Autonomous Mobile Robot Platform with Multi-Variant Task-Specific End-Effector and Voice Activation*

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***Abstract*—The purpose of the paper is to demonstrate how 3D printing can be used to aid in the construction, design and implementation of an autonomous robot to accomplish a variety of tasks. A robot is designed using Polylactic acid (PLA) that has 3 modes: remote control, autonomous, and voice activation. Using these modes the robot is able to accomplish two specific tasks based on the given end-effector. The two tasks are to open a valve and to pick up an object. In addition analysis on how 3D printing can aid educational use and high risk situations will be presented.**

***Index Terms*—Polylactic Acid (PLA), Acrylonitrie Butadiene Styrene (ABS), Mecanum wheel, Solid Works, Voice Recognition, Fused Filament Fabrication (FFF), 3D printing.**

I. Introduction

The advent of 3D printing has revolutionized the way prototyping is being performed in industry. One area that 3D printing has played a key role in is robotics. High-risk and dangerous situations are typically addressed by humans directly. Robots are rarely used due to the high cost and the specific criteria there design requires in order to function properly. In manipulation, end-effectors are usually too specific to a particular task to be useful in more than one type of situation. In an immediate need of a new end effector, robot operating crews would have to send off a design, or a request for one, to engineers and machinists. Given basic CAD modeling tools and a 3D printer, robot operators could quickly design end-effector prototypes to suit the requirements of time critical situations.

This paper aims to demonstrate the utility that 3D printing can provide in robotics applications. For a proof of concept design, a robot was 3D printed using polylactic acid (PLA) 3D printing material. In the first of two designs, the goal for the robot was to navigate to a valve and open or close it based on the current environmental conditions. In the second design, the goal for the robot was to accomplishing grasping tasks on a variety of objects with an underactuated gripper [1]. Different end-effectors were used in these two configurations to demonstrate the customization possibilities with 3D printed designs. In order to maximize the versatility the robot provides to the end user, it was designed to have a radio control, an autonomous mode, and a voice recognition mode. Given these goals it was investigated how 3D printing could be used to achieve the desired goals.

The rest of the paper is structured as follows. Section II introduces the 3D printer technology utilized for this paper. Section III covers the general robot chassis design. Section IV details the application specific manipulator designs. Finally, Section V provides conclusions and future work.

II. Utilized 3D Printer Technology

In the world of 3D printing, their are many different types of 3D printing that can be employed. Some of these methods are Selective Laser Sintering [2] and Stereolithography involves using a resin and UV light to form the desired shapes [3], [4]. The printers used for these design use the most common form of 3D printing, this being fused deposition modeling, which essentially involves laying down successive layers of plastic until the model is completed [3], [5]–[8].

Three 3D printers were utilized in the creation of the robot. The printers used were the Lulzbot Taz 4, the Cube 3, and the UPBOX. These 3D printers use Polylactic acid (PLA) filament and Acrylonitrile Butadiene Styrene (ABS) filament. PLA is a biodegradable thermoplastic that is used in most modern hobbyist 3D printers. ABS is a terpolymer that combines the most desirable features of three different kinds of polymer. The primary difference between the Cube 3 and the Lulzbot Taz 4 3D printers is their build volume and finished part quality. The reason the students decided to use three different printers was to take advantage of the strengths of each printer. When deciding which part to print on which printer both part size and part print quality were taken into account.

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Lulzbot Taz 4 which provided a large build volume of $20487.5cm^3$ while the Cube 3 provided a build volume of $3,456cm^3$. The UPBOX was added into the labs repertoire later in the development of the robot. The UPBOX provides a medium build volume at $10716.375cm3$ while in addition providing the best balance in print quality for the size. The UPBOX also provides the distinct advantage of having a hypo-filter which keeps the ambient particles from contaminating the prints. The UPBOX has a heated plate with perforated holes in it. This is a characteristic that helps with the removal of a finished print as well as aiding in the print remaining stable on the platform and sticking properly to the build plate until the print is ready to be removed. The printers can be observed in Figure 1.

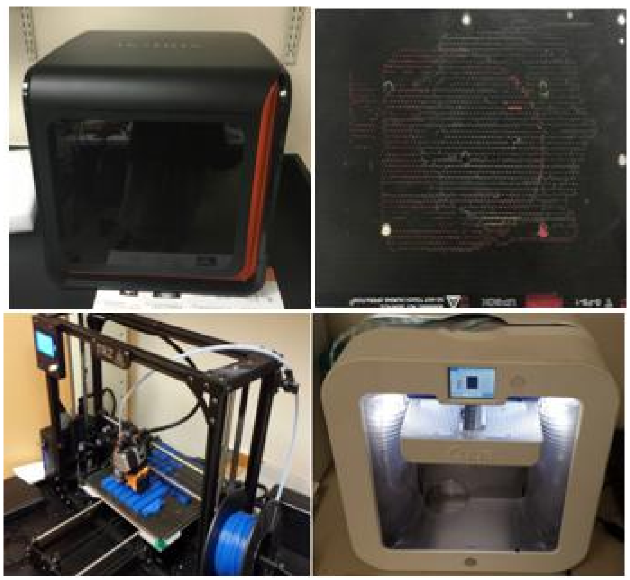

Fig. 1: UPBOX (Top Left), UPBOX Build Plate (Top Right), Lulzbot Taz 4 (Bottom Left) and Cube 3 (Bottom Right)

The Lulzbot Taz 4 was primarily used for printing the larger parts like the robot chassis due to its large build volume. The Cube 3 was used to print finer detail parts, such as the motor hub and wheel hub of the robot which needed more accuracy to properly fit onto the mecanum wheels. The printers use Fused Deposition Modeling (FDM) to create the desired 3-D printed object. At its heart FDM, is an additive manufacturing process where plastics and other materials are melted by an extruder and deposited layer by layer onto a printing surface.

III. Robot Chassis Design

To begin designing the chassis of the robot, the appropriate wheels had to be chosen. After a brief analysis of alternatives, the group decided to use mecanum wheels.

A. Locomotion

A robot using a mecanum wheel configuration is able to traverse 360 degrees without any kind of a turning system [9], [10]. The unique design of the mecanum wheels are a series of rollers along the circumference of the wheel, each at a specific angle. This wheel design was conceived in 1937 by Swedish inventor, Bengt Ilon allows the robot to be omni-directional. By programming each individual wheel to rotate forwards or backwards at certain velocities, all ranges of motion can be achieved on a flat surface. Figure 2 shows mecanum wheels used on the robot and where they are positioned.

TABLE I: Direction of robot movement vs wheel direction

Robot Movement	NW Wheel	SW Wheel	NE Wheel	SE Wheel
Forward	CW	CW	CW	CW
Reverse	CCW	CCW	CCW	CCW
Strafe Left	CCW	CCW	CW	CW
Strafe Right	CW	CW	CCW	CCW
Diagonal NW	None	None	CW	CW
Diagonal NE	CW	CW	None	None
Diagonal SW	CCW	CCW	None	None
Diagonal SE	None	None	CCW	CCW

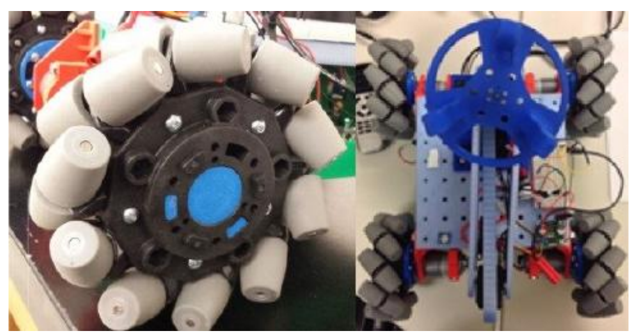

Fig. 2: Mecanum wheel (left) and positioning of wheels (right)

While mecanum wheels offer great capabilities with holonomic motion, they do have slippage issues. Slippage is an occurrence where the wheels slide off there projected path and cause a deviation in the intended destination of robot. To counter this effect the wheels need to be calibrated correctly. In order to ensure the desired motion, all four wheels need to spin at the proper speed in order to keep the robots path as accurate and deviation free as possible. This problem was deemed a necessary trade-off when compared to a normal set of wheels. The given motion of the wheels and the traversal direction of the robot can be seen in Table 1.

B. Motion Control

A controller was tested and implemented for the robots chassis. A proportional controller was designed to position the robot in front of the valve stand. The inputs to the controller consisted of data captured by the CMUcam5. The (x, y) position of the captured image as well as the width and height of the bounding image box. After the coordinates were captured by the Arduino, the coordinates were subtracted from a set pre-specified reference values. The errors in each set of data were then used to recursively position the robot in front of the valve assembly. The students chose Pololu DC motors with built in Cycles Per Revolution (CPR) encoders to provide locomotion for the robot. The motor gear ratio was chosen to be 70:1 in order to provide adequate torque to the mecanum wheels while allowing for a higher RPM.

The aforementioned gear ratio provides adequate torque to allow the robot to move laterally as well as in the forward direction, however the motor also provides a suitable RPM. The theoretical maximum velocity that the 3D printed robot can travel at is 1.19 m/s, although the mecanum wheels slightly detract from that. Given the radius of the mecanum wheels and the RPM of the motors, the forward velocity of the robot was simple to calculate with $v_{max} = r \times w$. Figure 3 shows the motors and the mount points.

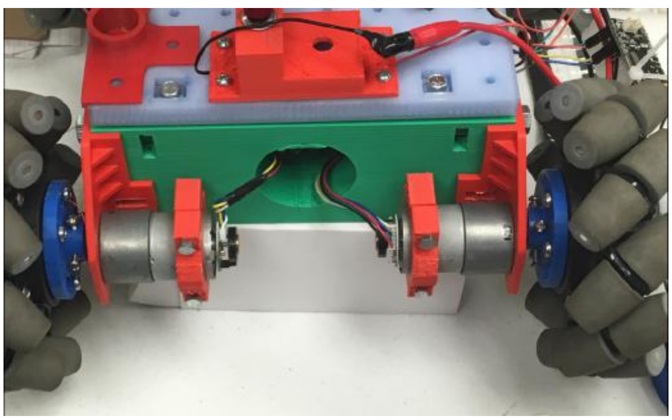

Fig. 3: Pololu DC motor with wheel encoders mounted to chassis

C. Power System

To power the robot a lithium battery was used to power all major components of the robot. These components were powered via a bus bar. The bus bar in turn provided power to the motor drivers, servos, and DC motors. The Arduino used was powered by a battery pack. The LiPo battery used has a discharge rate of 5000 mAh and is a three cell 11.1 Volts. Figure 4 shows the battery and power distribution bus bar.

Fig. 4: Battery (left) and bus bar (right)

IV. Application Specific Designs

This section presents two designs of the same mobile robot. The first design accomplishes a goal of opening and closing a valve. This situation mimics a hazardous event where a robot would be deployed to fix a problem. The second design features voice activated control of the mobile robot for object grasping tasks. This type of design would be useful in assistive robotic applications.

A. Goal 1: Autonomous Opening and Closing of a Valve

1) Testing Framework: The test framework for a faucet was composed of two wooden boards attached together with wood glue and multiple screws at right angle to each other. Both boards are of approximately the same size of $45cm \times 30cm \times 1.5cm$. For additional supports two triangular shape wooden board of $30cm \times 30cm \times 1.5cm$ were glued and screwed to the back of the vertical boards. A $3/4$ inch faucet was mated to a copper pipe of 16 inches in length. The pipe is stabilized by forcing the copper pipe into the base wooden board at the mid-section and further fastened by two copper clamps to the vertical wooden board. The entire framework was painted white for better recognition of designated color by a CMUCam5 Pixy camera.

2) Vision System: Pixy is the vision system for the UGV that has been programmed to find the constructed test framework. Two colored pieces of tape, red and green, were applied to the test framework for identification purposes. The Pixy camera was trained to detect the the red and green tape. With the framework detected, the UGV was to position itself to deploy the robotic arm to open the faucet.

3) Manipulator Arm: The arm is designed to allow the robot to reach objects all the way from the ground up to 24 inches high. In order to create a compact arm still able to accomplish a variety of tasks, we came up with a design able to fold onto itself for storage and transportation but extend out to several times its size if needed. With four degrees of freedom and the ability to quickly modify pieces, our arm can address a variety of objects at just as many angles. To demonstrate this, the team designed the manipulator to operate valves in potentially hazardous environments. The arm design can be seen below in Figure 5.

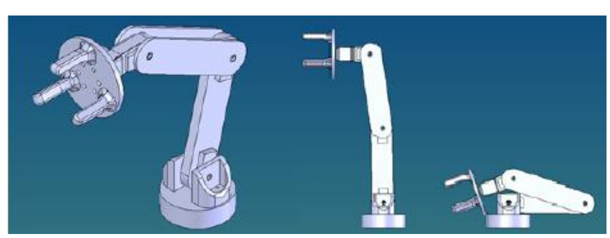

Fig. 5: Design of valve turning manipulator arm

a) Degrees of Freedom: Closing a valve requires that the operator be turned clockwise until seated. To do this we needed an arm that could reach the valve and an operator that could operate the valve hand wheel. Providing the greatest flexibility, the arm is mounted on a rotating base. The next two joints are rotational and position the arm along the operating plane of the arm. The first segment is one piece with the servo seated within. The second segment consisted of two pieces on either side of the servo. The wrist is for making the end-effector perpendicular to the valve knob and is constructed to accommodate both the positioning servo and the manipulators servo. The final joint is on the wrist and rotates the valve manipulator directly. This can be commanded to rotate clockwise or counter clockwise. The manipulator was designed after a piece called a "valve spider" that is used as an adapter between torque wrenches and valve hand wheels. The top of the robot is designed so that another manipulator or feature may be attached and controlled by the base.

b) Servos: The Dongbu HerkuleX 0201 and 0101 servos were used to operate the arm and a generic servo was used to operate the base. With a supply of 7.6V all segments are able to move. Current limitations may require current be applied to different sections from the source to prevent too much power loss prior to reaching remote servos. The base servo was DC powered with position controlled by PWM. Maximum power draw by the arm is 15W with a hold power of 6W and an operating power of 9W. The servo specification sheet reports the ability to utilize voltages up to 12VDC but in practice, this is not the case and the servos overheat and shut down utilizing this voltage. A LiPo battery was selected to fulfill the power needs due to its light weight and high power density.

c) Control Software: The program for the arm was written to interface easily with the other modules and require minimal overall resources. The servos are controlled via I2C and are addressed serially. There were a few libraries available to control the robot. The I2C library employed for this arm was convenient and straightforward to implement. The kinematics had to be configured to minimize motion force and holding current required of the servos. For example the order of deployment for the solution of the position must be reversed for retraction of the arm.

d) Finite Element Analysis: What makes the arm so useful is how light yet durable it is. Finite Element Analysis (FEA) was used to verify our arm designs could hold up to the loads required during the experiment. Our analysis showed the arm linkages were capable of holding 20lb loads with only a few millimeters of deflection. Figure 6 shows the arm under expected loads. Figure 7 shows the displacement of the arm under higher than expected loads.

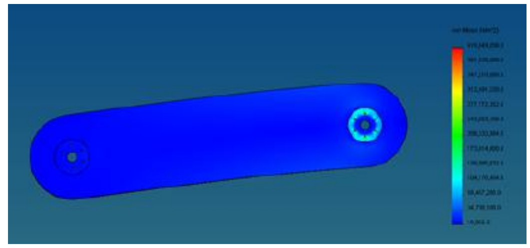

Fig. 6: Stress on arm due to load

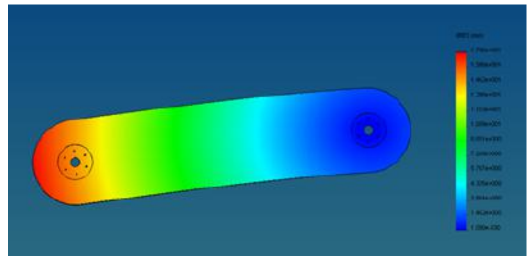

Fig. 7: Displacement of arm under exaggerated load

B. Goal 2: Voice Activated Object Pickup

The next goal of the project is to use voice control to direct the robot with another designed end-effector to pick up an object. To accomplish this task the EasyVR3 voice recognition module was used. This module in combination with the designed C++ Arduino code allows the robot to recognize commands such as forward, backward, left, and right.

1) End Effector Design: To further the robot design an additional manipulator was added onto the robot. This manipulator is a six fingered claw that will allow the designed robot the ability to pick up numerous types of objects. Depending the weight of the objects the robot will be picking up, the scale of the claw can be changed in order to accommodate the desired needs of the user. Figure 9 shows the 3D printed underactuated gripper.

The claw design consists of multiple parts with the primary pieces being the six fingers, a central hub for the fingers, the center piece, and the casing holding a gear. These pieces work in conjunction with a servo motor that turns a gear which spins against a piece of all thread which gives the claw its full range of motion. Essentially the gear hub allows changes rotational motion into linear motion. By doing this it allows the prismatic center piece in the claw to push forward and come back inward. This allows six fingers of the claw the ability to grip onto an object. The design of the fingers allows the fingers to conform to the objected being held to secure its grip properly. To test the claw the servo motor was connected and a simple Arduino code was run to ensure that the claw opens and retracts the proper amounts in order to pick up an object.

2) Manipulator Design: For the grapsing task using the underactuated gripper a new arm needed to be designed in order to correctly integrate the end-effector to the robot. In the design the servos used for the arm did not provide an adequate amount of torque in order to lift the load that was the claw. This limited the range of motion the arm was able to achieve to a point where it could only slightly alter its angle to receive something to hold. This lack of torque prevented the robot from being able to pick up an object. In the future

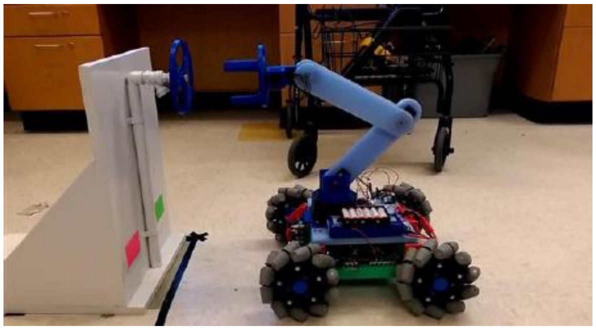

Fig. 8: Final design of valve turning robot next to valve

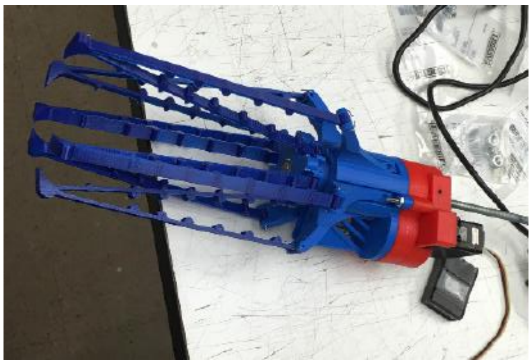

Fig. 9: Underactuated gripper in an almost closed state

a new arm design or stronger servos will need to be used in order to increase the base functionality of the claw. Figure 11 shows the underactuated gripper on the new manipulator arm.

3) Voice Control: In some scenarios video-feed control or remote control may not be enough in a given scenario. To improve the versatility of the robot voice control was added. This will allow a user whos in the immediate vicinity or has a live overview of the area to issue commands via voice to the robot based on a set of pre-programmed commands. This could allow manual control in movement when extra precision to accomplish a task is necessary. In addition this allows the robot to have its end-effector changed on site and with the use of voice commands the robots mode could be switched or the commands could be issued manually via voice. In the context done for the group created robot the robot can be told via voice to go in a given direction be it left, right, forward, or backward. With the use of mecanum wheels this allows the user a large degree of freedom with the positioning of the end-effector and the desired placement. When the robot was tested it could be seen that there are delays in the responsiveness between commands. The reason for the partial delays in responsiveness is due to the robot having to process which word is being said. The reason why the processing can take time is due to how the module is used. The module stores what is called wordsets. These wordsets have words that are programmed into the module for it to recognize. When the module has to switch between wordsets a delay is caused due to the switch. The reason for the switch as

Fig. 10: SolidWorks render of underactuated gripper in an open state

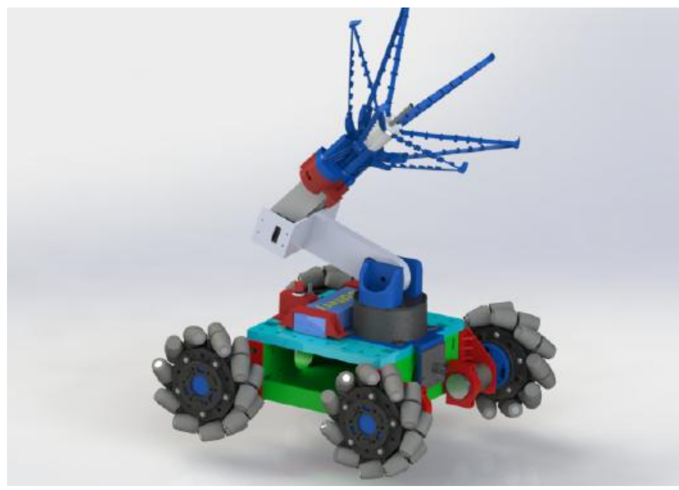

Fig. 11: SolidWorks render of underactuated gripper with new manipulator arm

in the coding a STOP voice command was used in addition to the other movement commands. It was tested like this in case the module misinterpreted a word and performed the wrong functionality. By having a fail-safe the robot was tested in a much safer way that could prevent damages. It found that in the testing the noise in the environment was a considerable factor in how the module performed. In the below image a sound wave can be seen and the spikes represent when a voice command was spoken. With more noise in the environment, errors in voice recognition were present. Figure 12 shows the waveform for an audio clip where the commands provided to the robot are located at the peaks.

Two important things to note is the difference between Voice Recognition and Speech Recognition. The difference between the two is that in Voice Recognition you can train the module to recognize specifically your voice and effectively train it to have an easier time recognizing your voice and the words you speak. In speech recognition the device recognizes

Fig. 12: Sound wave plot showing peaks where commands were received

words but isnt able to be trained to recognize a persons voice. The easyVR3 module is a voice recognition module and has some preset words incorporated into it as well as the function of adding additional words. The words allow the robot through use of the Arduino to recognize commands to move and deploy. The robot has the easyVR incorporated into it. In future iterations of the robot speech recognition can be incorporated and the robot could search and find a person by using their voice to locate them.

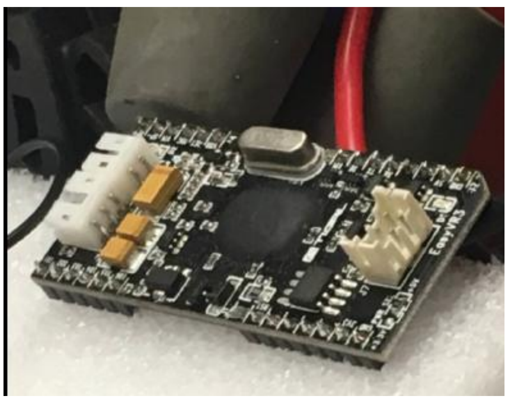

Fig. 13: EasyVR3 module for voice recognition

The final voice controlled robot can be seen in Figure 14.

V. Conclusions and Future Work

A fabricated 3D printed robot chassis was successfully designed and implemented to perform radio control, autonomous control, and voice recognition. For the valve opening/closing robot design, an autonomous controller was made to navigate the robot to its target. In the voice controlled design, voice guided driving and end-effector grasping were implemented. These two applications are the first steps into creating a completely modular robot. Maintaining a modular design will enable future improvements and modifications to be made. It was found that 3D printed parts are not only as capable as standard machined or molded pieces when used for testing and design, but were easier to fabricate and modify if a design change was needed. Even with design changes incorporated, 3-D printing provides reduced costs, faster prototype production and the ability to change the users design as necessary for any given task. 3D printing removes

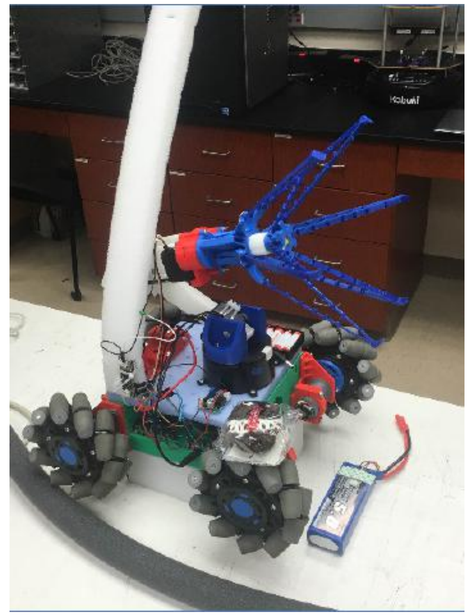

Fig. 14: Final voice controlled robot

the barriers preventing robot use in dangerous situations.

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