Mobile Manipulator and EOAT for In-Situ Infected Plant Removal

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Abstract. This paper discusses in detail the design of a roguing mechanism as an attachment to an Autonomous Ground Vehicle (AGV) for agricultural purposes. This mechanism is a part of a larger project for detection and removal of potato plants infected by virus Y (PVY). An unmanned aerial vehicle (UAV), equipped by hyperspectral camera and high precision GPS system, will fly over a potato field to locate a sick plant within a few centimeters and communicate the GPS coordinates to an AGV. This AGV will navigate to the target location and rogue (remove) the infected plant automatically. However, currently there is no roguing mechanism available off the shelf, which can be quickly attached to existing farm equipment to automate the process. Because of significant crop losses every year due to PVY, roguing in a timely manner is extremely important to the farming community. After multiple design iterations and simulations for the end-effector, a novel roguing mechanism was designed. Significant effort was also expended in assuring the designed mechanism can be easily connected to existing farm equipment. A 1/3rd scale prototype model was built for motion analysis. This prototype has been tested in a laboratory setting with promising results. Operational and design details of this mechanism have been successfully tested. The actual, field-size model construction is currently underway.

Keywords: Mobile Manipulator, Roguing Mechanism, Agricultural Robot, Autonomous System, Agricultural Virus Removal, End of Arm Tooling.

1 Introduction

The population of the world has gone from 3 billion in the 1960’s to 7.7 billion in 2019. This doubling in the population size has put significant stress on agricultural capabilities. More and more farm equipment and farming methods are turning to automation and smart technologies. To feed this fast-growing population, we will need between 100-110% increases in agricultural products by 2050. To achieve this challenging goal, significant improvements will have to be made to the present agro-ecosystem while minimizing the negative impact on the global ecosystem [1]. Recent improvement in the field of robotics and autonomous systems have paved the path forward for researchers to apply these advances to the field of agriculture. The end goal being significant improvements in efficiency, reduction of waste and development of smart autonomous systems aimed at increasing throughput [4].

Using mechanical systems and humans in agriculture is a traditional approach. Nowadays, with advances in the field of robotics, farmers are embracing fully or partially automated systems in various farming tasks; such as pesticide/herbicide spraying, irrigation and harvesting. Application of automation in other areas of farming, for example; identifying the size, shape of the produce, monitoring the growing conditions and its effects on the health of a crop is still in its preliminary stages. The complexities associated with different types of crops make it a big challenge for engineers to find an appropriate solution for each individual product.

In this research, we are focusing on roguing sick plants from a field. This narrows down our tasks to, grasping, and lifting mechanisms. Research in these areas mostly focus on two major components: Control and Kinematic design. In this paper, we focus on kinematic design and specifically discuss the design of an end effector to be used for roguing.

In the case of kinematic design, based on the target object and task, there are various options which one can consider as a designer. For roguing mechanisms, grasping the plant by a gripper, and pulling it out of the ground could be a method that can be applied. In [5], a 7 degree of freedom (DOF) robotic system, a serial link manipulator with 6 DOF is mounted on a prismatic base and the entire assembly connected to an end-effector, was used for grasping apples.

For adaptively grasping objects of various shapes, and in light of recent advances in multi-purpose universal grippers (MPUG) [6], end-effector designs could be based on a fully-actuated system. One such example is the universal gripper, a combination of linkage-driven underactuated gripper with suction gripping system, to grasp objects of irregular shape in different environments [7]. Soft robots are becoming more and more popular in robotic systems nowadays and can be considered as a possible option for grasping fruits and vegetables. Soft end-effectors and grippers are playing an ever-important role in grasping and handling soft fruits and vegetables. The amount of applied force for each task is an important factor too. To mimic human grasping capabilities, some elastic structures with variable stiffness are able to apply varying degrees of force, for a successful grasp, without causing any damage to the perishables [8, 9].

Pin array gripper is another example of universal manipulators that are made from an array of slidable pins in the gripper. These can conform to the shape of many objects in both vertical and horizontal directions using a single motor [10]. Vacuum based grippers are also used as a main technique or in combination with other methods in some universal manipulators to improve grasping capabilities [11].

Optimization methods can be applied in designing grippers as well for minimizing the weight and size of mechanisms [12]-[14]. For the problem we face, we elected to use a digging mechanism over grippers to get rid of infected plants from the field. In [15], a novel digging mechanism was analyzed and optimized based on finite element simulations. In addition to grasping mechanisms, extraction/digging mechanisms can be an alternative option. As of writing this document we have come across only one such digging mechanism for harvesting that is presented in [15].

In order to satisfy the objective for this project of extracting the sick potato plants, which have most of the plant still buried in the soil, from the field autonomously while minimizing cross-infection. We were compelled to design a universal extraction mechanism. This novel roguing mechanism could be used for roguing other plants too, by modifying the hydraulic forces needed to penetrate the soil and by minor modifications to the collection bucket. Widespread acceptance of the designed mechanism would only be possible if it can be easily attached to existing farm equipment. This was addressed by designing a universal attachment for the rouging unit.

2 Project overview and Simulated Model of Potato Field in the Lab

The general idea of this project is shown in Fig. 1. First, the UAV equipped with a hyperspectral cameras and high precision GPS flies over a field and takes images. These images, after analysis, indicate the location of sick plants in the field. The associated GPS location is sent to an autonomous ground vehicle (AGV) with precision RTK GPS [2], [3]. This AGV then navigates to the target location and has been proven in field tests to be precise to a few centimeters. This AGV will have the custom roguing mechanism, which can extract a sick plant from the ground, without infecting nearby plants. This will significantly reduce widespread pesticide spraying and discarding of nearby uninfected plants.

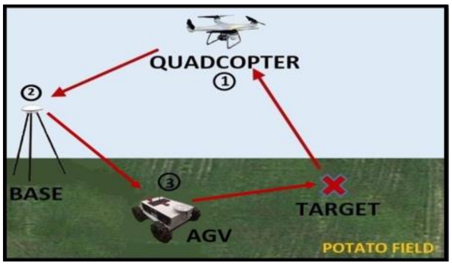


Fig. 1: Communication between Unmanned Air Vehicles (UAV) and Autonomous Ground Vehicles (AGV)

One of the first steps in designing the prototype was understating the details of the environment the AGV will be operating in. This knowledge will dictate the type of materials which can be used for the AGV, the drive mechanism, its onboard navigational system and finally the end-effector itself. We visited a local potato field and, based on our observations, created a simulated model of a field in SolidWorks®. This model was used in making calculations for our design. This simulated model is shown in Fig. 2. As can be seen in Fig. 2, a typical potato field is fraught with rough terrain and deep irrigation ruts. The distance between the top of two crests/bumps is around 60 cm. The plants are grown on top of the crests/bumps and the average distance between any two plants is about 30 cm. The hatched area in Fig. 2 reflects the amount of material (soil, plant roots etc.) that needs to be cleared around an infected plant.

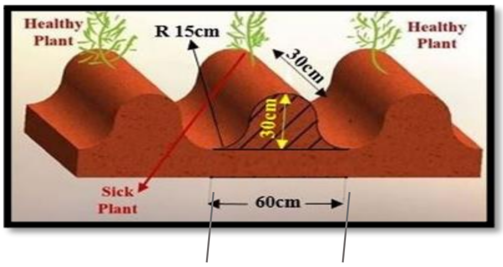


Fig. 2: Simulated shape and size of the potato field

3 Analysis the Possible Options for Roguing Mechanism

3.1 Grasping Mechanism Design Methodology

The first iteration of the prototype design involved analyzing the forces that could be applied to the connections between the stem and the tubers and shortlisting any grippers which may satisfy the requirements mentioned previously. There are different motions that can be applied by a gripper mechanism (for example: a human hand) for pulling plants out of the soil. We analyzed motions of different mechanism to see if the entire plant and tubers could be pulled out of the soil without breaking the plant. For this we conducted experiments to identify the maximum gripping force which might snap the stem thereby leaving the tubers in the soil. One of the challenges faced here, was that the forces varied significantly between plants. If we were to proceed with a design based on the gripping force itself, we would have to find actuators with a wide range to manipulate the force on the stem.

a) Grasping the plant by the stem and moving it several times up and down (vertical shaking). With this motion, we tried to loosen the soil around the tubers and the base of the plant before pulling the plant completely out (Fig. 3-a). As shown in Fig. 3-b, the connection between stem, potato tubers and roots broke due to this motion. The potato tubers and its roots remained in the soil, which does not satisfy one the design requirements - complete removal of the plant.

Fig. 3: a) Vertical motion b) Connection between roots, tubers and stem of plant were broke

b) Grasping the plant by the stem and moving it several times front and back (horizontal shaking). This motion was used to facilitate loosening of the connection between the soil and tubers (Fig. 4-a) before pulling the plant out of the soil. This test was repeated 3 times. As it is shown in Fig. 4-b, in the first attempt, the whole plant including the stem, potato tubers and roots came out of the soil and test was successful. But in the next two attempts the test failed and connection between stem and the tubers snapped.

Fig. 4: a) Horizontal motion b) Connections between roots, tubers and stem of plant remained intact in the first attempt but failed in the next two.

c) Grasping the plant by the stem and twisting it around the stem axis, and at the same time pulling the plant out of the soil (Fig. 5-a). As shown in Fig. 5-b, we observed the same results as the other two methods, the connection between stem, potato tubers and roots were broken. Therefore, the potato tubers and roots remained in the soil again failing to facilitate the desired outcome.

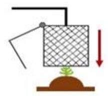
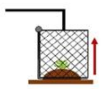
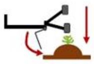
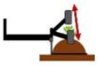
Fig. 5: a) Twist & vertical motion b) Connections between roots, tubers and stem of plant broke

3.2 The Best Options

According to the results in the last two sections, between all possible alternatives, we shortlisted three mechanisms as the best choices for roguing potatoes. The morphology chart for these three mechanisms is presented in Table 1.
The first design is made of a cage and blade for cutting soil. The cage goes down while surrounding the target plant. Then the cutting blades cut the soil (which includes potato tubers and roots of the plant) from one side and goes up and dumps all of the material in a disposal container. (Table 1 – design A)
The second design is made of two rake-shaped arms. When these arms reach the top of a plant, it goes down and closes from both sides to cut the soil and grab the infected

potato tubers, roots, and body of the plant. Then, it will pull up and dump all of the collected material in a disposal container. (Table 1 – design B)
The third design is a combination of a pinching gripper and a cutting blade. In this design, first, the entire mechanism goes down into the soil and gripper closes to engulf the top part of plant, while the blade cuts the soil grabbing the potato tubers and plant roots. Finally, the mechanism lifts up and discards all the collected material into a disposal container. (Table 1 – design C)

Table 1. Morphology chart

TYPE	1	2	3	4
A				
B				
C				

However, each of above designs had some issues. In design "C", because of variety in the shape of the bushes it would be hard to grasp only the top portion of the plant which includes all branches, leaves, and stem by the gripper completely. Also, cutting that much soil with just a single blade will require applying significant force on the blade. In design "A", we would have a better performance for collecting the entire plant, but still have the same issue, significant forces on one blade. While in design "B" the soil would be cut easier by splitting the forces over two arms. However, because of the shape of the rakes and the sides of the arms being open, there is a significantly high risk of losing a part of the infected plant in the field. Therefore, the best design would be a combination of these three mechanisms which includes the advantages of all of them while eliminating their weaknesses.

4 Final Design

4.1 Parts of the mechanism

As discussed in the previous section, the final design was generated based on combining the strengths of the three designs previously described. The mechanism contains a cage to making sure no part of the infected plant (including tubers, stem, leaves, roots, etc.) will remain in the field after roguing by this mechanism. Also, we will utilize two cutting blades to apply less force over each blade to reduce overall wear and chances of failure. In addition, two attached hydraulic actuators will be used to provide the necessary force to pierce the soil to a specified depth. Fig. 6 shows all the components for this mechanism. Detailed information about the dimensions and the size of the parts along with detailed drawings can be found in [16].

These components in general can be considered to fall into one of the following five categories:

i. *Frame:* This is the main structure of the mechanism which, holds the sick roots, stems, leaves, etc.

ii. *Movable Components:* This includes all components required for actuation and to bring about the desired motion of the blades.

iii. *Cutting Sections:* This includes all parts performing the actual digging action in the field and facilitate cutting the soil with ease.

iv. *Mechanism Strength:* To improve the overall rigidity of the system we included a T-Shape Angle Bar on the sides of the main body and Inside Frame Blades which connect two sides of main body to each other (back-front).

v. *Attachments:* This mechanism is designed so as to easily attach to various type of tractors or other farm equipment. Three possible adapters were designed to attach it to tractors: from the back, the Top and from the sides where they can be screwed to the holes which are placed on the sides of Main Body Top Frame.

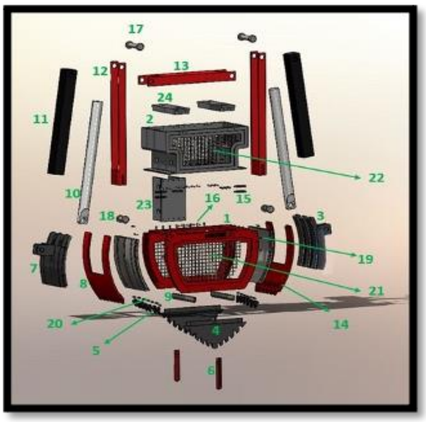


Fig. 6: Final design components

4.2 Motion study

The complete assembly of this roguing machine is presented in Fig. 7. Fig. 7-a shows the mechanism when the moving blades are open. Yellow arrows show the direction of motion of the hydraulic actuators which are connected to the arms. These hydraulic arms will actuate the opening and closing of the jaws while also providing sufficient force to pierce the soil. For closing the blades, the hydraulic system moves down and pushes the blades along the curved rails. Fig. 7-b shows the machine with the blades in the closed position.

Fig. 7: Actuation of blades by hydraulic system in final design

5 Prototype Model

Fig. 8 shows a prototype of the final design of the roguing machine which was built to 1/3rd scale of the actual model. The prototype was used for testing the motion and functionality of the system. There will be some differences between the final design and this prototype to accommodate in filed operation. First, the final design will be about three times larger than this prototype. In the final design, all major components are divided into sub-systems for ease of replacement and cleaning. Other small changes, are related to improving the functionality of system and attachments needed to integrate the prototype to commonly used farm equipment.

Fig. 8-a shows the prototype connected to an ABB robotic platform, Fig. 8-b shows the tracks along which the jaws will move, Fig. 8-c shows the jaws in a completely closed position, Fig. 8-d shows the teeth at the end of the jaws to help pierce the soil, Fig. 8-e shows a bottom view of the rouging mechanism with the jaws in a completely closed position with the teeth interlocking, Fig. 8-f shows the bucket in which the sample to be removed will be collected and disposed, off the field. The catch bucket grills can be modified based on the type of sample being collected.

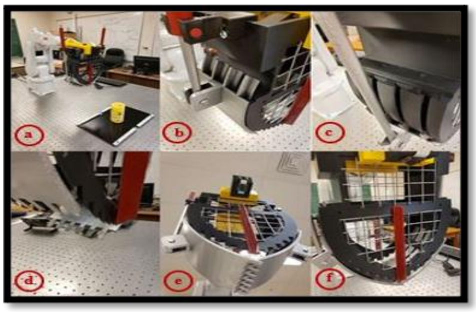


Fig. 8: Prototype of the mechanism (1/3 of the real size)

Fig. 9 shows the roguing process of a sample plant by the prototype mechanism. In Fig. 9–a, the robotic arm pushes the mechanism down and the soil is cut by the fixed blades. In Fig. 9-b & Fig. 9-c, the moving blades will be closed and infected plant along with tubers in the soil will be collected in the catch bucket. In Fig. 9-d, the robotic arm moves the mechanism up with the plant and soil inside to be discarded off the field.

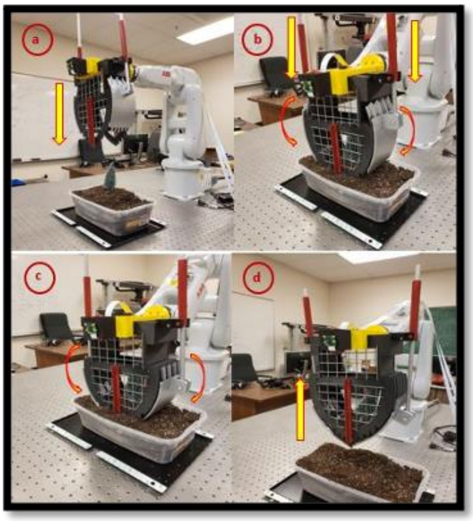


Fig. 9: Process of roguing the sample plant by prototype mechanism

6 Conclusion

In this paper, a novel mechanism for a roguing was discussed. Multiple designs and grasping types were considered, all relevant mechanisms were analyzed and three mechanisms based on primary analysis were considered for study. On comparing advantages and disadvantage of each of these three options, the final mechanism was designed utilizing the best combination of each design's strength and capabilities. Although this mechanism is designed to work in a potato field, because of it is versatility and ease of coupling to farm equipment, it could potentially be used for roguing other crops and work in different environments.
Finally, a prototype was built to 1/3rd scale of the actual model and successfully tested for motion and it performed exceptionally well to achieve the desired results. In the near future, we are going to build a real sized model to test it in the potato field.

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16. Taher Deemyad, Anish Sebastian, and Alba Perez-Gracia Provisional patent application for "Agricultural Roguing Machine" Application Serial No. : 63/104,937 Filing date: 10/23/2020