Prototyping High Mobility Inspection Robot

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ABSTRACT
Accelerator components are susceptible to failure, requiring personnel to identify and perform maintenance. A high-mobility reconnaissance robot can enter the tunnels to identify issues to decrease personnel exposure to radiation and improve beam delivery efficiency. This report details the process of designing a robot to complete such a task. The research and development robot nicknamed “RD” uses a rocker-bogie suspension to navigate uneven terrain and ascend stairs. RD also possesses high mobility with omnidirectional wheels, permitting ease of movement in confined spaces. The new robot underwent prototyping, testing, and research to evaluate the effectiveness of climbing stairs with omnidirectional wheels mounted to a rocker-bogie suspension. The RD prototype uses 3D printing for rapid testing and simplified electronics. The results from prototyping affect the full-scale robot's design and guide it toward the most optimal configuration.

I. INTRODUCTION

The AD Robotics Group specializes in developing multi-use robots, with the goal of pinpointing sources of failure in the accelerator tunnels to reduce radiation dosage for personnel and optimize beam delivery efficiency. The six-wheeled research and development robot, nicknamed ‘RD,’ aims to be an accelerator tunnel reconnaissance robot capable of passively climbing obstacles such as stairs using a rocker-bogie suspension. RD’s future goal is to use its cameras and sensors to safely navigate the tunnels and gather information about accelerator component failures. The robot can enter the tunnel without waiting for residual radiation to decay, reducing delays in beam operations. Personnel will also receive a lower radiation dosage by only needing to repair the issue instead of conducting both fault analysis and repair. Currently in the prototyping stage, RD deploys omnidirectional movement using four mecanum and two omni wheels; this resulting high mobility permits ease of movement in confined spaces. The primary goal of the prototype is to analyze the effectiveness of using omnidirectional wheels in tandem with the rocker-bogie suspension to climb obstacles. The mechanical focus of the prototype results in the utilization of simplified electronics and 3D printing.

II. PROGRESS

A. The Scaled-Down Prototype

The goal of the project is to design a robot capable of omnidirectional movement with mecanum and omni wheels while utilizing the rocker-bogie suspension to climb various obstacles such as stairs; these two movement systems are combined and prototyped. The purpose of prototyping is to test if this configuration could function in real applications. The prototype for RD is scaled down for cheap and fast testing of the integration of the suspension and wheel systems and if they successfully climb stairs. The robot and model wooden stairs are a 1:4.23 reduced-scale prototype; this scale approximates the full-scale robot’s initially planned 8-inch diameter wheels and obstacle of standard stairs. The selection of 8-inch diameter wheels results from limited commercial availability, meaning 8-inch wheels are the largest purchasable for omnidirectional wheels. Testing the prototype with the suspension and wheel systems combined reveals the need for larger wheels to achieve effective stair-climbing; the discussion about this change continues in the Future Design for RD section of the report.

The parts for the prototype are modeled in Siemens NX, and Figure 1 in the Appendix shows the fully assembled Computer-Aided Design (CAD) model. The resulting RD prototype uses 1.89-inch diameter wheels and stands 5.56 inches tall, 9 inches wide, and 9.5 inches long when all wheels are in contact with even ground. Figure 2 in the Appendix provides a detailed dimensioning of the linkages for the robot. The model stairs have a step height of 2.5 inches and are 12.75 inches tall, 10 inches wide, and 12.75 inches long. Figure 3 depicts the fully assembled prototype stairs and RD robot.

Figure 3. Scaled-down RD robot and stairs used for prototyping and testing.

The scaled-down RD's rocker and bogie linkages, chassis, and motor mounts are 3D printed in polylactic acid thermoplastic ("PLA") to allow for rapid prototyping and quick changes. Testing of the prototype robot motivated adjustments to the linkage dimensions, which needed to be reprinted. The reprints for the linkages switch from using PLA to polyethylene terephthalate glycol thermoplastic ("PETG") due to PETG having improved layer adhesion and reducing the opportunity for parts to snap. All electrical connections are contained within the chassis and mounted with custom 3D-printed stand-offs. The rocker and bogie linkages are fastened together using binding barrels and screws; these fasteners allow for pivoting of the joints while still securing the linkages together.

B. Building the Circuit

The primary tasks of RD's electronics are to supply voltage to six motors, the three DRV8833 DC motor drivers, and the Raspberry Pi Pico W from a 5V power supply and run a MicroPython software sending pulse-width modulation ("PWM") signals. The schematic in Figure 4 shows the electrical connections and how they relate to one another. The schematic exhibits the connections for only two of the robot's six motors for visual clarity; the remaining four motors follow the same connection pattern but with separate motor drivers. The motor drivers and Raspberry Pi Pico W mount inside the chassis of RD using custom cylindrical standoffs to secure the components in the chassis and prevent them from coming in contact with one another and shorting.

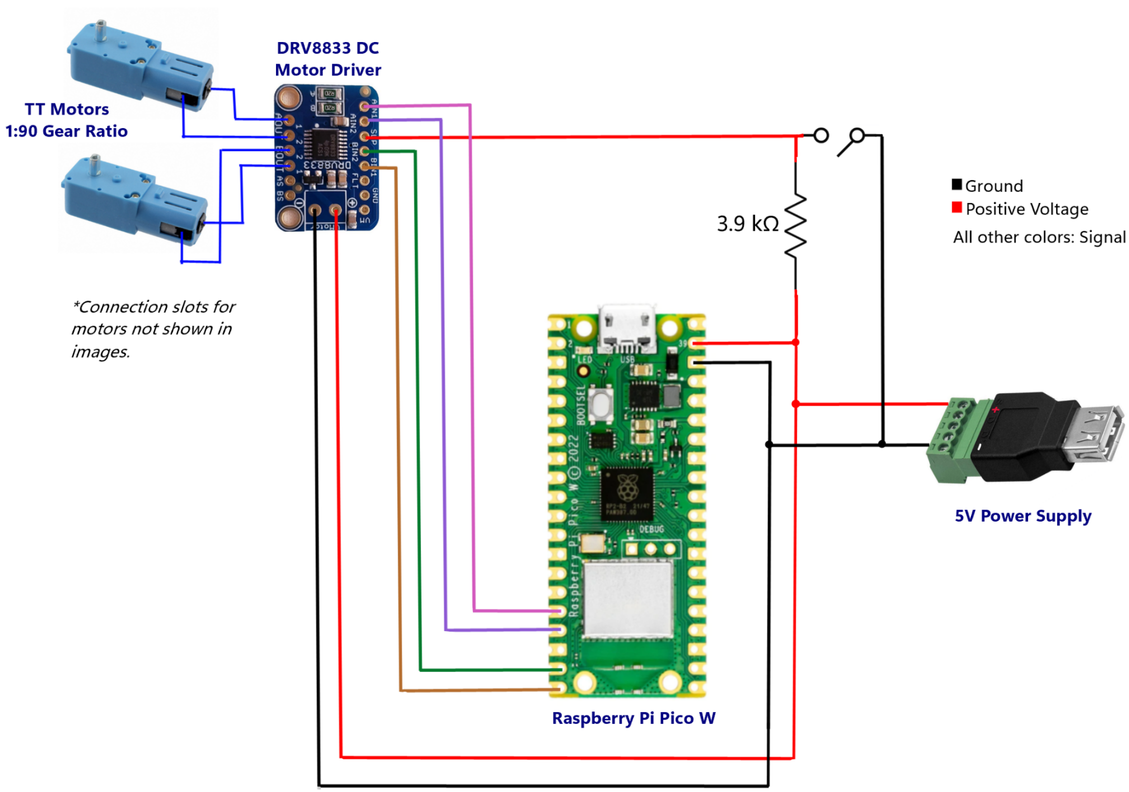

Figure 4. Electrical schematic demonstrating how one DC motor set is controlled and powered.

Since RD is a prototype and testing the suspension system is the project's focus, the electronics are simplified in two areas: the power supply is wired to an electrical outlet and real-time user control is not implemented. The motors and Raspberry Pi Pico W are powered by a 5V potential from a series of connectors. The official Raspberry Pi Power Supply draws 5.1V from a wall outlet. A panel mount cable screwed into the chassis connects to this power supply with USB-C and converts to USB-A. The last converter used is shown in Figure 4 as the 5V power supply, and it converts USB-A to a 5-pin terminal block. Jumper wires screw into the terminal block and connect to the DRV8833 DC motor driver and Raspberry Pi Pico W.

A key aspect of using the DRV8833 motor controller is activating the SLP pin; this is the sleep pin for disabling the driver. The pin is pulled low by default with an internal 500kΩ resistor, meaning a pull-up resistor must connect to the SLP to set the pin to logic high and activate the motor controller [1]. The circuit for the 3.9 kΩ pull-up resistor is shown in the top right of Figure 4.

The other simplification is that wireless control is not implemented; in other words, there is no controller (i.e. gamepad, keyboard, etc.) or control software in the MicroPython code other than for motor speed. A MicroPython script on the Raspberry Pi Pico W drives the robot prototype forward using PWM signals to alter the speed of the motors; the user's variation in the motors's speed must be entered in the code before running the robot. The use of PWM to drive the motors allows for testing and analyzing how the speed of the motors affects RD's stair-climbing ability. The motors receive the PWM signals through the DRV8833 motor controller.

C. Future Design for RD

After assembling the RD prototype, a series of tests are conducted to analyze the robot's climbing ability. The tests evaluate the distance between the wheels attached to the bogie linkage, which wheel type mounts in the front, and the readjustment of the chassis during operation. Readjustment of the chassis involves tilting the chassis slightly front-ward to ensure the center of mass does not tilt backward. The images in Figure 5 show the correct and incorrect orientation of the chassis during climbing. The necessity of tilting the chassis during operation is a direct consequence of using binding barrels and screws to mount the linkages; these fasteners allow 360° rotation, and there is no physical limit placed on the prototype to prevent the chassis from rotating backwards.

Table 1. Data collected from testing the climbing ability of the prototype.

	Front Wheel: Mecanum		Front Wheel: Omni	
Distance between Front Wheels [in]	3.71	2.95	3.71	2.95
Max Height without Readjustment [in]	0.905	0.905	0.905	1.35
Max Height with Readjustment [in]	1.35	1.35	1.35	2.50

The results from the data shown in Table 1 reveal that the optimal configuration for the RD prototype is to ensure the front wheels are omni wheels and the chassis maintains correct alignment. The climbing tests deduce that omni wheels can scale taller obstacles than mecanum wheels, meaning the scaled-up version of RD should comprise only of omni wheels. Also, limits need to be placed on the chassis to prevent the backward tipping experienced during testing; the misalignment of the chassis reduced the prototype's maximum climbing height, meaning that the repair of this issue will improve the scaled-up robot's climbing ability.

The next factor to consider is the size of the future design of RD and its dimensioning. The results from the climbing tests affect the scaling ratio of the wheel diameters. The scale derives from comparing the ratio of the prototype's wheel diameter to the maximum height ascended. With rigid chassis alignment, the scaled-up RD can implement the originally planned 8-inch diameter wheels. If some rotation is allowed in the chassis positioning, then RD would require 11.14-inch diameter wheels to safely ascend stairs. Commercial availability limits the largest diameter of omni wheels to 8 inches, meaning the required 11.14-inch wheels for the scaled-up RD will need to be custom-built. The chassis and rocker-bogie linkages will also need to be custom-built. RD's custom chassis will be comprised of aluminum U-channel extrusions and linkages made of aluminum rods. The linkages mount with custom brackets in the orientation depicted in Figure 6 in the Appendix. As mentioned previously, the reduction scale of the prototype is 1:4.38. Applying this scale to the full-sized RD using the prototype dimensions results in the following sizing: 24.35 inches tall, 39.42 inches wide, and 41.61 inches long.

The development of RD's components continues with its electrical system and software. RD's design implements visual and physical sensors to navigate its environment safely. The list includes a LiDAR sensor and stereoscopic RealSense camera to view its environment. RD implements two visual sensors to ensure the robot maneuvers with a full view of its environment at all times. Also under consideration are ultrasonic sensors and microswitches for proximity location and collision detection. In terms of software, the design for RD plans to use the open-source robotics library ROS 2 for control and operations.

A key aspect of designing the scaled-up RD is selecting the robot's motors and batteries. Python scripts simplify the calculations necessary for balancing multiple factors when selecting motors and batteries. The motor specifications code allows the user to input a variety of parameters such as the weight of the robot, wheel diameter, maximum angle the robot will ascend, nominal speed, and the time to reach nominal speed. After entering these inputs, the code provides the necessary power capability and torque for each motor to operate the robot. The battery lifetime code functions similarly, but instead, it provides an estimate of the robot's total runtime. The links for the Python files are provided in Appendix C of the report.

III. CONCLUSION

The high-mobility inspection robot RD aims to improve accelerator and beamline maintenance safety and efficiency. RD's design allows for ease of movement through tunnels with the ability to climb stairs and maneuver omnidirectionally. RD will be used as a reconnaissance robot, performing visual diagnosis of accelerator component failures and preventing unnecessary radiation exposure for personnel. RD uses a rocker-bogie suspension to maneuver over obstacles and mecanum and omni wheels to obtain omnidirectional movement. The combination of these systems underwent prototyping and testing before designing a full-scale robot. The results from the prototyping reveal that the rocker-bogie suspension climbs taller obstacles when using omni instead of mecanum wheels on the front of the robot; this discovery impacts the design of the full-scale RD which will now use only omni wheels. Future work for RD revolves around using the new-found information obtained from the prototype and applying it to the design and construction of the full-scale robot. There are still many steps to take to complete this robotic system and will require invaluable input from future interns and members of the AD Robotics Group.

IV. ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to my mentor Adam Watts for his invaluable feedback and advice. He was a fantastic mentor and a reliable source of encouragement throughout my internship.

V. APPENDIX

A. Figures

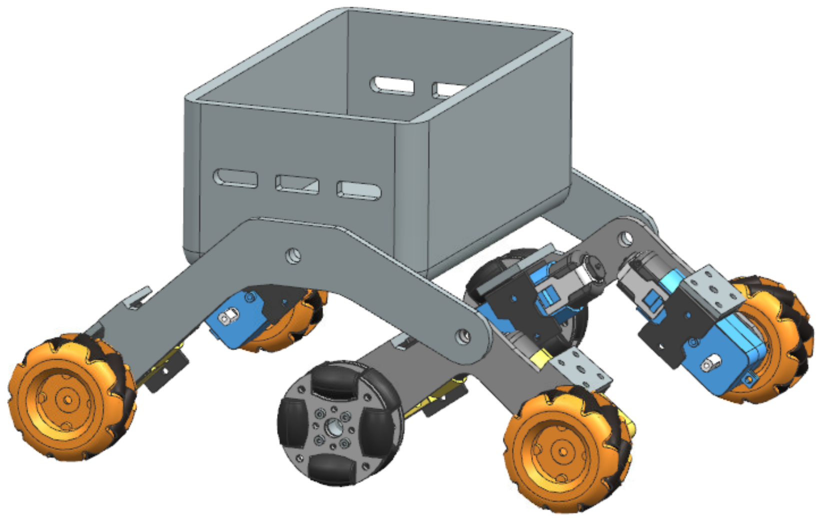

Figure 1. CAD model of the scaled-down RD robot.

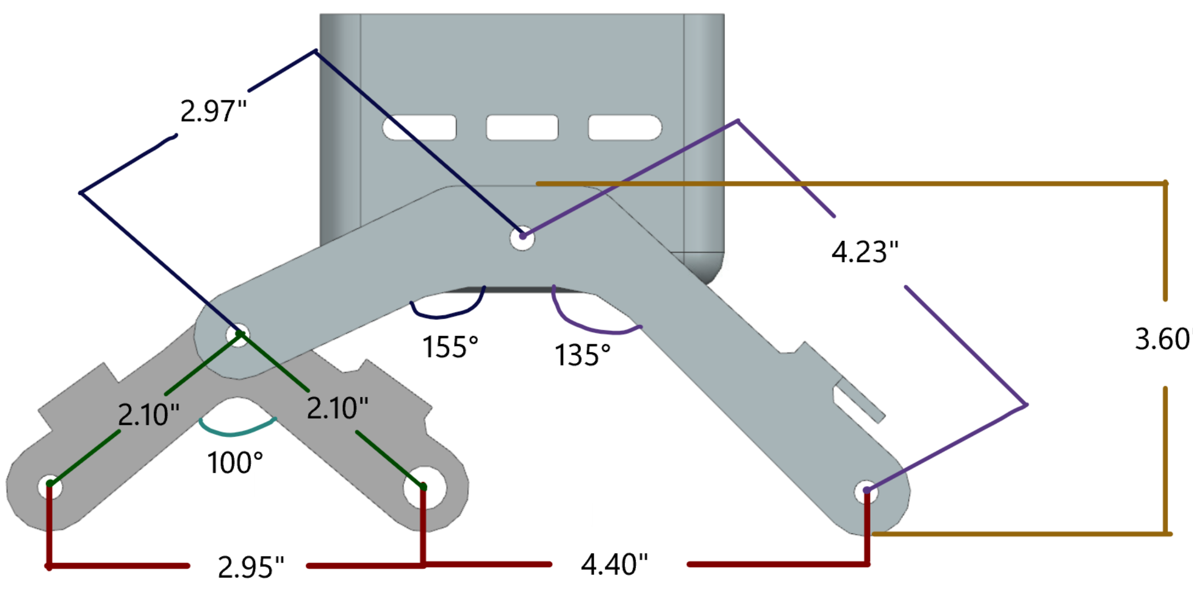

Figure 2. Dimensioning of the rocker-bogie linkages. All lengths are measured in inches.

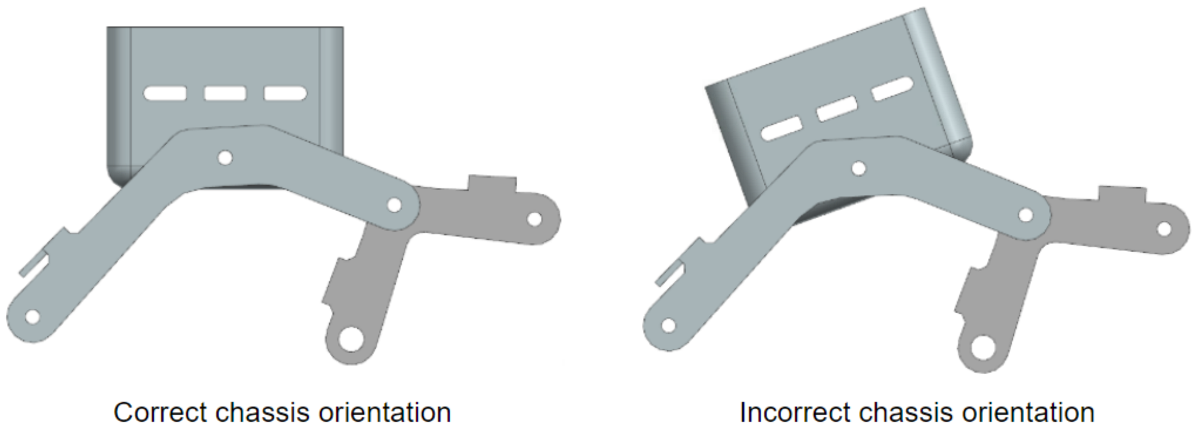

Figure 5. Depiction of the correct and incorrect chassis orientation during climbing.

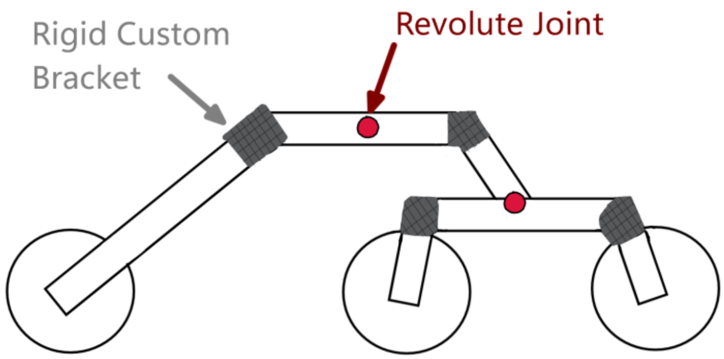

Figure 6. Sketch of the linkage orientation of a rocker-bogie suspension.

B. Resources

[1] Ada, Lady. "Adafruit DRV8833 DC/Stepper Motor Driver Breakout Board." *Adafruit Learning System*, learn.adafruit.com/adafruit-drv8833-dc-stepper-motor-driver-breakout-board/pinouts. Accessed 28 July 2023.

C. MicroPython Code
Motor specifications:
https://colab.research.google.com/drive/1Q76g5Vdlyj6FhWoMN72kVGgy0wJNWp4-?usp=sharing
Battery lifetime:
https://colab.research.google.com/drive/1zk5jBPvzLJ8p3kcIChxMf8FOQAa4HAX_?usp=sharing