3D-Printed Mobile Robot Platform with Multi-variant task specific end-effector and Voice Control

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***Abstract*—The purpose of the paper is to detail how 3D printing can be used to aid in the construction of a robot to accomplish a variety of tasks. A robot was designed using Polylactic acid (PLA) that has 3 modes the modes being 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 performed.**

***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 has traditionally been performed in industry. One area that 3D printing has played a key role in is robotics. This paper aims to demonstrate the utility that 3D printing can provide in robotics applications. Specifically, the robot was designed to navigate to a valve and open or close it pending on the desired operation and to pick up an object using another end-effector. The robot performs its operations in one of three ways. The first way the robot operated was as a remote controlled ground vehicle. The second way that the robot functioned was as an autonomous ground vehicle. The third way that the robot functioned is via voice control for its movement. Given these goals it was investigated how 3D printing could be used to achieve the desired goals. When a High-risk or dangerous situation occurs it is 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. This project discusses the newly available versatility and expediency of 3D printing for use on robots. With the ability to alter designs to serve a specific task and the unmatched turnaround time gives 3-D printing a very high ability to accomplish job specific designs at much lower costs due to the nature of the materials used when compared to what industry uses today. An arm bearing robot capable of carrying different end-effectors or attachments was designed, produced, and tested for performance and reliability accomplishing its desired tasks. It was found that 3D printed parts 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 the barriers preventing robot use in dangerous situations. For a proof of concept design, a robot was 3D printed using Polylactic acid (PLA). The robot was designed to navigate to a valve and open or close it based on the current conditions in the environment of the robot and to pick up an object. These goals are accomplished based on the currently attached end-effector on the robot. Two end-effectors were used. In order to maximize the versatility the robot provides to the end user, it was designed to have a Radio Control, autonomous mode, and a voice recognition mode. To show the customizability of robot design using 3D printing was feasible; SolidWorks was used as the teams primary design software. SolidWorks is a mechanical software package that enables students to visualize, modify, and test their design in a variety of different scenarios. The 3D printers that were used in the design of this robot was 3D systems Cube 3 printer and the Lulzbot Taz 4. In a commercial scenario, different types of 3D printers that support materials like metal and carbon fiber would be used. In essence, this paper details the utility and freedom that the 3D printing industry can provide to improve robot design for both practical and educational use.

II. Utilized 3D Printer Technology

Two 3D printers were utilized in the creation of the robot. The printers used were the Lulzbot Taz 4 and the Cube 3. Both 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 two aforementioned 3D printers is their build volume and finished part quality. The reason the students decided to use two different printers was to take advantage of the strengths of both printers. When deciding which part to print on which printer both part size and part print quality were taken into account. The Lulzbot Taz 4 which provided a large build volume of 20,500 cm^3 while the Cube 3 provided a build volume of 3,456 cm^3. The printers can be observed in Figure 1.

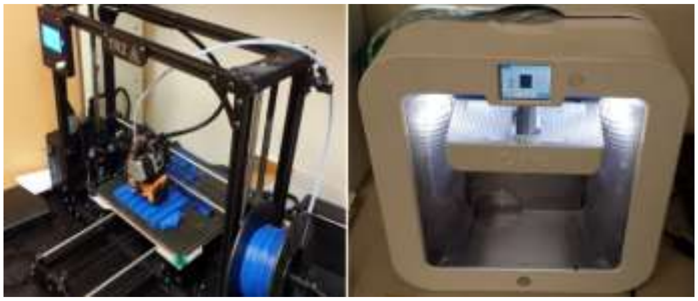

Fig. 1. Lulzbot Taz 4 (Left) and Cube 3 (Right)

Since both printers provided different strengths and weaknesses each had to be considered when printing. 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 printed part quality partially comes from the size of the extruder nozzle. The Lulzbot Taz 4 has an extruder diameter of .5 mm and the Cube 3 has an extruder diameter of .3mm. Although the difference between the two is small, the students noticed a significant difference in the finer details of the parts when using the same material in both printers. Both printers use Fused Filament Fabrication (FFF) to create the desired 3-D printed object. At its heart FFF, is an additive manufacturing process where plastics and other materials are melted by an extruder and deposited layer by layer onto a printing surface. In the case of the Lulzbot Taz 4 and Cube 3, both extruders are suspended by a gantry system. The gantry system is what allows the extruder to move along a predetermined path to deposit its filament.

III. 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 robot using a mecanum wheel configuration is able to traverse 360 degrees without any kind of a turning system. 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 through pulse width modulation, all ranges of motion can be achieved on a flat surface.

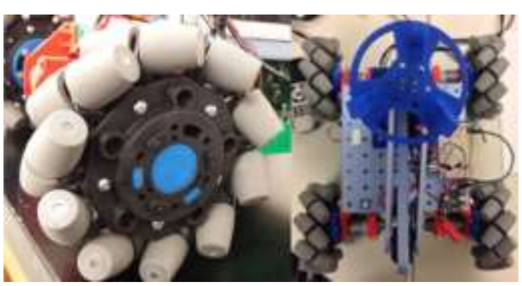

Fig. 2. Mecanum Wheel

The mecanum wheels offer a wide variety of direction but 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 tradeoff was made in order to gain the increased flexibility the mecanum wheels provide. The given motion of the wheels and the traversal direction of the robot can be seen in Table 1.

Table 1: Robot Direction Given Wheel Rotation

Direction of Movement	Direction Wheel is Rotating			
	Northwest	Southwest	Northeast	Southeast
Forward	Forward	Forward	Forward	Forward
Backward	Backward	Backward	Backward	Backward
Strafe Left	Backward	Backward	Forward	Forward
Strafe Right	Forward	Forward	Backward	Backward
Diagonal NW	No Direction	No Direction	Forward	Forward
Diagonal NE	Forward	Forward	No Direction	No Direction
Diagonal SW	Backward	Backward	No Direction	No Direction
Diagonal SE	No Direction	No Direction	Backward	Backward

The terrain the student's robot was tested on is flat due to the simplicity of not having to deal with rugged terrain and the associated locomotion issues. The students robot could be modified later to enable navigation on an uneven terrain. The versatility of being a 3D printed robot allows the students to customize the robot according to the student's needs at a particular time.

IV. Goal 1: (Faucet) Design

The framework for faucet is 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 45 cm X 30 cm X 1.5 cm. For additional supports two triangular shape wooden board of 30 cm X 30 cm X 1.5 cm were glued and screwed to the back of the vertical boards. To produce a better aesthetic result, most screws were embedded using countersunk screw holes method followed by plugging or filling the site with wood or combination of wood particles and glue.

The faucet, ¾ inch, is placed on a cupper pipe of 16 inch high and ¾ inch diameter. The pipe is stabilized by forcing the cupper 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 pixy camera.

The Pixy camera utilized for this project was CMUcam5 a product of Carnegie Mellon Robotics Institute and Charmed Labs. Pixy is the vision system for the rover robot that has been programed to navigate and find the constructed framework. Next, the rover would position to deploy the robotic arm to open the faucet. In this project the students placed two square blocks of Green and Red tape on the constructed framework of white background in close proximity of each other on the same horizontal line. Pixy has been programmed to detect these two color blocks placed closely together thus directing the rover in front of the faucet.

To install the Pixy the team connected the Pixy to the Arduino by a mini-USB cable. The students downloaded the Arduino library for the CMUcam5. Next the team taught Pixy the color of interest (Green and Red.) The CMUcam5 was then secured to the rover.

V. Goal 2: Picking Up an Object Via Voice

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”.

VI. Arm Design

The arm is designed to allow the robot to reach objects all the way from the ground to 24in 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.

Fig. 3. Arm Design

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. This may contribute to overheating issues of the first and second joints. The second segment consisted of two pieces on either side of the servo. The wrist is for making the operator perpendicular to the valve operator 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 used to adapt from torque wrenches to valve hand wheels. The “top” of the robot is designed so that another manipulator or feature may be attached and controlled by the base.

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 spec 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.

The program for the arm was written to interface easily with the other modules and require very little in the way of resources. The servos are controlled via I2C and are addressed serially. There were a few libraries available to control the robot. The one employed for this arm was convenient and easy to implement. There was a problem in development where it was difficult communicating to the string, but it was caused by a faulty wire, and once replaced there were no further communications issues. The weight of the arm was a concern so servo operation was not as simple as go to place. The kinematics had to include minimizing motion force and minimizing hold 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.

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.

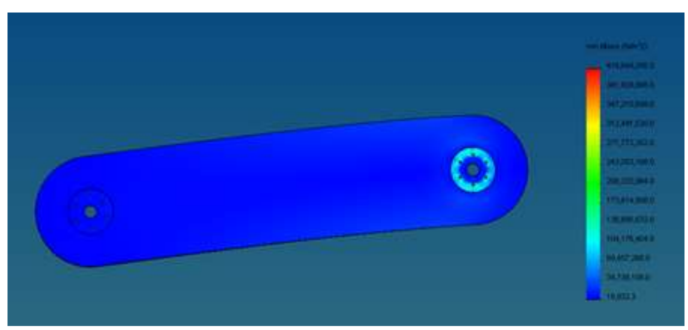

Fig. 4. Stress on Arm Due to Load

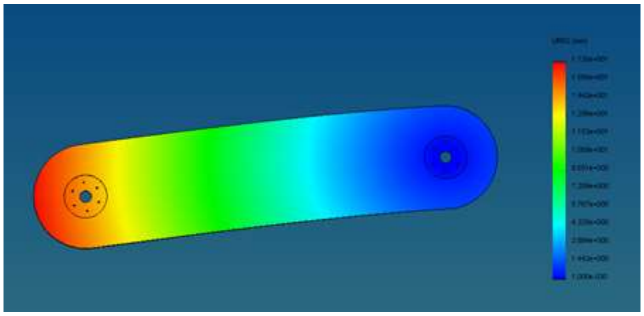

Fig. 5. Displacement of Arm Under Load (Exaggerated)

VII. ADDITIONAL END-EFFECTOR CLAW

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 objects relative to the claws size. Pending 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. The use of the claw was to show the versatility 3-D printing can provide even further by showing how the base function of a robot can be changed by changing one portion of the design.

Fig. 6. Second End-effector: Six Fingered Claw

The claw design consists of multiple pieces the primary pieces being the six fingers, the main 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 the piece of all thread which gives the claw its full range of motion. 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.

Figure 7. Solidworks Render of the Claw

VIII. ROBOT CONTROLLER

Multiple controllers were implemented for control of the 3D printed robot. The control for the arm was comprised of four separate PID controllers for each individual joint. The PID controllers for the arm servos are actually built into the servo themselves. The team of students tuned each controller until the desired operation of the arm was completed. The software that was used to tune and observe how the arm servos behaved was the HerkuleX Manager. The software allowed for real-time configuration of each servo. This allowed the students to perform "on the fly" tuning. An example of the configuration output can be seen below.

Fig. 8. Smart Servo Configuration Manager

The next controller that was implemented was for the robot chassis. At first, the students attempted to utilize the Arduino's built-in PID library to no avail. Next, the students decided to make their own proportional controller to position the robot in front of the valve stand. The first part of designing the controller was to discern the inputs. In this case, the inputs to the controller consisted of information captured by the CMUcam5. The specific information that was provided to the controller was the X and Y position of the captured image box 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.

IX. VOICE ACTIVATION FOR ROBOT 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 who's 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 responsivity between commands. The reason for the partial delays in responsivity 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 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. When there was more noise than normal the chances for an error to occur rose.

Figure 9: Sound Wave

X. Easy VR Voice Recognition Model

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 words but isn't able to be trained to recognize a person's 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.

XI. Using 3D Printing For Education in Robotics

3-D printings low cost for design can allow for teaching kits to be made. These kits will allow future students to have a pre-designed robot that they can 3-D print out. Knowing the design beforehand has already been proven to work. This will allow future students to have an example to base their work off of and solely focus on the electrical and coding parts of the robot. Since the cost of the plastics that can be used for 3-D printing are cheaper this in combination with cheaper end electrical components will allow cost efficient robot design kits for multiple groups of users to use.

XII. Using 3D Printing For Robotics in Industry

In industry having the ability to change designs via software and have a machine print the desired object to specification allows for a wider variety of applications to be accomplished due to the fact 3D printers require only the STL type files to print the object. When compared to manufacturing facilities that are locked into molds and can only accomplish one thing without stopping the entire process entirely to change said mold. 3D printers have the distinct advantage of being able to produce exactly what is necessary as long as the desired object is selected and printed. The only defining factor of 3D printers is the material used and what its inherent weaknesses and strengths are.

XIII. Using 3-D Printing for Robots in dangerous areas

In some scenarios having a high cost robot go into an area with radiation may no longer allow it to be in normal contact with humans or the electrical components may degrade to the point of inoperability. Even with techniques such as radiation hardening which can protect electrical components from harm it is a costly technique to perform on its own and can be very costly when done is great numbers. 3-D printing will allow essentially a cheap throw away robot to be designed for areas such as this to be used to gather information/data. If the robot is sent into a harmful area the loss in components will be minimized due to the nature of 3-D printings cost. In addition even if higher caliber robots are necessary cheap plastic parts can be designed in order to test and verify a design can accomplish its task before committing to manufacturing a metal or carbon fiber robot this helps eliminate unforeseen errors in the design phase by putting the cost of mistakes in the plastic parts versus there more expensive counterparts.

XIV. Future Work Involving the Robot

Being a modular design the robot can have additional end-effectors created in order to suit different needs. In addition to this fact future work involving this robot would be to pair it with another robot to work as a unit in order to accomplish more complex tasks. As stated in the Educational section the design can be easily replicated and produced so similar robots can be produced. Since similar robots can be produced they can be worked on by more than just the original team.

In terms of optimizing the current design some coding and parts could be replaced and modified. As was stated prior the robot currently switches between wordsets in order to accomplish its task. By modifying the wordsets using the easyVR commander software a more robust system could be made. More words could be programmed or specific words could be programmed and trained for use for each end-effector being used. In addition the current design of the robot could use stronger servos in order to improve its overall functionality. Depending on the desired future requirements the robot may need having stronger torque in each servo would be beneficial.

XV. CONCLUSION

A fabricated 3D printed robot chassis was successfully designed and implemented to do radio control, autonomous control, and voice recognition. For the autonomous control case, only navigation to the valve was implemented. For voice control movement in the general four cardinal directions was implemented along with deployment of the end-effector. The two accomplished applications are the first steps into creating a completely modular robot. In the future the student would also like to add different end-effectors to the robot in addition to a new arm design in the future to increase the utility of the 3D printed robot. 3-D printing offers so much potential for industry, education, military, and hobbyists. The ability to alter a design and have a proof of a proof of concept product made to verify its integrity in person is invaluable. As 3D printing improves and matures as a technology the applications and the overall efficiency of 3D printing should become more effective over time. With all the modifications done the new version of the robot can be seen below with its new end-effector.

Figure 10: Completed Robot

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