# Pneumatic end-effector for precise seeding

**Piyush Malpure[1] Hrishikesh Chowkwale[2] Abhishek Gore[3] Aumkar Inamdar[4]Kunal Kale[5] Vaishali Gongane[6]**
[1,2,3,4,5,6] Pune Vidyarthi Griha's College of Engineering and Technology &
G. K. Pate (Wani) Institute of Management, Pune, India

[1]malpurepiyush07@gmail.com, [2]hchowkwale@gmail.com, [3]goreabhishek396@gmail.com,
[4]auminam23@gmail.com, [5]kale.kunal4898@gmail.com, [6]vug_entc@pvgcoet.ac.in

## Abstract

Robotics has brought a huge revolution in farming technology. Precision and accuracy are key features of robots. Automation in agriculture is an emerg-ing field that explores new and innovative techniques in farming. Robotic farming is a new research area which is attracting a lot interest. Precision farming is the area where this work focuses on gaining more yield, using opti- mum resources. The proposed system advances precise farming, leveraging a specially designed end-effector. The innovative device plays a crucial role in precise sowing of seeds for various plants. The efficacy of the end-effector has rigorously tested on vegetable seeds, mainly onion(light weight) and pumpkin seed (heavy weight), which form the ends of the seed weight spectrum. The end-effector incorporates a custom designed nozzle attached to the pneumatic actuator which can be changed according to the seed diameter. The nozzleis designed such that it is durable and sows the seeds precisely at required depths which are necessary for higher germination chances. An accuracy of 92% was obtained on pumpkin seeds and 93.34% on onion seeds with the designed end-effector.

*Keywords:*
Agriculture Robot, End-effector for seeding, Pneumatic end-effector,Precise seeding, End-effector

## 1. Introduction

A lot of research is being done in the field of agriculture. A lot of scien- tists are focusing on the development of techniques which will give high yieldof a particular crop. As the population rises the demand for food increases. Though the demand is increasing, land under cultivation is decreasing rapidly [1]. As the land under cultivation decreases more work needs to be done on the techniques which high quality yield per hectare. Many techniques have been researched by scientists to increase the crop yield, but the knowledge is not reaching the farmers in certain cases. Even if it reaches the adaptation rate is very low. The most effectively used technique is calledprecise farming [2].

Precise farming methodologies focus on growing quality and quantity of crop, thus giving high returns to the farmers. They take into consideration a lotof aspects, from seed weight and dimension to the final harvesting methods. Precise seeding is a sector where many aspects of sowing are to be considered, so that the final yield is obtained with minimum use of seeds. This kind of precision is difficult for humans to obtain over a longer time. Thus, involving robots is a valid choice to complete this task. This reduces human error and helps attain the desired precision [3][4].

## 2. Related Work

Agriculture robotics has been a domain where a lot of work is being donein the past couple of years. The most challenging part for robots in the agriculture domain is its diversity. Tough and robust designs are needed for successful implementation of robots. Work has been done by implementing aerial as well as ground robots for different tasks like seeding, weeding and harvesting [5].

In the domain of precise seeding, advantage can be taken of the already available precise industrial robots. The robotic arms are available in a large variety and are easily tunable to do a lot of tasks. With an effective design for end-effector this technology can be brought for mass use faster. The precision english seeder, a man operated seeder used for precise seeding in small areas, uses the pneumatic flow to pick up seeds with the help of a small needle tip attached to it. This type of structure can be made robust and automated for large scale use. Thus, we have focused on building an effective end-effector which can be adopted for a large variety of seeds. We have focused for itsuse on vegetable seeds.

Furthermore, the study done by Bracy et. al. [6] shows that the seed depth and spacing is of huge importance for increasing the yield. It also shows that the pneumatic suction on its own will not give great results, but when combined with other control techniques gives it a great advantage over othermethods. Thus, using precise robotic arms for precise seeding is bound to give good results.

## 3. Comparative Analysis

Most of the technologies which are used for sowing use huge machinery equipment. Most farming technologies use a tractor which is fit with the necessary modules, which are used for seeding. The tractors use grain drillsand planters. A variety of different types of such drills are already in use.These are heavy, bulky and costly modules [7].
Current robotic systems focus on the use of drill and belt seeders which are bulky [8]. Drill and belt seeders focus on speed rather than precision. Yanget. al. [9], have developed a precising smooth sowing robot which is also based on belt seeders. Lu et. al. [10], simulate a high-speed precise seeding device in lab, this system is comprised of large motors and gear system. A study shows that they also give a different performance for different types of seeds [11]. The review done by Nardon [12], showcases different requirements for different crops and the different types of systems which are used. Customizing the machine to give high performance for each type of crop is very difficult and costly as the complete system needs to be redesigned. Though itis easy to sow seeds on a large scale using faster components, many farmers use crop rotation and plant a variety of crops throughout the year, thesesystems then add up to his costs. The system design proposed, is easy to customize and adopt for a variety of crops. It also focuses on precision thus minimizing seed wastage.

## 4. Pneumatically Controlled Nozzle Design

Many factors go into deciding the design of the nozzle for seeding. Thesize and the surface area of the seed need to be taken into consideration so that only a single seed is picked up at a time. The depth at which a seedis sown also affects the chances of seed germination. A vegetable seed mustbe sown at least at a depth of 25mm for higher germination chances (This information was gathered from a survey done in College of Agriculture, Pune, India). The nozzle has a specially designed tip for different seed size and itstip extends down to the depth of 30mm thus providing the required depthfor sowing, thereby increasing the chances of germination.

The figure 1 shows proposed nozzle design. The hinder part of the nozzle is fixed to a vacuum pump permanently whereas the rest of the cylindrical part of the nozzle, which extends up to its tip canbe changed. This flexibility provides ease of changing the nozzle tips which come in different sizes and shapes, so that a variety of crops can be sownusing the same extruder. The two magnets hold in between them a thin fine-grained metallic filter thatfilters out the extra dust and sand which might due to some conditions enterupwards via the nozzle, thus blocking it and saving the pump from damage. The figure 2 shows a tip of diameter 5mm which can be used to pick upbigger seeds like pumpkin seeds. The figure 3 shows the nozzle with a tip diameter of 3mm which can be used to pick up small seeds like onion seed.

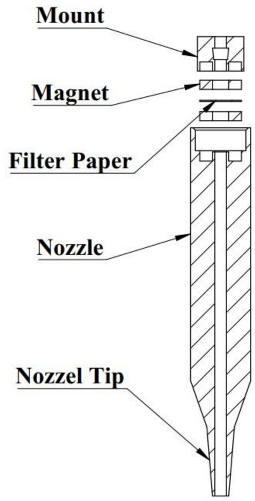


Figure 1: Exploded view of nozzle showing internal structure.

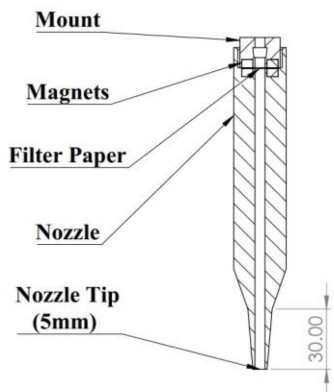


Figure 2: Nozzle with 5mm tip diameter for bigger seeds

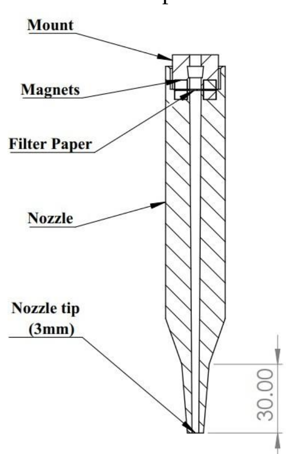


Figure 3: Nozzle with tip diameter to 3mm for smaller seeds.

## 5. Pneumatic End-effector

The nozzle is connected to a 12V vacuum pump by spark fun which provides a 15.1L of maximum flow capacity of air through it. The block diagram in figure 4 shows the connection for the vacuum pump. A 12V LiPo battery is connected to a DC motor driver, which has PWM control pins, using which speed of the suction pump motor can be varied. As the speed varies the flow velocity can be changed

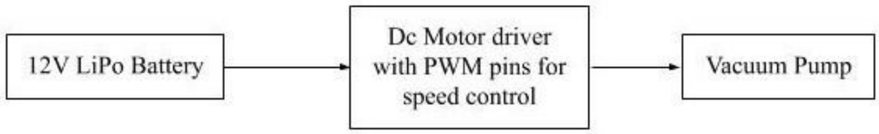


Figure 4: Block diagram for connection of vaccum pump.

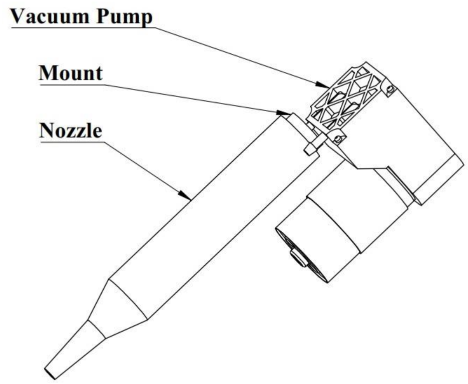


Figure 5: Nozzle mounted with suction pump.

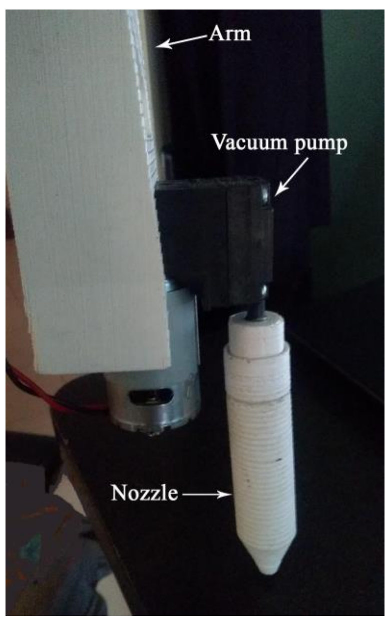


Figure 6: Actual constructed nozzle mounted with suction pump.

as per the requirements. This makesit ideal to be used for a variety of seeds. The complete end-effector assembly is as shown in the figure 5. The figure 6 shows the implementation of the assembly. Doing some simple calculations to check the capacity of the pump so thatit can be applied to a variety of crops with different weights, dimensions andsurface area.

The calculations for determining vacuum pump parameters are as follows. Since most of the vacuum pumps can be decided based upon the flow rate(litre per minute), following steps are performed. Using the data regarding seed weight per unit, and nozzle diameter, preliminary required pressure can be obtained Table 1, shows the important and decisive steps in calculation. The concept followed during this calculation was based on primary physics. The pressure required was calculated using the weight of seed as load forceand area of nozzle tip as the pressure action area.

This pressure is caused due to the vacuum pump [14].

$$Pressure(Pa) = \frac{Weight\ of\ unit\ seed\ (kg)}{Cross\ Sectional\ Area\ of\ Nozzle\ tip\ (m^2)} \quad (1)$$

Using Bernoulli's equation [14],

$$\mathrm{P} = \frac{1}{2}\,\rho v^2 + \mathrm{pgh} = \mathrm{Constant} \quad (2)$$

the pressure differential is acquired between the pump outlet and interface between nozzle and seed. Here considering the maximum datum difference during operation. Let $P_1$, $v_1$, $h_1$ be the values of Pressure, velocity of air and Height from datum, for plane containing seed-nozzle interface. Similarly, let $P_2$, $v_2$, $h_2$ be the values of Pressure, velocity of air and Height from datum, for plane containing pump outlet. Therefore, after modifying equation 2 optimally, according to the design requirement, following equation (3) is received,

$$\Delta P = \frac{1}{2}\rho v_2^2 + \rho g h_2 \quad (3)$$

Since $h_1$ is datum, and hence $h_1 = 0$. Also, since there can be no flow at seed-nozzle interface, $v_1 = 0$. Using Pressure from equation 1, and using itin equation 3, we get $v_2$. This velocity can be used to find out volume flowrate using area of cross section of nozzle tip.

Table 1 Flow rate calculation for pumpkin seeds (heavy weight)

| | |
|---|---|
| Weight of seed [13] | 0.208 *gram* |
| Diameter of nozzle | 4.80 *mm* |
| Datum height difference | 230 *mm* |
| Density of Air | 1.225 $kg/m^3$ |
| Pressure Difference required | 112.76 *Pa* |
| Flow Velocity | 13.7336 *m/s* |
| Flow rate | 14.911 *litre/minute* |

Table 2: Flow rate calculation for onion seeds (light weight)

| | |
|---|---|
| Weight of seed [15] | 0.003 *gram* |
| Diameter of nozzle | 2.80 *mm* |
| Datum height difference | 230 *mm* |
| Density of Air | 1.225 $kg/m^3$ |
| Pressure Difference required | 4.7795 *Pa* |
| Flow Velocity | 3.509 *m/s* |
| Flow rate | 1.2965 *litre/minute* |

Performing similar calculations for lighter and smaller seeds, like onion seeds. This shows that the system can be adopted to a huge variety of seeds.

## 6. Agricultural Seeding Robot

The above designed end-effector is then attached to an arm with 3 DegreesOf Freedom (DOF), which will act as a complete seeding system. The arm will then go to the pick-up location, the seed tray, the suction pump willstart, the seed then gets attached to the nozzle and then the arm takes itto the sowing location and lowers it into the soil. The nozzle reaches the required depth, once reached the suction pump is switched off and the seedis dropped in the soil. After this the arm is retracted and so the processrepeats itself in a loop. This arm is placed on a mobile robot which moves forward and stops at a particular interval of distance where the arm will sow the seeds at regular intervals. This ensures distance between two seeds and thus increases chances of germination of the seed.

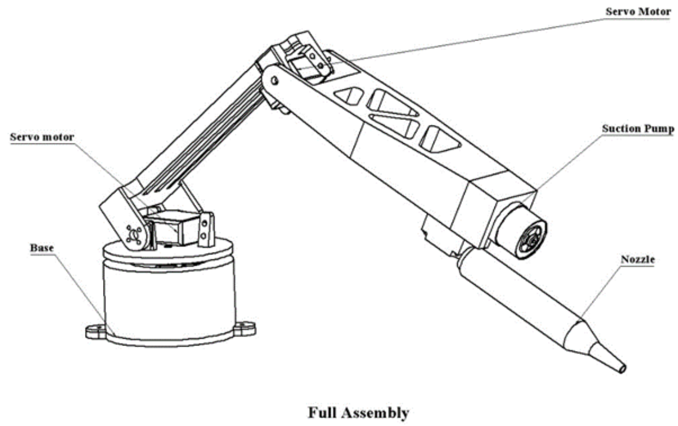


Figure 7: 3-DOF arm attached with the end-effector.

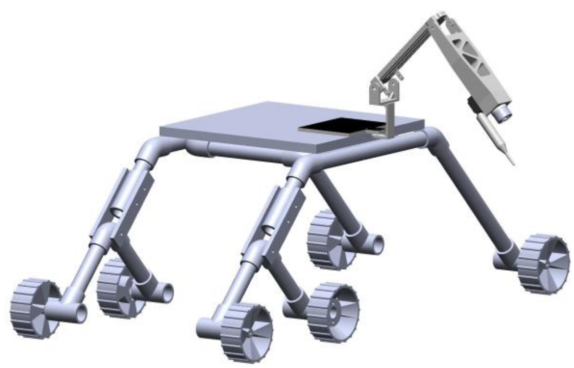

Figure 8: Complete rover shown in CAD model with the arm.

The arm structure shown in the figure 7 has been used to make the complete seeding system. Figure shows the end-effector connected to it.

This arm was mounted on a mobile robot, which was inspired by rocker bogie [16] mechanism. The complete assembly is as shown in figure 8. The rover can move over rough surfaces without any problem. The rover was designed for mars rovers and is open sourced by NASA [16]. With certain modifications to it, keeping the basic frame structure similar, this structurecan be thus used in the field of agriculture.

## 7. Results

After sowing 50 pumpkin seeds in the laboratory for testing the mecha- nism, it was found that 46 of them germinated, after observing the seeds for6 days after sowing. This gives an accuracy of 92% for heavy pumpkin seeds.30 onion seeds were also sown out of which 28 germinated on observing the seeds for 5 days after sowing. This gives an accuracy of 93.34% for light onion seeds. Giving the system an overall accuracy of 92.67%. This certainly givesan accuracy more than hand and tractor sowing seeds which has accuracy of upto 65 to 75% (This value of accuracy was given by professors from Collegeof Agriculture, Pune, India).

Table 3 shows comparison of the pneumatic end effector system with other commonly used systems, with different parameters. The system doesn’t just offer high accuracy but also provides easy and cost effective, customizable design. With use of more precise and faster industrial arms the speed of the whole system can surely be improved.

**Table 3: Comparison with different systems.**

| | Tractor | Drill and belt seeder | Pneumatic seeder |
|---|---|---|---|
| **Speed** | High | Medium | Low |
| **Precision** | Low | Medium | High |
| **System Size** | Very Bulky | Very Bulky | Handy |
| **Customization complexity** | Very High | High | Low |
| **Cost of customization** | Very High | High | Low |

## 8. Conclusion

Vacuum precision seeder provides better accuracy and high germinationchances, with the use of such an end effector. This thus provides 92.67% chances of germination. With the flexibility and ease of nozzle design, this provides a cost-effective solution that can be implemented on a wide variety ofseeds. It also provides great reliability for a wide variety of seeds. Onion seeds are very small and have light weight while the pumpkin seeds are large in sizeand are heavy. With good results for both far ends of the spectrum it showsthat it can give good results for the large variety of seeds by just changing thenozzle easily. Thus, ease of customization, with good germination accuracy, at low costs is attained in comparison with other systems. Using the extruderwith mobile robotic arms this can be adapted to a variety of environments, from small greenhouses to large farms.

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