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Automatic Ejection of Plug-type Seedlings using Embedded System for use in Automatic Vegetable Transplanter

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This paper presents an automatic ejection mechanism using micro-controller based system for various plug-type vegetables seedlings grown in pro-trays. The developed system consisted of an electro-mechanical unit for actuating metering shaft through stepper motor and feed roller through DC (Direct Current) motor by computer programme. Both the stepper and DC motor were linked to the micro-controller via universal asynchronous receiver-transmitter protocol using an Arduino Uno. Here, computer programme was used to integrate with electro-mechanical unit using drivers which controls the stepper motor as well as DC motor. The main objective of this paper is to provide an automatic ejection mechanism to automate the transplanting operation for plug-type seedlings directly from pro-trays. The mechanism was tested under actual field conditions for various performance parameters like plant spacing, miss planting, transplanting efficiency, effective field capacity, and field transplanting efficiency. Also, the effective field capacity was compared with conventional method of transplanting (manual transplanting). The spacing between consecutive plants was found in the range of 564 mm to 599 mm, and the miss planting was about 4.5 to 5%. Also, the transplanting efficiency and field transplanting efficiency was observed to be 90.0–92.6% and 74.1–75.6%, respectively. The effective field capacity with developed automatic vegetable transplanter was 0.093 ha/h whereas it was 0.027 ha/h with manual transplanting for both type of seedlings. The results indicated that automatic ejection mechanism can be used for automatic planting of plug-type seedlings viz. tomato, eggplant, chilli, etc. as an alternative to hand transplanting by providing a better transplanting efficiency, optimum plant spacing and ensuring timeliness in operation. Additionally, due to automation it will considerably reduce the man power requirement and enhance the productivity as compared to manual transplanting.

Keywords: Automatic, Mechanism, Micro-controller, Seedlings, Transplanting

Introduction

Use of electronics and instrumentation have made the agriculture production system hitech as well as convenient for working under adverse conditions such as during labour shortage or extreme climatic condition. Also the use of robotics and Artificial Intelligence (AI) has brought the change in the improved machinery manufacturing to foster the agricultural operations. The low level of mechanization is the major limitation in enhancing vegetable production.[1] Mechanized cultivation not only increased the crop production but also saves time involved in agricultural operations. Hand transplanting seedlings on a large scale was a labour demanding as well as expensive operation as compared to transplanting with mechanical means.[2]

It is relatively not possible to achieve accuracy in terms of uniformity in plant spacing while seedling transplanting by manually or mechanically. Hence to reduce inefficiencies, the most efficient way was to incorporate some Automatic Ejection Mechanism (AEM) that can do the required task. In most of the transplanters, metering system was the main unit which needs to be upgraded. However, studies reported that manual feeding of seedlings into metering mechanism of Semi-automatic Vegetable Transplanters (SVT) have limited scope which decreases with time and duration of operation. The transplanter uses ground wheel drive to transmit motion through chains and sprockets arrangement. Again, the ground wheel also drives the metering unit in reference to forward motion of the prime mover and therefore, the resulted slip affects the transplanting in actual field operations. As a result, there is non-uniformity in plant spacing due to the wheel slip.[3]

As mentioned above the constraints in SVTs, an automatic system would be an alternative to mechanized transplanting operation. Studies showed

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that most of Automatic Vegetable Transplanters (AVT) were developed either for plug-type seedlings or for paper pot seedlings.

The developed AVTs uses pick-up mechanism, planting as well as feeding system or an end-effector having a pneumatic system that grasp and place the seedling using micro-computer.[4–9] An AVT integrated it with gantry system were also reported for brinjal grown in individual pots for use in greenhouse.[10] Most of the studies on AVTs are carried on seedling pick-up mechanisms that are tested laboratory condition. Khadatkar & Mathur developed an AVT using a novel rotating finger with push-type mechanism that directly ejects seedling from the pro-tray.[8]

The success rate of AVT having seedling pick-up mechanism can be 97% with extraction rate of about 30 seedlings/min,[6] whereas a conveyor-type mechanism transplants 90 seedling/min in plastic mulch by making holes.[10] Also, in another study, a linked chain-type mechanism used in AVT plants 1300–1700 seedlings/h for planting at 360 mm spacing.[11] Since, most of the developed AVTs were tested under laboratory conditions; the performance results could be validated by testing them in field for actual field conditions.

Also, the impacts of greenhouse emissions, increasing prices of vegetables, peak prices in off-season and escalation in population have exaggerated the study on developing the advance technologies for vegetable cultivation. As per UN FAO report, we need 70% increases in total production to feed world.[12] AVT is an alternative method due to their capability to perform transplanting operation in time, reduce drudgery, increasing field capacity, higher transplanting efficiency and less labour requirement. However, in spite of substantial study and effort carried in the past years the main concerns related to develop automatic or robotic transplanters which are a need of the hour. Furthermore, SVTs developed are yet to reach production level mainly due to higher initial cost, manual intervention in operation and low speed of operation. Singulation and difficulties associated with its manual feeding of seedlings into tubes are also the major constraints with SVT that could be resolved by developing automatic technologies using electro-mechanical systems.

In India, seeding and transplanting operations, that are mainly performed manually account for 40% of total working hours of cultivation. The traditional practice was to hold a bunch of seedlings in one hand and separate seedlings by the other hand and press down the roots in the soil with fingers and compacting the soil around it. The labour requirement in manual transplanting of vegetable seedlings varies from 180–420 man-h/ha.[13] However, delayed planting, leads to drastic reduction in yield due to labour shortage.[14,15]

The aim of this paper was to develop and evaluate a novel AEM using micro-controller for automatic planting of seedlings. This paper also delivers a brief contextual on vegetable transplanting, Arduino, micro-controller, metering mechanism and hardware as well computer programming. The primary part focuses on the background of the hardware development, interfacing of Arduino with stepper motor with driver and later part briefs about the development of software and coding. The hardware as well as the computer programme developed could be easily adapted or modified as per the requirements in order to adjust the plant to plant spacing.

Materials and Methods

Development of Embedded System

A stepper motor rotates in discrete steps due to its unique design. It was generally used for precise positioning without feedback. Here, six wired stepper motor having step angle 1.8° was used with TB6560 stepper motor driver. Direction and enable wires of stepper motor were connected to the 4 and 9 number digital pins of the Arduino Uno. TB6560 driver acts as a bridge between Arduino and stepper motor. Different switches of the driver were used for operating the motor at different modes (steps). Direct current motor having torque of 50 Nm and 72 rpm was used to operate the pro-tray feeding roller unit. The DC motor was operated by 12V power supply and Arduino provide 5V output power. Hence, it was not directly connected to microcontroller. The DC motor driver has 3 pins which were connected to the Arduino through 5V, GND and 10 number digital pin of the Arduino Uno.[3] Other end of driver contains two wires for 12V power supply, connected with battery and two wires for DC motor. The driver acts a bridge between microcontroller and DC motor. In the output stage, hybrid IC power MOSFET used by the DC motor driver was used for controlling the direction of motor using constant-current Pulse Width Modulation (PWM) system. Direction of stepper motor was reversed horizontally by using leaf switches on either sides of the shaft.

Micro-controller based Actuating Unit

The developed hardware unit comprised of Arduino Uno (ATmega 328) microcontroller board having 20 input/output pins (14 for digital, 6 for analog), DC motor having maximum rpm 72 with rated torque 50 Nm, stepper motor of 22.4 kg·cm holding torque, pro-tray feed roller, leaf switches, drivers for motors and 12V DC power supply. The maximum current and voltage requirement for Arduino, DC motor, Stepper motor were 2A, 4A, 4A and 12V, respectively. The stepper motor use has stepping angle of 1.8º, number of phase 2 and rated voltage 3.2 V. The detent and rotor torque of motor is 700 and 480 g·cm, respectively. The frequency signals varies the speed of stepper motor which was provided by the Arduno Uno. The motor used has 2 phase bipolar having 4 wires; two wires for each phase, respectively. The stepper motor provides back and forth motion to the metering shaft whereas row wise tray shifting was addressed by the DC motor. The pro-tray feed roller unit contains seedlings pro-tray which eject out into the delivery unit. In order to change direction of stepper motor the leaf switches were used on either side of plate. When the switches were pressed the direction of motor changes.[3]

DC Motor Driver

The speed and direction of DC motor was adjusted using a DC motor driver shown in Fig. 1. This driver acts as an interface between micro-controller and the motor. The Arduino Uno provided PWM pulses to the driver which varied the duty cycles of PWM pulses to control the speed of motor. The micro-controller provided three types of inputs to the driver viz. changing the direction, speed controlling and halting the motor. The main feature of the driver was to stop the reverse current from the circuit which may cause damage to the motor of circuit components. It also includes safety electric circuit to safe the controller from electrical fluctuations or reverses current. This driver works on 5V DC which was supplied by Arduino.[3]

Stepper Motor Driver

The stepper motor was required a driver for interfacing the motor to the micro-controller. The microcontroller binary and PWM output of the micro-controller controlled the direction and speed of the motor. The leaf switches provided high digital input signals to the controller. These signals were forwarded to the driver for rotating the motor in desired direction. The driver contains micro-stepping controller to provide constant current PWM output signals to the stepper motor. The developed unit has TB6560 stepper motor driver (Make-Robokits, Model-V2) for actuating the stepper motor and controlling the motor direction (Fig. 2). The driver includes heat sink for proper heat dissipation and opto-coupler isolation circuit.

Working Principle

The pro-tray of the seedlings were placed over the feed roller, which was moved by the DC motor in forward direction. The metering shaft was attached on the stepper motor which operates the rotating fingers mounted on L-shaped fingers were used to drop the seedling from pro-tray by the action of striking. When the pro-tray reaches the right position of the machine, the leaf switch at that end gets pressed and the direction of stepper motor gets reverse automatically. Due to this action the metering shaft start moving to another side (left side). The stepper motor provides linear back and forth motion to the metering shaft. The L-type fingers attached to the metering shaft when reached to the middle of the pro-tray cell, the fingers strikes the cell bottom from outside. This striking action at the cell bottom reasons the seedling to jump out of the cell. These jumped out seedlings automatically drops into the delivery tube of the

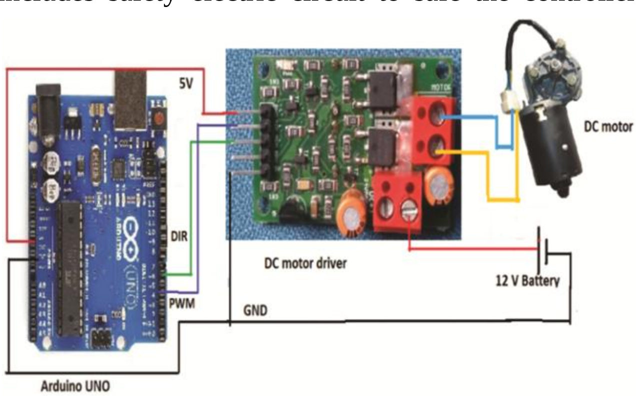

Fig. 1 — Integrating DC motor with microcontroller

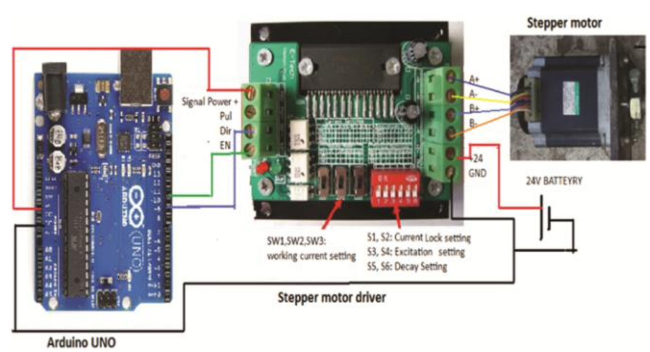

Fig. 2 — Integrating stepper motor, driver with Arduino

system by gravity. The delivery tube was just like a guiding tunnel which helps the seedling to reach the seedling successfully into the ground. When the leaf switch was pressed by shaft then direction of shaft changes and rotating finger reached their initial position. The block diagram of the developed system was shown in Fig. 3.

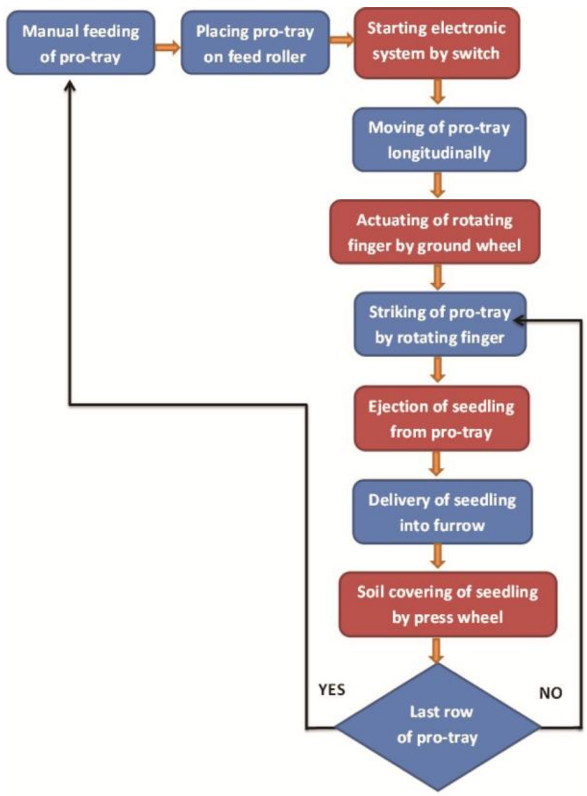

Fig. 3 — Block diagram of working principle of the AEM

Development of Software and Coding

The programming of microcontroller was developed in Arduino IDE software.[16] This software was user friendly and open source based on C and C++ language. There are two main structures in Arduino programming "void setup and void loop". The declaration of variables, initialize serial communication, setting of pin mode were done in void setup() for one time execution of programme whereas, void loop() consecutively running the program to control the function of Arduino board.[17] PWM signals were provided to the stepper motor by the microcontroller defined in stepMotor() loop and by reading the push button status in controller direction of motor changes. The motor moves in previous direction when both button switches remain low. The DC motor was operated by providing PWM signals at the enable pin of DC motor driver.

Testing of Developed System

The developed system consists of an automatic transplanter with automatic ejection mechanism for plug-type seedlings. The AEM is integrated with 12V battery, embedded system, stepper motor with driver and dc motor with driver. A 12V battery was used to operate the system and the ground wheel to operate the metering mechanism of the AEM. The automatic transplanter consisted of pro-tray feed roller unit, delivery unit, furrow opener, press wheel and ground wheel and was mounted on the tractor drawbar (Fig. 4). The developed system was tested with 30 days old chilli and tomato seedlings. The specification of developed AVT with AEM is given in Table 1.

Fig. 4 — Developed automatic vegetable transplanter with its components (1-Seedling pro-tray; 2-DC motor; 3-Battery 12V; 4-Stepper motor; 5-Microcontroller based system; 6-Delivery box; 7-Delivery pipe; 8-Ground wheel; 9-Press wheel; 10- Furrow opener; 11-Tractor; 12-Developed transplanter; 13-Transplanted seedlings)

Table 1 — Specifications of developed automatic vegetable transplanter

Sl. No.	Particulates	Specifications
1	Processor	ATmega328
2	Power supply mode	12 V, 24 Ah Battery
3	DC current per I/O pin	40 mA
4	Torque on feed roller unit	50 Nm
5	Torque on metering unit	2.2 Nm
6	Rotational speed	82 rpm (metering unit)
7	Overall dimension (l × b × h)	2030 × 1295 × 1015 mm
8	Working width	600 mm (adjustable)
9	No. of rows	2
10	Weight of seedling transplanter	200 kg (approx.)
11	Horse Power required (hp)	20–35 hp

***Plant Spacing (Ps)*:** The spacing between consecutive plants was measured along the row of 20 m length by using standard measuring tape.[3]

***Miss Planting (Mp)*:** The seedlings that are missed to transplant are expressed as the percent miss planting and is given below.[3]

$$\text{Mp} = \left(\frac{\text{Number of seedlings missed to plant}}{\text{Number of seedlings to be planted}}\right) \times 100 \qquad \dots (1)$$

where, Mp = Miss planting, %

***Transplanting Efficiency (Et)*:** It was determined by the ratio of number of seedlings successfully transplanted vertically upright with less than 30° inclination (3) and is given below.[3]

$$\text{Et} = \left(\frac{\text{Number of seedlings successfully transplanted}}{\text{Total number of seedlings transplanted}}\right) \times 100 \qquad \dots (2)$$

where, Et = Transplanting efficiency, %

***Field Transplanting Efficiency (Ef)*:** It was determined by the ratio of the actual time required to transplant the seedlings to the total time required for completing the transplanting operation in field which include turning time, loading tray and other time losses.

$$\text{Field transplanting efficiency, Ef} = \left(\frac{T1}{T1+T2+T3}\right) \times 100 \qquad \dots (3)$$

where, Ef = Field transplanting efficiency, %

T_1 = Time required to actually transplant the seedlings, min.

T_2 = Time required for taking turns at headland, min.

T_3 = Time required for initial adjustments, loading/unloading plug trays, etc, min.

***Effective Field Capacity (Fc)*:** The effective field capacity of the tractor operated vegetable transplanter was measured in the field by,

$$\text{Effective Field Capacity, Fc} = A / (T_P + T_N) \qquad \dots (4)$$

where, Fc = Effective field capacity, ha/h

A = Area covered, ha

T_P = Productive time, h

T_N = Non-productive time, h

Results and Discussion

The developed system with automatic transplanter mounted on the tractor was tested in field (Fig. 4). The performance of the AEM on developed AVT was evaluated based on the performance factors viz. Ps, Mp, Et and Fc in field with chilli and tomato seedlings.

The field experiments were conducted in the field of ICAR-Central Institute of Agricultural Engineering, Bhopal on a 58 × 8 m^2 sized field. It was located at the north of Bhopal at 77º 24′10″E, 23º18′35″N at 495 m above sea level. Soils of the testing site were categorized as vertisols with 34% sand, 22% silt and 44% clay content. The field capacity of soil ranged from 28.5 to 31%.

In the experiment, the developed AVT was operated at the best operating parameters obtained during the soil bin studies i.e. operating speed of 2.0 km/h, pro-tray feed roller angle of 30°, and reversible shovel type furrow opener with press wheel type soil covering cum compaction. The developed transplanter attached to 51 hp tractor (New Holland-3630 model) tested with 30 days old chilli (variety-PusaJwala) and tomato (variety-Abhilash) was used for transplanting in field.

The transplanting operation was done by the developed system, for 3 repetitions for each application on a 0.046 ha (58 × 8 m^2) area. The transplanting was carried out at 2.0 km/h operating speed with targeted plant to plant spacing of 600 mm. Performance parameters such as plant spacing, miss planting, transplanting efficiency (Et), field transplanting efficiency (Ef) and Effective field capacity were estimated for transplanting of chilli and tomato seedlings in the field and compared with manual method of transplanting.

The plant to plant spacing during the field experiment was shown in the Fig. 5. The mean value of plant spacing was found to be 564 mm and 599 mm for chilli and tomato seedlings, respectively. The mean value of miss planting was found to be 4.5% and 5% for chilli and tomato seedlings, respectively. The miss planting of tomato seedling was higher as the seedling is quite soft and hence may damage

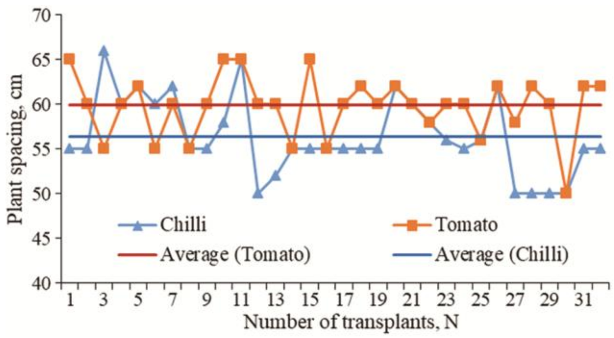

Fig. 5 —Plant spacing of chilli and tomato seedlings

easily. The Ef with AVT was found to be 92.6 % and 90.0 % for chilli and for tomato seedlings, respectively whereas; the Ef with manual method was about 75.6% and 74.1% for chilli and for tomato seedlings, respectively. Since, tomato seedlings were soft and delicate as compared to chilli seedling, the transplanting efficiency are relatively higher for chilli seedlings as compared to tomato seedlings. The effective field capacity was higher with developed AVT i.e. 0.093 ha/h with both seedlings as compared to manual transplanting (0.027 ha/h).[18]

The developed AEM integrated with AVT delivers synchronized drive between ground wheel and metering unit. The plant spacing thus obtained with developed AEM found close to the recommended spacing with improved efficiency over manual practice.

Conclusions

In this research work, an AEM based on micro-controller for transplanting of vegetable seedlings automatically was developed and tested. The developed system was tested in laboratory condition to optimize the performance parameters and then in field condition. The developed AEM can automate the transplanting operation by ensuring the timeliness in operation. The spacing between consecutive plants was found in range of 564 mm to 599 mm, whereas the Mp was reported to be 4.5 to 5%. The Et and Ef were found to be 90.0–92.6% and 74.1–75.6%, respectively. The Fc was 0.093 ha/h with developed AVT and was 0.027 ha/h with manual transplanting for both seedlings. The outcomes indicated that AEM used in AVT for planting of plug-type seedlings of chillies and tomatoes as an alternative to hand planting as it provides a greater efficiency, uniformity in plant spacing and timely operation.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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