Hybrid Remote-Controlled and Automatic Rover with Scooper and Gripping Mechanism

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***Abstract*—This paper presents the design and evaluation of a semi-autonomous robotic system developed for the competitive arena of navigation and object manipulation. Employing a dual-mode operational framework, the robot operates in both autonomous and manual modes. The autonomous mode utilizes a line-following algorithm in order to traverse and leave the first portion of the track and then it is set to manual mode where it collects and transport dinosaur toys and Ken dolls, within a designated arena in a specific amount of time. Despite achieving its main objectives, the robot faced challenges such as inadequate weight distribution and intermittent communication failures due to external UDP communication issues, which limited its performance in the final competition. This report discusses the mechanical, electrical, and software configurations of the robot, evaluates its performance limitations, and proposes enhancements such as a gripper-only mechanism and advanced ultrasonic sensors to improve future designs. Through iterative design and testing, this project contributes valuable insights into effective strategies for robotic navigation and object manipulation in competitive environments.**

I. Introduction

The field of robotics has continually advanced through innovations in design and control systems. As a part of the Mechatronics and Robotics Engineering curriculum at Queen's University, the team was tasked with creating a robotic system capable of navigating autonomously and moving objects manually, specifically toy dinosaurs on the floor and on top of rocks into a bucket and a Ken doll in a trench on the gameboard to a separate location. This report presents the design, development, and operational assessment of our semi-autonomous robot, the DinoDrive Robot.

DinoDrive was designed to line follow a predefined path within the autonomous mode and corral dinosaurs within the mannual mode.

DinoDrive is built upon previous manual and automatic rover designs, while allowing for a seamless transition between autonomous line-following and remote controlled manual mode with a button press. Three servo motors are used to control the scoop and gripper on the arm and two DC motors are used for the robots driving.

The novelty of our work lies in our approach to combining various materials, such as Polylactic Acid (PLA), Thermoplastic Polyurethane (TPU), and Medium-Density Fiberboard (MDF), to construct a versatile and resilient robot tailored for the competition's unique demands. Moreover, the introduction of an adaptive, soft gripper inspired by Festo's "Adaptive Gripper Finger DHAS" reflects our dedication to innovation in robotic design.

Our overall strategy was to create a robot that could excel in corralling dinosaurs, hypothesizing that the integration of an adaptive TPU gripper would significantly enhance the robots efficacy. We anticipated that the DinoDrive would not only meet the competition's requirements but also provide insightful data and experience to inform future iterations of robotic design in our field.

Through meticulous planning, iterative design, and extensive testing, the DinoDrive project endeavors to contribute valuable knowledge and methodology to the domains of robotic navigation and object manipulation, particularly in competitive and task-oriented contexts.

II. Methods

A. Design Dimensions and Materials Used

The mechanical design of the robot consists of mainly a body and arm. To give an idea of its dimensions the robot can be simplified to fit within a 23 cm by 24 cm by 10 cm rectangular prism. The materials used consist of PLA, TPU, and MDF. A more detailed design of the robot can be seen in Fig. 1 and the specific amounts of each material is summarized in Table 1.

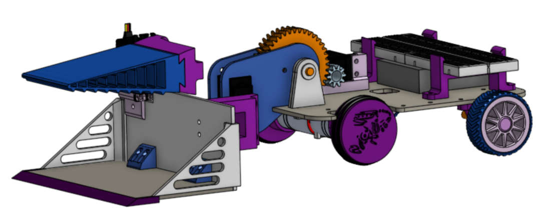

Fig. 1. DinoDrive Robot CAD made with OnShape.

TABLE I. Material Usage Breakdown for Robot Fabrication

Metric	Material		
	PLA	***TPU***	***MDF***
Volume (cm^2)	150	90	N/A
Percentage of total material used	62.5	37.5	75

B. *Soft Gripper*

The primary end effector used in this design was an adaptive gripper, inspired by Festo's "Adaptive Gripper Finger DHAS." This gripper is uniquely capable of conforming to objects of various shapes, such as dinosaur models and a Ken doll, due to its morphing capabilities. Enhanced gripping is facilitated by additional indents that increase the surface area in contact with the objects. Constructed from TPU, the gripper was produced using an fused deposition modelling (FDM) 3D printer. The design allows the gripper to wrap more tightly around objects as greater force is applied, effectively adapting to objects with pronounced curvature. This morphing action is illustrated in Fig. 2, as documented by Festo [1].

TPU is a versatile class of polyurethane plastics known for its elasticity, transparency, and resistance to oil, grease, and abrasion. It is a thermoplastic elastomer made from linear segmented block copolymers, which include both hard and soft segments. The hard segments provide toughness and rigidity, enhancing physical performance, while the soft segments impart flexibility and elastomeric traits. This inherent compliance, characteristic of soft robotic systems as noted by Laschi and Cianchetti (2014), allows a soft robotic gripper made of TPU to generate highly passive deformations and adapt to the shape of the object it handles [2]. TPU's benefits extend to robotic applications, particularly in the construction of grippers. Its durability minimizes damage risk while handling objects, making it ideal for repeated use in robotics [3].

NinjaFlex is a prominent brand of TPU known for its exceptional flexibility and strength. It is particularly noted for producing some of the softest TPU available, specifically their formulation that has a shore hardness of 85A. This makes it one of the softest TPUs on the market, providing significant advantages in applications requiring high levels of flexibility and elasticity [4].

The 85A shore hardness rating of NinjaFlex indicates a very soft material, akin to the flexibility of shoe soles or rubber bands. This softness allows for the creation of parts that can withstand bending and flexing forces without cracking or losing form, which is crucial in dynamic environments.

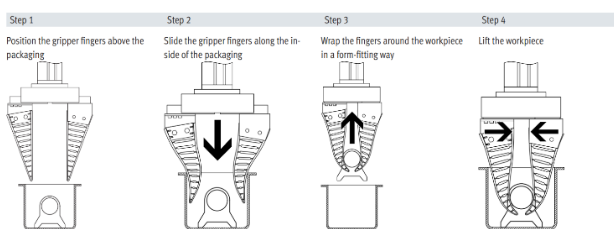

Fig. 2. Demonstration of Festo gripper adapting to an object.

C. *Gear Design*

Two double helical gears were incorporated into the design to actuate the arm, which includes both a loader and a gripper. A servo, rated for a torque between 3.3 kg·cm and 4.1 kg·cm [5], powered the smaller gear, while the larger gear was directly connected to the arm. The initial design utilized a direct servo connection to the arm; however, due to the excessive weight of the final arm design, this configuration proved inadequate torque, necessitating the addition of gears. The gears, with a ratio of 1:4, consisted of a small gear with 10 teeth and a larger gear with 40 teeth. The double helical gear configuration was selected to enhance load-carrying capacity and tooth durability [6]. The limitation posed by the maximum printable volume of PLA, which required the use of a low infill percentage, was mitigated by the helical design, ensuring durability of the teeth independent of the infill percentage. Fig. 3 depicts the gear assembly. This gearing arrangement proved effective for lifting both the arm and the simulated loads, represented by either a dinosaur model or a Ken doll.

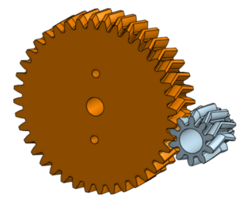

Fig. 3. Gear train with a 1:4 gear rario for lifitng the arm (scooper and gripper).

D. *Wheel Design*

The front and rear wheels of the robot are illustrated in Fig.4 and Fig. 5, respectively. The front wheels are designed with two indents to securely accommodate the Buna N cord, which was cut diagonally and adhered using super glue. To enhance the traction on the arena surface, each front wheel was equipped with two rubber wires. Additionally, the rear side of each front wheel includes a space designed for a press-fit connection with the DC motor shaft. Conversely, the rear wheels are mounted on freely spinning axles. The wheels utilize blue TPU for improved traction and purple PLA for the inner wheel structure. The pattern on the wheels, while not chosen for any specific technical advantage, was designed to increase the surface area for better traction.

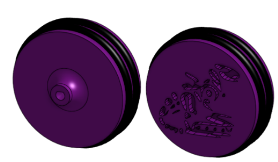

Fig. 4. Front wheels of the DinoDrive robot.

Fig. 5. Back/rear wheels of the DinoDrive Robot.

E. *Software and Control Algorithms*

The team implemented software and control algorithms to navigate a rover with the ability to drive manually using a Logitech F310 Wired Gamepad and automatically using the DFRobotShop Rover Line Follower. Additionally, the team implemented an arm control mechanism for both picking up the dinosaur toys and Ken doll. The software is written in both Python and Arduino script for communicating with the Gamepad to control the robot's microcontroller operations.

a) Manual Drive Control: User Datagram Protocol (UDP) communication between the controller and the rover was enabled by utilizing the inputs library within the python script to interface with the gamepad. The rover's movements coud be mannualy controlled wirelessly with over the air (OTA) updates enabling real-time transmission of control signals. The rover was able to execute both directional movement and speed adjustment using front wheel drive.

b) Automatic Line Following Control: Upon activation with a button press, the Arduino script running on the rover's microcontroller alowed the rover to navigate a predetermined path marked by a black line on the track. The rover could detect the line and adjust its course as needed with the help of a control loop. Proportional-integral (PI) control algorithms were used to process sensor inputs and calculate the necessary steering adjustments to to refine the rover's path following accuracy.

c) Arm Control: The arm of the rover was controlled by three servo motors. The first two servos were programmed to control the location of the arm and the final servo was used to open and close the gripper. The arduino script included bounds such that the servos can only rotate within a safe range to avoid any mechanical interferances with other parts of the rover's structure. The Python script controlled the arm via gamepad inputs and was changed to include a condition that not only checked for when a button was pressed, but also when a button is released after being pressed. This way the arms movements were both smooth and responsive to the operator's input.

F. Electrical Design

The main components of the electrical design of the rover can be seen as the physical electrical subsystem in Fig. 6 and an electrical schematic in Fig. 7.

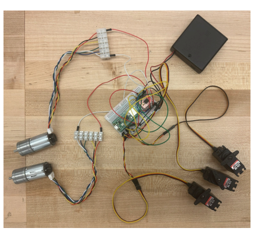

Fig. 6. The physical electrical subsystem for DinoDrive robot.

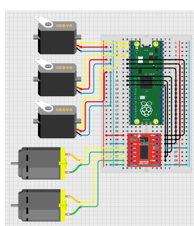

Fig. 7. Electrical schematic for DinoDrive robot made using Cirkit Designer.

Given a full charge the battery pack will allow the rover to run for approximately 44 minutes to 2 hours and 56 minutes. However the torque the servo motors can handle and the speed the DC motors will run at decline with a lower charge. The power budget for the main rover components are portrayed in Table 2.

TABLE II. POWER BUDGET FOR DINODRIVE ROBOT

Component	**Nominal Voltage (V)**	**Nominal Current Draw (A)**	**"worst-case" Current Draw (A)**	**Nominal Power (W)**	**"worst-case" Power (W)**
Servo Motor x 3	4.8-6.0	0.15	0.15	0.72	0.9
DC Motor x 2	6	0.13	3.2	0.78	19.2
Motor Driver	5.5	1.2	1.2	6.6	6.6
Raspberry Pi Pico W	1.8-5.5	0.5	0.9	2.75	4.95
Total	33.7-330	2.41	8.55	11.22	52.65

III. RESULTS

A. Autonomous Mode

During the testing, the robot was able to line follow and get through the door using integral control more than half of the time. The robot had no issues when moving in a straight line, the problems began when the robot attempted to turn using line following which was reflected during the qualifying rounds when the robot missed the left turn. To mitigate this error proportional control was added in order to adjusts the robot's steering based on the current error. While this change increased the rate at which the robot can complete the turn to about 80% of the time, the robot missed the turn once again during the final competition.

B. Manual Mode

The robot's manual mode proved to be effective, successfully picking up dinosaurs of various shapes. The control system consisted of three servos: one for tilting the gripper/loader, another for operating the gripper, and a third for raising the arm. Each servo was linked to two buttons—one to rotate the servo clockwise and the other counterclockwise. The buttons were designed to be press-and-hold for operation, with the right button of each pair configured to raise the arm and the left to lower it. Specifically, Servo 1 (Tilting scoop) was controlled by the RB and LB buttons, Servo 2 (Gripper) by the A and B buttons, and the arm lifting by the X and Y buttons. The robot's driving was managed through thumb sticks: the left stick controlled forward and backward movement, while the right stick handled turning, gradually adjusting the speed to each wheel based on the direction of the turn. This layout made driving and operating the arm both easy and intuitive. The robot responded promptly to these controls, exhibiting no noticeable delay. Initial testing rounds were essential for becoming familiar with the robot's movements and optimizing the button mappings. After three iterations of refinement, the final design of the control layout was established, enhancing the overall usability of the robot.

IV. DISCUSSION

A. Robot Performance

The robot's performance was close to expectations, with its primary objective being to collect four dinosaur toys and disregarding the Ken doll. The line-following functionality was operational approximately 80% of the time, with performance inconsistencies largely attributed to variations in battery power. This fluctuation hindered the ability to make precise adjustments in the code. In autonomous mode, line-following issues were particularly noticeable after the arena's designated turn point. In manual mode, the robot managed to collect only one dinosaur due to time constraints and a code timeout caused by UDP communication errors that were beyond the teams control. However, the scooper and loader were successful in gripping and transporting the dinosaurs to the designated drop-off cage.

B. Limitations and Proposed Improvments

Several limitations were observed in the robot's design and functionality:

a) *Weight Distribution:* The robot's weight was distributed in such a manner that picking up Ken dolls was impractical. Redesigning the weight balance could enhance versatility in object handling.

b) Line Following Code: The line-following code had a success rate of only 80%. Improving the algorithm and incorporating adaptive features to better handle power variability could increase reliability.

c) *Scooper and Arm Mechanism:* Occasionally, the scooper and arm pushed the dinosaurs away instead of scooping them up. A design shift towards a gripper-only mechanism might yield better results in securing and lifting objects.

d) *Sensor Enhancement:* Integrating high-quality ultrasonic sensors would improve the robot's environmental awareness, potentially enhancing navigation and object detection capabilities.

These improvements are aimed at overcoming the current limitations, thereby enhancing the robot's operational efficiency and reliability in future iterations.

C. Conclusion

The study detailed in this report outlines the design and operational testing of the DinoDrive, a semi-autonomous robot. This robot is engineered to navigate a specified path and manipulate objects within a competitive setting, primarily focusing on collecting dinosaur toys while avoiding static obstacles like rocks and walls. The DinoDrive operates under a dual-mode system, alternating between autonomous line-following and manual control via controller input change, enhancing usability and precision in object handling. Although the robot achieved its fundamental goals, it encountered issues related to weight distribution and communication errors, impacting its performance in critical situations. The proposed future enhancements, including a shift to a gripper-only mechanism and the addition of ultrasonic sensors, aim to refine its capabilities. This project illustrates the potential for iterative design processes to advance robotic technology in complex, task-oriented environments.

Credit authorship contribution statement

Aria Maz: Conceptualization, Data Curation, Formal analysis, Investigation, Software, Visualization, Writing - Original Draft. Daniel Dubinko: Conceptualization, Data Curation, Formal analysis, Investigation, Methodology, Software, Visualization, Writing - Review & Editing. Amy Wu: Resources, Supervision. Graziella Bedenik de Oliveira: Supervision. Jenny Lee: Supervision. Abigail Lee: Supervision

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