Design Of Automated Desktop Seed Dispensing Robot For Bio-Laboratories

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***Abstract*—An automated seed dispensing robot is a useful tool to save time with manual work in bio-laboratories for more efficiency, but it is not yet popular because of the cost and the fact that some of the functions are complex and redundant. In order to address these issues, the paper presents the design of an automated handling robot to dispense seeds in the bio-laboratory based on a modified 3D printer frame with an additional axis and sensors. The robot was equipped with additional sensors and functionalities for control and monitoring. Seeds are picked up and dropped accurately by a vacuum tool mounted on the mobile carriage of the robot's frame. The pick-up process is guided by a seed detector sensor. Moreover, an additional needle length sensor combines with the distance sensor to detect the released distance for an accurate position. In the experiments, we investigate runtimes, the archive accuracy and describe the modular design of the robot to show that the prototype is well sufficient to distribute accurately small seeds to the dish.**

Keywords—Intelligent robots, Intelligent sensors, Micropump, Microvalves.

I. Introduction

The seed has an important role in the inheritability of the next generation and is the key to the distribution and evolution of a high-level plant. Knowledge has been gathered by bio-laboratories and researchers around the world. Automated handling robots were used in the bio-laboratory from 1957, which were large and expensive. However, it is a useful tool to save time with manual work for more efficiency. Moreover, it also uses automatic monitoring and logging of the results. However, it is not yet popular with laboratories in the world because of the challenges. The first challenge is connected to all the functions required of the laboratory. One of the most time-consuming tasks for researchers is to dispense the seeds manually. The manual dispensing work is one of the useful functions required of the robot in the bio-laboratories to save time because it is not worth the time of the researcher. Various kinds of seeds in the bio-laboratory include a variety of length, volume, mass, weight, shape of the seed. Popular seeds in the bio laboratory have open-source gene maps such as Zea Mays, Hordeum, Petunia Hybrida, Arabidopsis Thaliana. In the pass, Zea Mays was used widely in a lot of the bio-laboratory which has big size, shape of seeds like smooth round. Nowadays, Arabidopsis Thaliana is one of the most popular seeds in the laboratory in the world with an open source gene map, with an average diameter of about 0.5 mm, weighing 20-30 µg/seed when dried, while the Solanum Lycoperium only weighs 3 mg/seed. The challenge for the automatic robot is to work with the various shapes, sizes and weights of seeds.

Artificial life research is often performed in small, government funded labs and as such the cost of acquisition is a limiting factor. Hence, the cost is the second challenge of the robot design. The approach using robot design based on open-source software and hardware provide technically feasible methods to create low-cost, highly customized scientific research equipment. Open-source 3D printers have proven useful for manufacturing scientific tools. Therefore, an open-source 3D printer has improved to become a highly flexible scientific platform. Here an automated robot using improved open-source 3D motion control platform is presented that has the ability to perform scientific applications. The approach using SCARA (Selective-Compliance-Articulated Robot Arms) such as a robot phenoSeeder [1] improves the handling of individual seeds of very different sizes and is suitable for jobs that require flexibility and speed. They have predefined ratings of accuracy that makes it easy to define their repeatability of movement. It means that the robots lock their owners into one level of accuracy at the time of purchase, which makes SCARA rather expensive. The robot in our research used the approach using Cartesian style for better precision, ease of programming and lower cost.

II. Implementation

A. Overview

We describe the general concept of the system which enables picking and placing the seed from the test tubes to the Petri dish. As mentioned, the key to the mechanical robot design is based on the 3D printer frame structure with additional parts. The design allows to build a fast prototype to evaluate the performance of the robot. We built the robot from off-the-shelf components and where possible used components made of ABS (Acrylonitrile Butadiene Styrene) plastic material. Nema17 step motors were used for motion on the axes X-Y1-Y2-Z and the controller was based on Arduino to control the movement on the axes of the robot. The robot consists of a plastic structural frame, electronics and software for HMI (Human Machine Interface). The frame is made of ABS plastic profiles and the device can have a work area 250x250x50mm, which can be extended. The actuation module of the robot contains a head, which can move in a horizontal plane using a micro pump and needle for sucking and releasing seeds. We will describe the operation of the robot in more detail by the implementation of the modules. User prepared seeds in the test tube for the initial operation and after that process, the header is mounted on the Z axis as the robot moves to the selected test tube for sucking the seeds. The header is moved down to the position

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beyond the test tube, sucks the seed, moves up and goes to the position of the seed detector sensor to monitor the suction process. An overview of the system is described in Fig. 1.

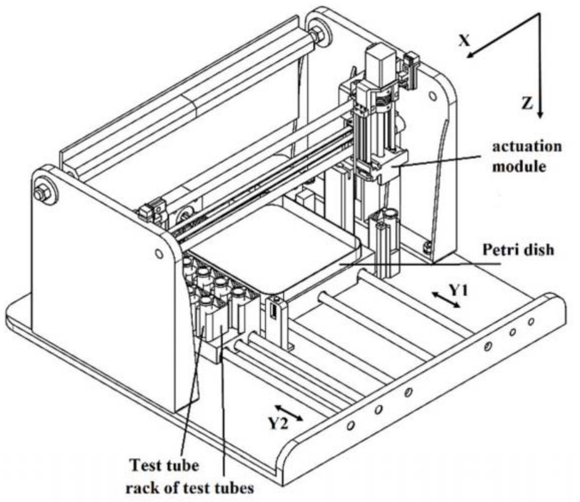

Fig. 1. Mechanical frame of the robot.

If the header sucks the seed successfully, the header is controlled to move down to the close-up position on the surface of the dish to release the seed, but if the process is not successful, the header is moved back the test tube position to repeat suction again until the seed is sucked by the vacuum force or time out.

In microbiology, very sensitive living seeds are handled by the suction force. However, to handle the micro-parts, the gripping force of the suction from the vacuum tool is not only because of the bigger gravity force. In papers [2] and [3], the adhesive force is used directly to grip the small objects. The adhesive force is usually divided into three major components: electrostatic attraction, Van der Waals force and capillary force as shown in the demonstration in Fig. 2.

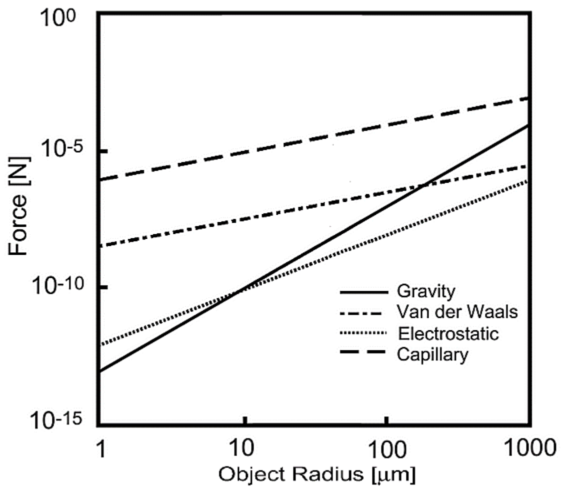

Fig. 2. Main components of adhesion force [3].

Electrostatic attraction F_{el} is the Coulomb forces between electrically charged objects. The force F_{el} between a charged object and an uncharged plane can be quantified by [4].

$$F_{el} = \frac{\pi}{4\varepsilon_0} \cdot \frac{\varepsilon - \varepsilon_0}{\varepsilon + \varepsilon_0} \cdot d^2 \cdot \sigma^2 \tag{1}$$

where σ is the charge density of the surface, ε_0 and ε are the air's and the plane's dielectric constants respectively and d is the object diameter.

The Van der Waals force F_{vdw} is an intermolecular force caused by momentary movements of electrons. The following equation demonstrates the relation between the force and the Hamaker constant H, the object diameter d and the object-plane distance z.

$$F_{vdw} = \frac{H.d}{12.z^2} \tag{2}$$

The capillary force F_{cap} appears from a liquid film between the objects, that normally originates from the air's humidity. The graph n Fig. 2 shows that capillary force F_{cap} is bigger than gravity force when the object is small. The relationship can be expressed as the following equation:

$$F_{cap} = \pi . d . \gamma \tag{3}$$

With d is the diameter of the contact surface between the seed and the needle, γ is the surface tension force.

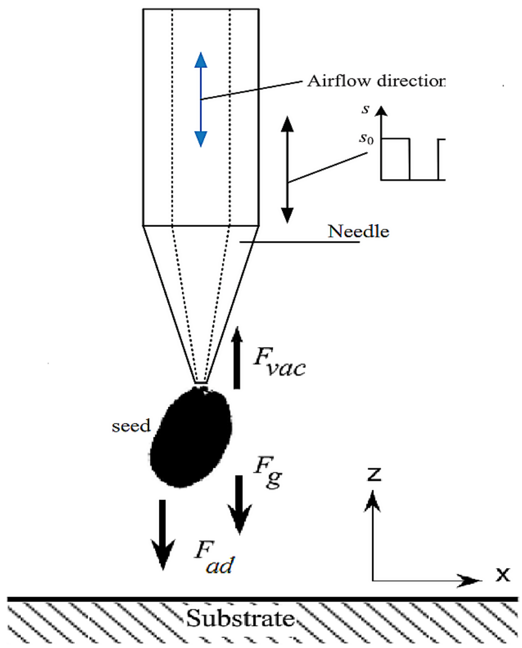

Fig. 3. Forces acting onto the object during suction operations.

The major forces acting on the small seeds were in contact with both the substrate and objects: the gravity force F_g and the adhesion force on the substrate F_{ad}. The necessary conditions to realize suction operations can be derived by the combined forces acting on the objects:

$$F_{suc} > F_g + F_{ad} \tag{4}$$

For the release operation, the simple condition is that the suction force of the vacuum tool be cancelled by turning off the micro pump.

B. Driver and controller

In order to create a low-cost prototype, we built the robot from off-the-shelf components and, where possible, used components used by the open-source 3D printer community and therefore readily available. For instance, we used Nema17 motors for actuation and Arduino based electronics for controlling the robot. This was to lower the production time and to improve the quality of the produced components

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in comparison with the elements produced through a steel frame. However, the prototype will not achieve as high accuracy as the metal frame. Specifically, the Arduino MEGA2560 with the shield RAMPS v1.4 was used to feed a cheap electronics platform to build on, but perhaps more importantly, allows us to build on existing open-source software. A good feature of the electronics design was the number of wires between components as low as possible to avoid interference between parts in the system and to give the robot a clean look. In order to do this, the actuation tool includes a micro pump which is connected to a removable needle and mounted on the head Z for the suction of seeds. A circuit board was designed to route power, the controller and the communication parts to the other modules on the top side of the robot.

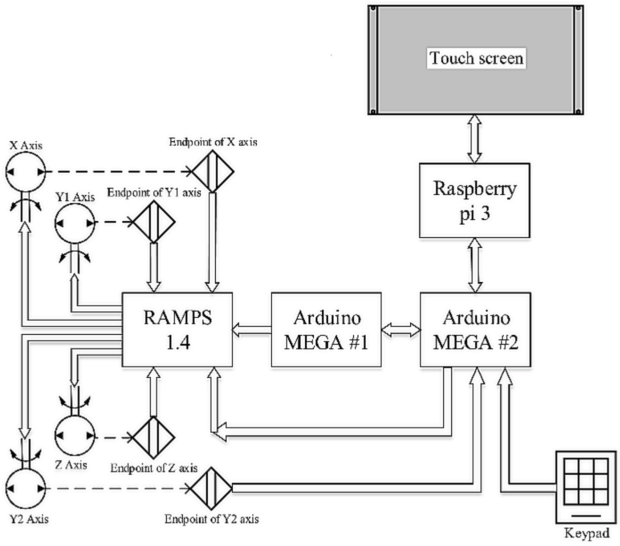

Fig. 4. General model of system.

The Marlin-based firmware on the first Arduino is an extended version of Marlin, firmware used to control open-source 3D printers. The head Z that is mounted on the actuation is controlled directly using the functionality that Marlin provides. The use of Marlin is also useful as it is our research to improve an extruder module, which can be a modified mechanism to bring the rack of test tubes as the additional fourth axis Y2. The rack moves along the Y2 axis to feed the seed. The additional fourth endpoint sensor is a mechanical or optical switch to detect status of Y2 axis for identifying the initial position. The second Arduino controls the movement on the Y2 motor for detecting the initial position by an interrupt from the fourth endpoint sensor.

C. Sensors

As has been mentioned, the rack of test tubes is controlled by the motor of the additional axis Y2. To identify the initial position, the second Arduino uses the algorithm, as described in Fig. 5. The second micro-controller also uses the additional sensor to detect the suction process. The approach using a sensor to monitor the success of the suction process has advantages such as simplicity, accurate time-keeping, simplicity, relatively low in cost. In short, the sensor system, which is based on a slotted optical switch, is screened by the shadow screen. The screen is made of light-weight and flexible material such as a section of aluminium foil, etc. When the needle sucks the seed at the tip, its suction force on the surface of the shadow screen is not enough to change the status of the sensor. However, the suction of the needle without the seed at the tip is enough to change the position of the shadow screen.

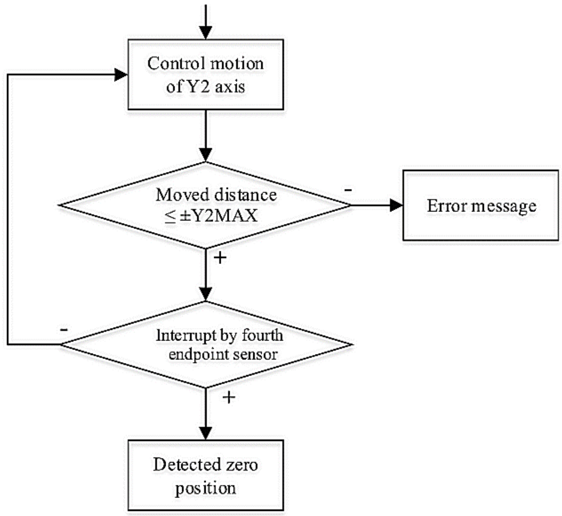

Fig. 5. Algorithm for additional fourth endpoint sensor.

It means that status of the sensor was changed to show whether the seed was sucked successfully or not. The model of sensor circuit is demonstrated in the Fig. 6.

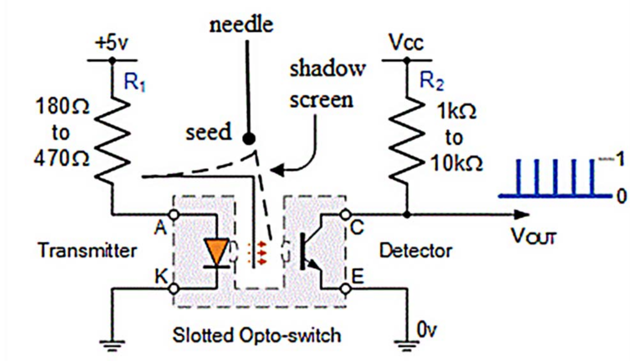

Fig. 6. Seed detector sensor.

The flow chart of firmware on the second Arduino is briefly outlined in the following description:

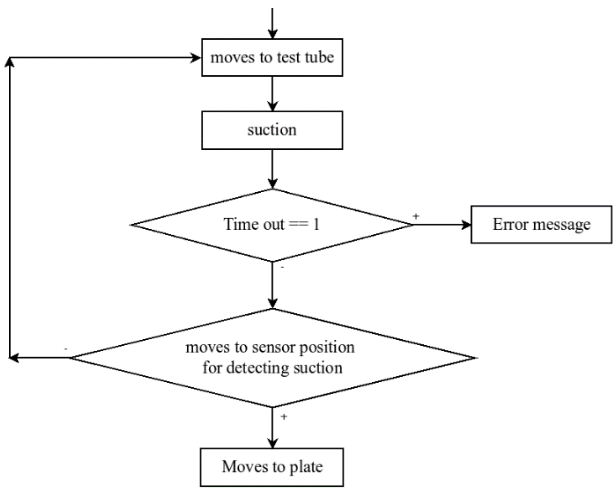

Fig. 7. Algorithm of seed detector sensor.

The seed detector sensor works as a closed-loop control to ensure the performance of the seed suction. This solution is simpler than the solution using a camera and image

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processing [5] but it is also reliable. The Fig. 8 demonstrates the real picture of the sensor:

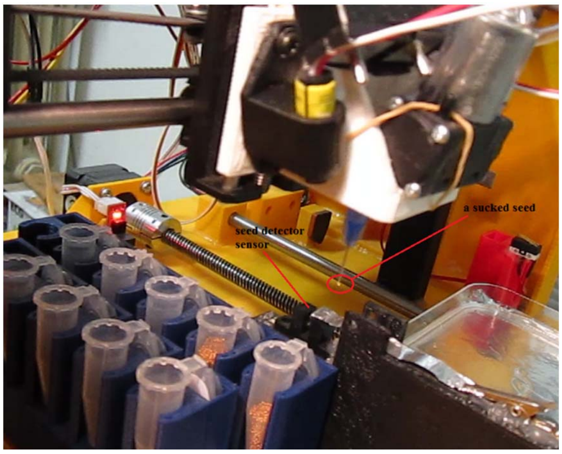

Fig. 8. Seed detector sensor.

The seed in the above experiment is about ten times bigger than the Arabidopsis Thaliana seed. As is mentioned, the Arabidopsis Thaliana seed is a popular object in biotechnology. The shape of the Arabidopsis Thaliana dry seed is almost a prolate spheroid. The seed also is also small and light. The suitable force was calculated in the above equations. The real test with this kind of seed is important and Fig. 9 shows the tested results using a microscope.

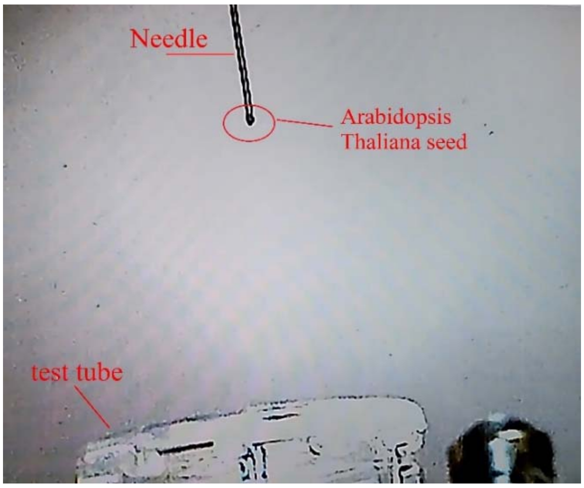

Fig. 9. Real test with the suction of an Arabidopsis Thaliana seed.

D. *Software*

The software includes two parts: HMI software on the host's side and firmware on the robot's side. The purpose of the HMI software provides the end-user with a GUI (Graphic User Interface) manual control interface to the robot. The firmware on the first Arduino is a modified version of the Marlin firmware used in open-source 3D printers and the firmware on the second Arduino implement above algorithms to control the motion of the robot and signal processing from sensors. A keypad to control directly the instrument was connected to the second microcontroller. On the host side, the chosen language, Python, was implemented on the platform Raspberry Pi with the Linux operating system for its simplicity. This is a feature that has saved a significant amount of development time. The interface gives the user access to moving the robot head Z and to moving the actuation module. Moreover, it exhibits visually the status of the seed suction and release process.

III. Precision and Performance

In this part of the paper, we demonstrate below a careful investigation of the precision and performance of the robot. Firstly, our research evaluated the parameter speed. An important parameter to perform experiments is the implementation speed of the robot because the experiments in the laboratory could take a long time. However, in the practical application, the speed of the robot should be faster than the speed of a human. Hence, the test consisted of movements on each axis, increasing its acceleration and maximum speed until the robot makes an error. It means that the maximum speed of the robot is when the position of the robot is not accurate after some movements. In fact, the speed of movement on the axis Y2 containing the rack of test tubes was not evaluated because the rack does not need high speed. Table I. demonstrated the results of the tests and shows that they are significantly higher than the expected accuracy

TABLE I. Speed and Acceleration Tests

Axis	X	Y1	Z
Max speed (mm/s)	160	160	220
Acceleration (mm/s^2)	2500	2500	220

Secondly, the accuracy of position using the ISO standard 9283:1998 was tested. The head of the robot was modified to hold a test probe. The probe was positioned so that an end effector to the laser pointer dot is projected across the room onto the opposite wall about 3 meters away. The red diode laser works as the optical sensor to detect accurately the distance from the head Z to the dish. The optical lever magnifies the steps for accurate readings. In the test, the robot moved to the initial position or zero position. Then, the robot moved one axis sequentially to three different positions and the real position of the probe was measured. This step was repeated 10 times at half the max speed. The accuracy was calculated by comparing the real value with the average value of 10 measurements. The results are shown in Table II.

TABLE II. Accuracy of Axes of Motion

Position (mm)	***0***	***12.5***	***25***	***37.5***	***50***
X (mm)	0.12	0.1	0.01	-0.08	-0.1
Y1 (mm)	0.18	0.07	-0.05	-0.09	-0.12
Z (mm)	0.2	0.23	0.32	0.48	0.31

The accuracy of testing results shows the impression when the main material of the robot is made of ABS plastic and structure is based on the popular 3D printer machine.

IV. Conclusion

At the time the paper was presented, the robot was based on the improved open-source 3D platform as a low-cost instrumental ecosystem for bio-laboratories. It was developed for the automatic process as above, but there are still possibilities for improvement and extension because of its modular design. There are many future approaches such as improving the delivery system for multi-seed or adding image processing for colour and pattern recognition, etc. Moreover, the robot also can be used for a large number of applications, such as the automated handling of liquid handling for gripping micro-objects. Thus, the robot's design

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provides a versatile and low cost way of carrying out research in multiple fields. However, the tested data shows that the positioning performance of robot is not perfect in some high-precision applications. This can be improved by making the structure of metal because issues caused by the mechanical error will be reduced.

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