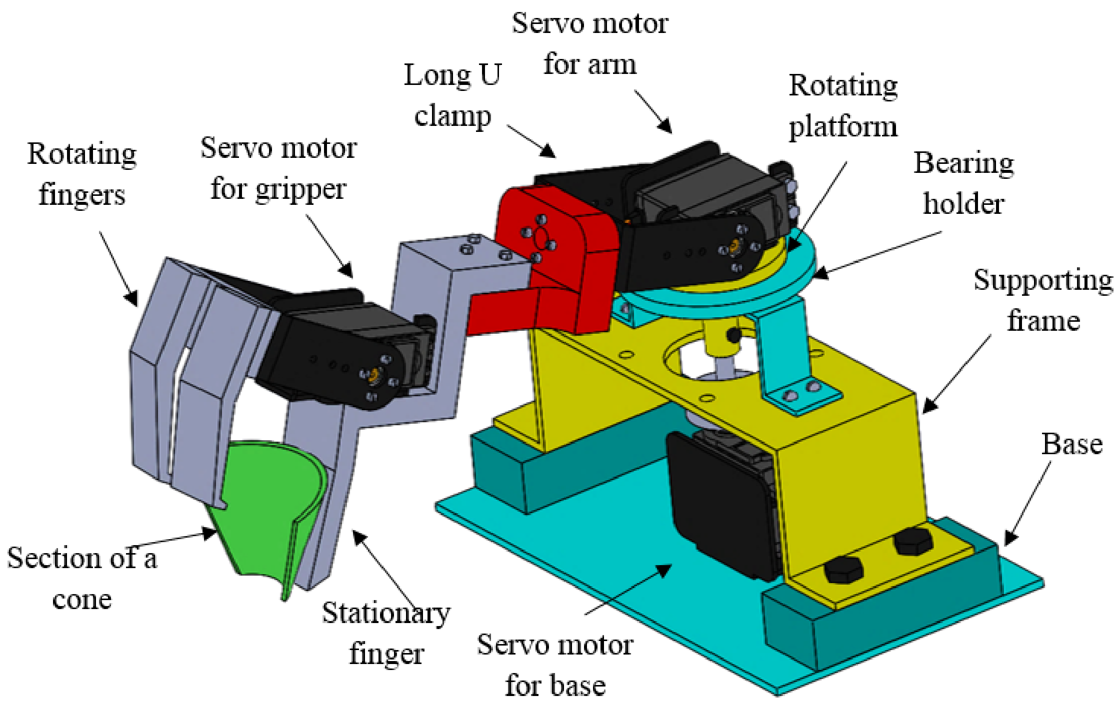


Figure 4 Isometric view diagram of the CAD model of the robotic arm

2.5 Mechanical construction of planter

2.5.1 Hopper and conveying system of the planter

The developed planter was a three-wheeled, single row planter with length, width, and height as 1050, 600, 750 cm, respectively (Figure 5). The volume of this hopper was 0.01125 m^3 with inclination at the base. The inclination was kept greater than the angle of friction so that onions could flow towards the central region from both ends. A rectangular opening was made at the middle of the base of the hopper along its width. An opening of suitable size was made on the front face of the hopper. Belt conveyor was beneath the hopper which could bring onions to the workspace of the robotic arm. A suitable channel was attached to the hopper outlet. At the end of the channel, a 3D printed end gate was attached. Circular slots were made for fixing one LDR and laser light was placed on the two opposite sides of the end gate. It was designed such that one onion set came at a time to the picking region and interrupted the laser light to fall on the LDR hence stopped the DC motor powering the belt conveyor.

Before selecting the DC motor and belt speed in the conveying system, a trial was conducted with that hopper. An existing set up of belt conveyor was used for this trial. DC motor was used to drive the belt with the help of a belt and pulley. It was found that belt speed of 80 mm.s^{-1} gave a satisfactory flow of onions without clogging in the hopper. Required torque for the pulley was determined using the following equation:

$$T = \frac{1}{2}D(F + \mu mg) \tag{9}$$

Where D was diameter of the pulley (m), F was external force (N), μ was friction coefficient, m was mass of load (kg), g was gravity acceleration (m.s^{-2}).

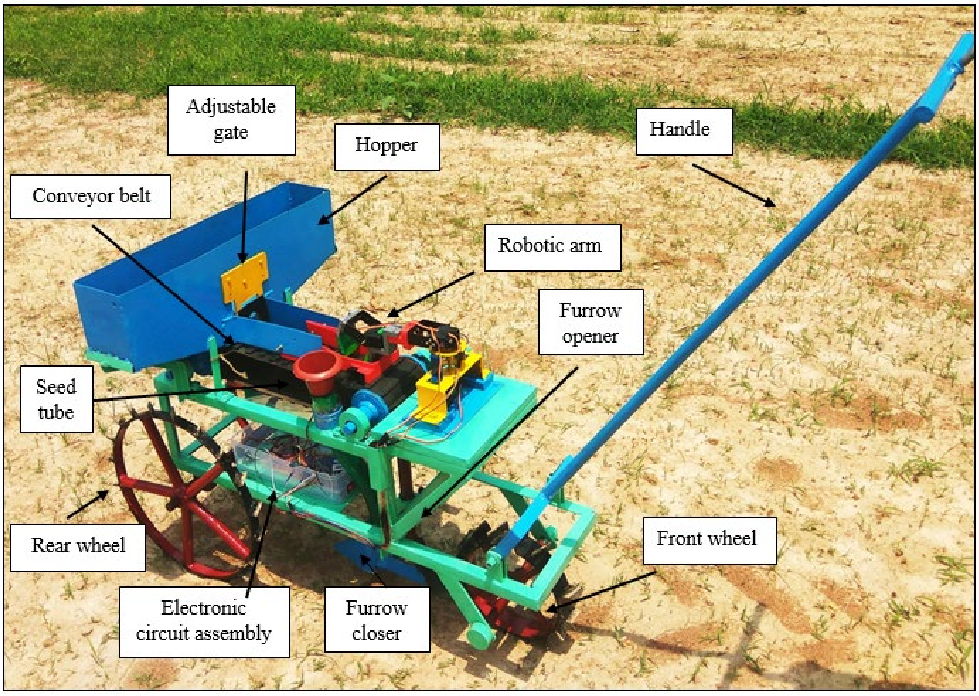


Figure 5 Diagram of the developed manual onion set planter

2.5.2 Ground wheels, seed tube, furrow opener, and closer

Three ground wheels, two as rear wheels and one as the front wheel, were provided. These two wheels were made of mild steel and lugs were provided on its periphery. The seed tube was made up of a PVC pipe with an inner diameter of 50 mm and a length of 450 mm. A funnel was attached at the top opening of the seed tube and the other end was connected to the furrow opener. A shovel type furrow opener was fitted to the planter. The width of the opener was 57 mm and the depth of it could be adjusted by lowering and lifting it inside a square bush fixed to the mainframe. Two 'V' shaped blades were attached to the seed tube to act as furrow closer.

2.6 Electronics circuit

Main components of the LDR circuit for controlling the belt conveyor were LDR, LASER light, 10k resistance, potentiometer, opamp LM258, 12 V relay, and 12 V DC motor (10 r.min^{-1}). A lead-acid battery (12 V, 12 A·h) was used as the power source for the robotic arm and the conveying system. 5 V voltage regulator was used to supply 5 V for 650 nm laser light. The complete circuit diagram is shown in Figure 6.

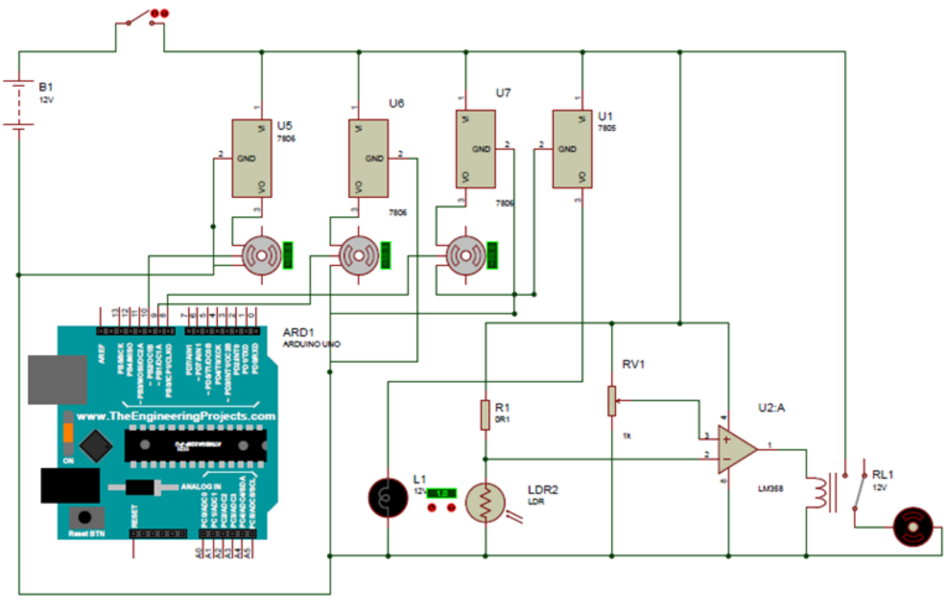


Figure 6 Schematic layout of the complete electronic unit of the developed planter

2.7 Testing procedure of the planter

2.7.1 Laboratory testing of the robotic arm and conveyor system

The experimental plan of laboratory testing of the robotic arm is given in Table 2. Weight of onion sets, delay in microseconds, hopper fill, and speed of conveyor belt were set as independent factors. Levels (the values of the independent parameters or factors in an experiment) of the weights of onion sets were set as six and for the rest factors, it was set as three.

Table 2 Experimental plan of laboratory testing of the robotic arm

Variables	Levels	Values
Common Parameters		
Supply voltage for robotic arm (V)	1	6
Supply voltage for conveyor system (V)	1	12
Independent Parameters		
Weight of onion sets (g)	6	8.26, 12.38, 16.89, 19.37, 25.94 and without onion
Delay in microseconds (µs)	3	100,200,300,400,500
Hopper fill (%)	3	0, 20, 40, 60, 80, 100
Speed of conveyor belt (m.s^{-1})	3	0.08, 0.12, 0.16
Dependent Parameters (to be measured in the laboratory experiment)		
Cycle time (s)		
Picking efficiency of arm (%)		
Percentage of correct dropping (%)		
Power requirement for arm (W)		
Power requirement for dc motor (W)		
LDR circuit response (ms)		

Current requirements by DC motors were measured using an ammeter and the power requirement was found from the following formula:

$$P = V \times I \quad (10)$$

Where, P was the power requirement by the DC motors (W), V was the applied voltage to the DC motors (V), and I was the current flow through it (A).

The picking efficiency (Q) and percentage of correct dropping (D) were found by using Equation 11 and Equation 12. Five different delays were put under each belt speed. Three replications were there for each combination. Each experiment was carried out with 30 onion sets.

$$\mathrm{Q} = \frac{\mathrm{R}}{\mathrm{T}} \times 100\% \quad (11)$$

$$\mathrm{D} = \frac{\mathrm{F}}{\mathrm{R}} \times 100\% \quad (12)$$

Where, Q was the picking efficiency (%), R was the number of picked onion sets, T was the total number of attempts, D was the percentage of correct dropping (%), F was the number of dropped onion sets in the seed tube.

2.7.2 Field testing of the planter

Before going to test the planter in the field, soil was prepared for sowing the onion sets. Soil conditions were given in Table 3.

Field performance tests were carried out to obtain actual data on overall machine performance, i.e. row to row spacing, the distance between hills, depth of planting, missing hill percentage, ease of handling and operating, actual average traveling speed, actual operating hours, time spent for turning at the headland, time spent for adjustment of the machine and machine trouble, working capacity (hm^2.h^{-1}), draft requirement. The plot area of 10m x 2m was chosen for the testing of the planter. Two operators were engaged for field performance evaluation. Their average forward speeds were measured using a stopwatch and found as 0.582 km.h^{-1} and 0.85 km.h^{-1}.

Table 3 Soil conditions for the field testing

Type	Sandy loam
Bulk density (g.cm^{-3})	1.54
Particle density (g.cm^{-3})	2.34
Moisture content, db (%)	12
Cone index (kPa)	350

The theoretical field capacity and field efficiency of the onion planter were calculated using the following equations.

$$AFC = \frac{Area\ planted}{time\ taken} \quad (13)$$

$$TFC = \frac{S \times W}{10} \quad (14)$$

$$F_{eff} = \frac{AFC}{TFC} \times 100\% \quad (15)$$

Where, AFC was actual field capacity, hm^2.h^{-1}, TFC was Theoretical field capacity, hm^2.h^{-1},F_{eff} was field efficiency, %, W was width of the machine, m, S was forward speed, km.h^{-1}.

From the analysis of collected data, missed planting percentage (M), overall planting efficiency (O), soil covering efficiency of furrow closer (S), were calculated as follows:

$$M = \frac{B}{A} \times 100\% \quad (16)$$

$$O = \frac{C}{A} \times 100\% \quad (17)$$

$$S = \frac{N}{C} \times 100\% \quad (18)$$

$$A = B + C \quad (19)$$

$$N = C - L - E \quad (20)$$

Where, A was the number of theoretical planting sets (total number of the complete cycle of robotic arm), B was the number of missing hills, C was the actually planted sets in the plot, N was the number of sets covered with a sufficient amount of soil, L was the number of planted sets covered with less amount of soil, E was the number of planted sets covered with excessive amount of soil.

2.7.3 Measurement of draft

Required pull to draw the planter was measured using an S type load cell (500 N capacity). The load cell was attached with the handle of the planter as shown in Figure 7. HX711 load cell amplifier and Arduino UNO were used. The schematic diagram of the circuit of this draft measurement set up is given in Figure 8.

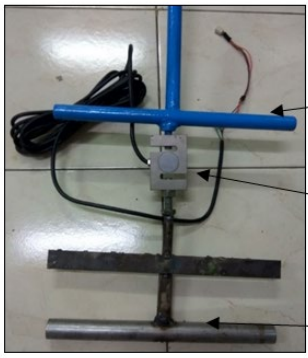


Figure 7 Draft measurement set up at handle of planter

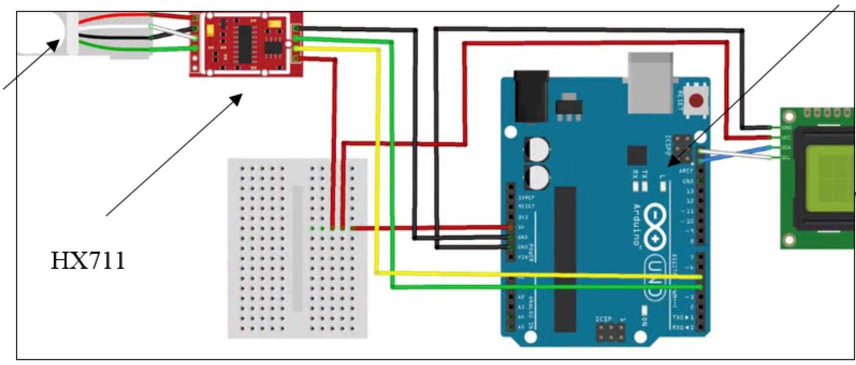


Figure 8 Circuit diagram for the LCD to measure the pull

3 Results and discussion

3.1 Geometric properties of onion

Thirty onion sets were taken for the measurement and the average values of polar diameter, equatorial diameter, thickness, geometric mean diameter, shape index, and sphericity of onion sets were 27.23 mm, 30.75 mm, 27.23 mm, 28.28 mm, 1.14, and 0.91 respectively. As the shape index was less than 1.5, the onion sets were considered spherical. Mass of individual sets was measured using a digital weighing balance. The angle of friction between onion sets and a mild steel plate was determined using a setup for the plate friction test. Average weight, angle of friction, and coefficient of friction were found to be 12.11g, 11.81°, and 0.21 respectively.

3.2 Performance evaluation of the robotic arm

3.2.1 Picking efficiency and holding capacity of the robotic arm

The picking efficiency of the gripper was evaluated using different sizes of onion sets (geometric mean diameter ranging from 24.34 mm to 33.61 mm). It was found that smaller size sets were efficiently picked up by the gripper i.e. sets slid into space between rotating and stationary fingers as shown in Figure 9. But the larger size sets, weighing 32.86 g, obstructed the rotating fingers from closing completely as shown in Figure 10. Hence, the gripper couldn't grip properly. As the onion sets to be planted are required to be lesser than 25 g, hence, the developed gripper could easily grip the onion sets.

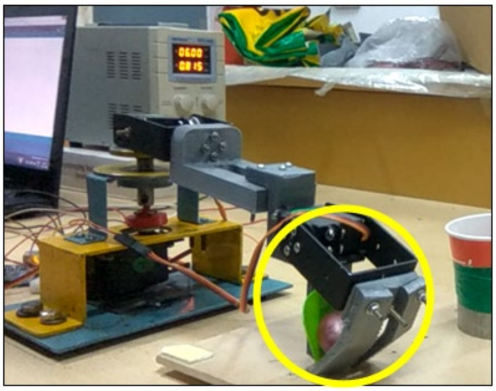


Figure 9 Gripping small onion set

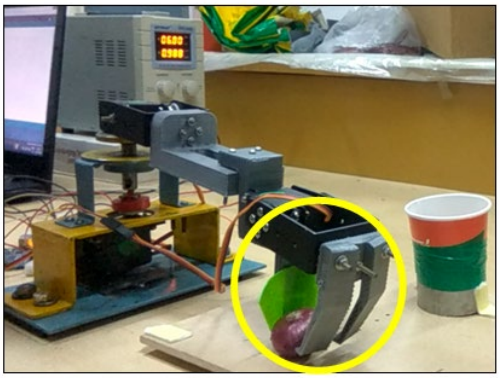


Figure 10 Gripping large onion set

The holding capacity of the robotic arm was tested with onion sets weighing up to 25.94 g. The robotic arm successfully gripped, lifted, and released the set in the seed tube.

3.2.2 Measurement of cycle time

The cycle time was measured to monitor the speed of carrying out the operation. One complete cycle of robotic arm operation in handling the onion set included the time for picking a set, lifting it, carrying and dropping the onion set in the seed tube, and returning to the initial position.

Cycle time was measured using a stopwatch. Delay time for servomotors was varied between 100 µs to 500 µs and the corresponding cycle time was measured and found to be varying between 0.8 s to 3 s as shown in Figure 11.

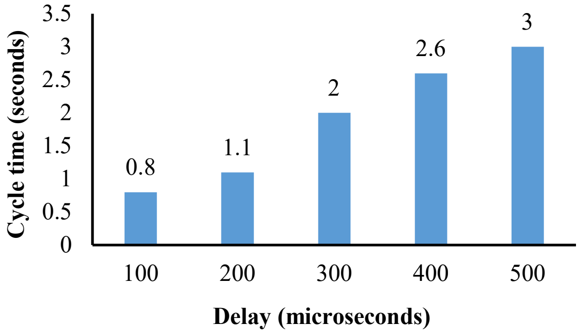


Figure 11 Measurement of cycle time

3.2.3 Performance of robotic arm

The picking efficiency of the robotic arm at different conveyor belt speeds (0.8, 0.12, 0.16 m.s^{-1}) are given in Table 4. It can be observed in Table 4 that at 0.08 m.s^{-1} the picking efficiency was less. This lower speed could not create enough disturbance at the hopper and could not maintain a proper flow of onions. That was why a timely supply of onion was not there and the robotic arm performed a false cycle without picking any onion set. Again at the higher belt speeds, the onions were not steady after reaching the workplace due to their higher momentum hence causing a problem for picking. Higher picking efficiency was observed at the belt speed of 0.12 m.s^{-1}. The two-way ANOVA analysis (Table 5) with replication showed that belt speed and delay had affected the picking efficiency significantly (p<0.05) where interaction did not affect this (p>0.05).

Correct dropping percentages of the robotic arm at different belt speeds and delays were given in Table 6. It was clear from the analysis (Table 7) that the only delay had a significant effect on the correct dropping percentage (p<0.05). At 100 µs delay, vibration was too much that a majority of picked onion sets were dropped outside of the seed tube. On the other hand, a delay of 400 µs and 500 µs could perform the complete cycle very gently and all picked sets were correctly dropped into the seed tube. But these delays resulted in higher cycle time which could affect the hill spacing. Thus the belt speed of 0.12 m.s^{-1} and the delay of 200 µs were chosen for the field experiment.

Table 4 Picking efficiency of the robotic arm at different conveyor belt speeds and delays in microcontroller

Picking efficiency of the robotic arm (%)						
Belt speed(m.s^{-1})	Replication	Delay (µs)				
		100	200	300	400	500

0.08	1	69.76	69.76	73.17	75.00	76.92
	2	69.76	73.17	73.17	71.42	75.00
	3	71.42	69.76	71.42	73.17	76.92
0.12	1	93.75	100.00	90.91	93.75	93.75
	2	96.77	96.77	93.75	93.75	88.24
	3	96.77	93.75	90.91	96.77	96.77
0.16	1	81.08	78.95	78.95	81.08	83.33
	2	81.08	81.08	78.95	78.95	83.33
	3	78.95	76.92	83.33	78.95	76.92

Table 5 ANOVA analysis on the effect of belt speed and delay on picking efficiency (significance at 0.05 level)

Source of Variation	*SS*	*df*	*MS*	*F*	*P*	*F crit*
Belt speed	2174.358	3	724.7861	28.82799	3.98×10^{-8}	3.008787
Delay	44251.75	5	8850.35	352.018	1.25×10^{-21}	2.620654
Interaction	616.9364	15	41.1291	1.635888	0.136874	2.107673
Within	603.4021	24	25.14175			
Total	47646.45	47				

Table 6 Correct dropping percentage of the robotic arm at different belt speeds and delays (significance at 0.05 level)

Correct dropping percentage of the robotic arm (%)						
Belt speed(m.s^{-1})	Replication	Delay (μs)				
		100	200	300	400	500
0.08	1	60	93.33	93.33	100.00	100.00
	2	56.66667	90.00	90.00	100.00	100.00
	3	56.66667	90.00	93.33	100.00	100.00
0.12	1	56.67	96.67	96.67	100.00	100.00
	2	53.33	93.33	96.67	100.00	100.00
	3	56.67	90.00	93.33	100.00	100.00
0.16	1	63.33	93.33	96.67	100.00	100.00
	2	56.67	90.00	93.33	100.00	100.00
	3	60.00	93.33	93.33	100.00	100.00

Table 7 ANOVA analysis on the effect of belt speed and delay on correct dropping percentage (significance at 0.05 level)

Source of Variation	*SS*	*df*	*MS*	*F*	*P*	*F crit*
Belt speed	12.82176	3	4.27392	1.587561	0.218417	3.008787
Delay	60187.05	5	12037.41	4471.334	8.37×10^{-35}	2.620654
Interaction	70.49769	15	4.699846	1.745772	0.108299	2.107673
Within	64.61111	24	2.69213			
Total	60334.98	47				

3.2.4 Power consumption of robotic arm

The robotic arm was tested for its power consumption during operation with a delay of 200 μs at the microcontroller. The current in all three servo motors while picking, carrying, and releasing the onion sets were measured using an ammeter keeping the voltage at 6 V. Five onion sets of different weights were taken for measuring power consumption (Figure 12).

Power consumption of the servo motors increased with an increase in the weight of the onion sets. The power in the base motor was higher only while carrying. The servo motor for the arm needed maximum power for lifting the onion sets and minimum power releasing the onion set as the torque required was reduced. For the gripper motor, power requirement was higher only for lifting and releasing whereas it was constant during carrying. The power requirement in the gripper motor was less than the arm and base motor as it required power only to open and close the gripper.

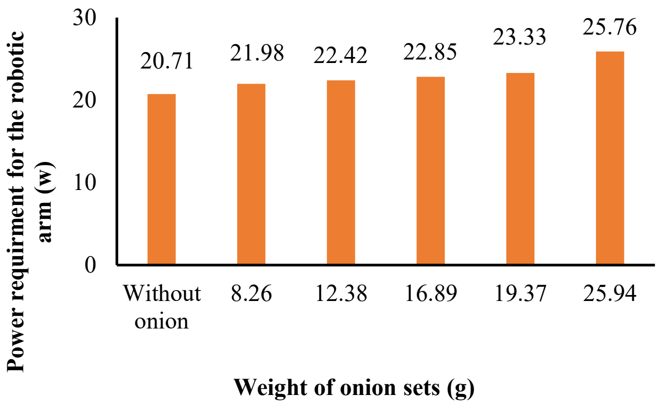


Figure 12 Power requirement for the robotic arm

3.3 Performance of the conveying system

3.3.1 Test for LDR (Light dependent resistor) time response

The response time of LDR was observed with the help of an oscilloscope. Time was measured to run the motor of the conveyor belt when an onion tuber was lifted off by the robotic arm from the fixed position. The time was calculated with the analysis of waveform electronic signal. The response time of LDR was found to be 450 ms.

3.3.2 Power consumption of DC motor

Power consumption of the DC motor to convey the belt was affected by the percentage of hopper fill (Figure 13). The current in the DC motor was measured keeping the voltage as 12 V. The maximum power consumption was found to be 29.74 W at 100% hopper fill which was 11.09% and 16.31% higher than that of 80% and 60% hopper fill, respectively.

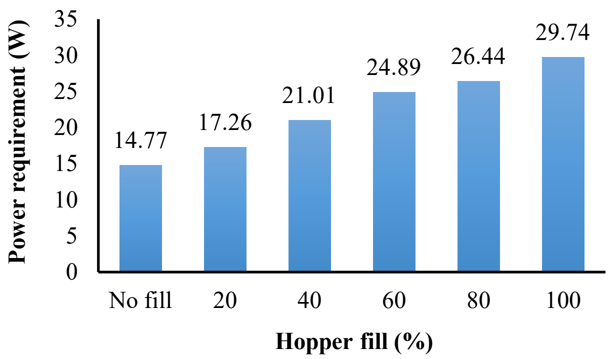


Figure 13 Power requirement for the motor at different hopper fills

3.4 Performance evaluation of planter in the field

The whole field experiment was conducted at two speeds of operation by two different operators. Average operating speed was measured with 5 trials with 20 m walking. Two speeds of operation were measured as 0.582 km.h^{-1} and 0.85 km.h^{-1}.

3.4.1 Row to row and hill spacing

The chosen field had a dimension of 10 m×2 m. The row to row spacing was maintained at 25 cm. Hence, onion sets were planted in 8 rows. For measuring the spacing between sets, 10 readings were taken randomly for both the speeds of operations and given in Table 8. Average hill spacing was found to be 160.2 mm with a standard deviation of 4.4 mm at the operating speed of 0.582 km.h^{-1} as compared to 237.1 mm and 3.2 mm for operating speed of 0.85 km.h^{-1}. Depth of planting was found to be (45±5) mm for all planted sets.

Table 8 Spacing of onion sets obtained from developed planter

Sl. No	Spacing between adjacent sets, mm	
	0.582 kmph speed	0.85 kmph speed
1	160	236
2	156	241
3	154	226
4	165	235
5	169	251
6	157	258
7	161	231
8	163	223
9	156	234
10	161	236
Mean	160.2	237.1
SD	4.64	10.65
Variance	21.51	113.43

3.4.2 Percentage of missing hill

Theoretically, the number of sets in a row should be equal to the total number of complete cycles of the arm. But in some cases, the arm took more than one cycle to pick the onion set and drop it into the seed tube. The number of complete cycles (NCC) and actual onion sets dropped (AOSD) are listed in Table 9. The average missed planting of onion sets was 7.8% at the operating speed of 0.582 km.h^{-1} as compared to 17.45% at 0.85 km.h^{-1}. The ANOVA analysis of the effect of speed on missing hill percentage is shown in Table 10 and it can be concluded that changes of speed affected missing hill index significantly (p<0.05).

Table 9 Theoretical and actual hill droppings and missing hill percentage in field test

	0.582 km.h^{-1}			0.85 km.h^{-1}		
	NCC	AOSD	Missing hill percentage (%)	NCC	AOSD	Missing hill percentage (%)
Row 1	63	58	7.93	42	38	9.52
Row 2	62	58	6.75	43	37	13.95
Row 3	60	58	3.33	40	33	17.5
Row 4	64	56	12.5	45	35	22.2
Row 5	61	57	6.55	43	31	27.9

Row 6	65	61	6.15	43	36	16.51
Row 7	65	59	9.23	43	34	20.93
Row 8	60	54	10	45	40	11.11

Table 10 ANOVA analysis on the effect of speed on the missing hill (significance at 0.05 level)

Source of Variation	*SS*	*df*	*MS*	*F*	*P*	*F crit*
Between Groups	372.8761	1	372.8761	16.53728	0.001155	4.60011
Within Groups	315.6665	14	22.54761			
Total	688.5426	15				

3.4.3 Soil covering efficiency of furrow closer

The number of planted sets, uniformly covered sets, less covered sets, and excessively covered sets at both speeds of operations were listed in Table 11. The soil covering efficiency of furrow closer was 88.93% and 90.14% at the speed of operation of 0.582 km.h^{-1} and 0.85 km.h^{-1}, respectively.

Table 11 Performance of the furrow closer

Speed (km.h^{-1})	**Total planted sets**	**Uniformly covered sets**	**Less covered sets**	**Excessively covered sets**
0.582	461	410	28	23
0.850	284	256	19	9

3.4.4 Calculation of field capacity

Table 12 Field capacity, field efficiency at two operating speeds

	0.582 km.h^{-1}	**0.85 km.h^{-1}**
Number of turns	7	7
Turning time loss(min)	1.3	1.4
Planting time (min)	8.25	5.71
Total time (h)	0.159	0.1185
Planted area (hm^2)	0.002	0.002
Actual field capacity (hm^2.h^{-1})	0.012	0.018
Field efficiency (%)	59.88	60

Actual field capacity was calculated using Equation 13. Theoretical field capacity was computed using Equation 14 and was found to be 0.021 hm^2.h^{-1}and 0.03 hm^2.h^{-1} at the operating speed of 0.582 km.h^{-1} and 0.85 km.h^{-1}, respectively. The number of turns, operation time, time loss for turning are listed in Table 12.

3.4.5 Measurement of force required to pull the planter

The pull was measured at both operating speeds for different hopper fills. The angle of pull force was 35° for the operator height of 5'4". The pull values at different hopper fill at two operating speeds are shown in Figure 14. ANOVA analysis (Table 13) showed that both the speed and hopper fills affected the pull requirement of the planter (p<0.05).

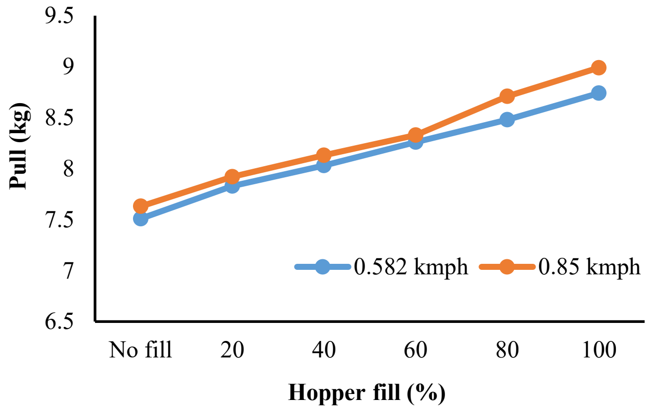


Figure 14 Values of pull at different hopper fills at both operating speeds

Table 13 Two-way ANOVA analysis on the effect of speed and hopper fill on pull (significance at 0.05 level)

Source of variation	*SS*	*df*	*MS*	*F*	*P*	*F crit*
Hopper fill	2.246267	5	0.449253	152.1174	1.86×10^{-5}	5.050329
Speed	0.061633	1	0.061633	20.86907	0.006011	6.607891
Error	0.014767	5	0.002953			
Total	2.322667	11				

Pull increased with an increase in hopper fill and speed of operation. At 100% hopper fill, pull was 2.86% higher in 0.85 km.h^{-1} speed than 0.582 km.h^{-1} speed. Pull increased by 17.82% and 16.38% from no fill to 100% hopper fill at 0.85 km.h^{-1} and 0.582 km.h^{-1} respectively.

3.5 Cost of the planter

The manufacturing cost of the planter is given in Table 14. The total cost of the developed planter was 13500 INR (164 USD), which was affordable for the small and rural onion producers.

Table 14 Cost of the developed planter

Particular	Specification	Quantity	Price (INR)
Electronics parts			
DC motor	120 kg-cm	1	600
Servo motor	11.2 kg-cm	3	900
3D printed robotic arm parts			1000
Arduino UNO	ATmega328	1	500
Necessary electronic circuit components			400
Battery	12 V, 12 A.h	1	1800
Mechanical parts			
Angle iron, MS sheets, Bearings, Shafts Belt, Pulley			4000
Others			
Paints			300
Labor cost			4000
Total			13500 (184 USD)

4 Conclusions

By using mechatronics, an onion set planter was developed with a specially designed hopper having a cut section at the middle of the base. A robotic arm, controlled by Arduino UNO microcontroller, with a special type of gripper, was developed to properly pick, carry and drop onion sets without damaging them. A conveyor belt powered by a DC motor, placed beneath that cut section of the hopper, which moved onion sets to the workspace of the robotic arm. There were a laser light and LDR circuit at the workspace. The rotation of the DC motor was dependent on the output of the LDR circuit. Onions coming at the workspace of the robotic arm interrupted the laser light from falling over the LDR hence stopped the belt movement. The robotic arm picked, carried, and released the onion sets into the seed tube. This planter was better than other existing ones (cup elevator type, inclined plate type metering mechanism) in terms of less missing hill percentage, less damage to onion sets, and proper planting.

5 Scope of future work

The developed robotic arm and the conveying system performed successfully to meter the onion sets for planting. The operator walking speed has been recommended around 0.58 km.h^{-1} for maintaining hill spacing. But it is quite tough to maintain a uniform speed at all time. That's why the plan is to make this planter fully automatic and multi-row.

References

Bechar, A., and C. Vigneault. 2016. Agricultural robots for field operations: concepts and components. *Biosystems Engineering*, 149: 94–111.

Cho, S. I., S. J. Chang, Y. Y. Kim, and K. J. An. 2002. AE-Automation and emerging technologies: Development of a three-degrees-of-freedom robot for harvesting lettuce using machine vision and fuzzy logic control. *Biosystems Engineering*, 82 (2): 143-149.

Colby, W. G., C. J. Gilgut, and H. M. Yegian. 1945. The culture of sets in the Connecticut valley. *Massachusetts Agricultural Experiment Station Bulletin*, 424: 1-16.

Foglia, M. M., and G. Reina. 2006. Agricultural robot for radicchio harvesting. *Journal of Field Robotics*, 23:363-377.

Grift, T., Q. Zhang, N. Kondo, and K. C. Ting. 2008. A review of automation and robotics for the bioindustry. *Journal of Biomechatronics Engineering.*, 1 (1): 37–54.

Hwang, H., and F. E. Sistler. 1986. A robotic pepper transplanter. *Applied Engineering in Agriculture*, 2 (1): 2-5.

Ketema, S., L. Dessalegn, and B. Tesfaye. 2013. Effect of planting methods on maturity and yield of onion (Allium cepa var cepa) in the Central Rift Valley of Ethiopia. *Ethiopian Journal of Agricultural Sciences.,* 24: 45-55.

Khokhar, K. M., S. I. Hussain, Hidayatullah, T. Mahmood, and M. H. Bhatti. 2001. Effect of set size on bulb yield, maturity and bolting in local and exotic cultivars of onion during autumn season. *Sarhad Journal of Agriculture*, 17(3): 355-358.

Madan, P. A. 2013. Development of metering device for onion (Allium cepa. L) bulblet planter. M.S. thesis. Madhya Pradesh: Jawaharlal Nehru Krishi Viswavidyalaya, Jabapur.

Megalingam, R. L., G. V. Vivek, S. Bandyopadhyay, and M. J.

Rahi. 2017. Robotic arm design, development and control for agriculture applications. In *2017 4th International Conference on Advanced Computing and Communication Systems (ICACCS),* 1-7. Coimbatore, 6-7 Jan. 2017.

O'connor, D. E. 1994. Use of onion sets to aid continuity in bulb onion production. *Acta Horticulturae*, 371: 91-95.

Pandharinath, S. M. 2000. Tractor driven onion transplanter. National Innovation Foundation – India.

Rahul, K., H. Raheman, and V. Paradkar. 2019. Design and development of a 5R 2DOF parallel robot arm for handling paper pot seedlings in a vegetable transplanter. *Computers and Electronics in Agriculture*, 166: 105014.

Ranthikumari, A. C., and D. M. Jesudas. 2015. Design and development of tractor onion set planter. *Indian Journal of Agricultural Science*, 85 (8):1038-1041.

Ryu, K. H., G. Kim, and J. S. Han. 2001. AE-Automation and emerging technologies: development of a robotic transplanter for bedding plants. *Journal of Agricultural Engineering Research*, 78 (2): 141-146.

Sadhu, R. R. 1982. Development of an onion set planter based om design criteria of plant transplanter. M.S. thesis. Texas: Texas Tech University.

Turbatmath, P. A., Y. C. Bhatt, and P. B. Kadam. 2011. Development and field evaluation of tractor operated onion transplanter. *International Journal of Agricultural Engineering*, 4(1): 52-55.

Vandermark, J. S. 1977. Onions are finicky growing, curing; and garlic may not be joy either. *The Year book of Agriculture*, 152-156.

Xiong, Y., C. Peng, L. Grimstad, P. J. From, and V. Isler. 2019. Development and field evaluation of a strawberry harvesting robot with a cable-driven gripper. *Computers and Electronics in Agriculture*, 157: 392–402.

Zhao, D., J. Lv, W. Ji, Y. Zhang, and Y. Chen. 2011. Design and control of an apple harvesting robot. *Biosystems Engineering*, 110 (2): 112-122.

Zhao, Y., L. Gong, C. Liu, and Y. Huang. 2016. Dual-arm robot design and testing for harvesting tomato in greenhouse. *IFAC PapersOnline*, 49(16): 161–165.

Zion, B., M. Mann, D. Levin, A. Shilo, D. Rubinstein, and I. Shmulevich. 2014. Harvest-order planning for a multiarm robotic harvester. *Computers and Electronics in Agriculture*, 103: 75–81.