Bot: A mobile robotic agent for hostile animal handling and critical search-and-rescue operations.

Nathan T. Duncan and Avery W. McFadden

***Abstract*— Remotely controlled mobile robots have the potential to perform tasks deemed too dangerous for human operators including advanced search-and-rescue operations and working with aggressive animals. Due to the unsafe nature of these operations, scaled model testing is an effective method to evaluate the capabilities of such systems. The purpose of this project was to design, manufacture, and program a robot that would be able the overcome challenges of the ”Dino Rescue”. The robot must navigate an autonomous area to find the dinosaurs where it must then cage the said dinosaurs and bring Ken to safety. However, work within this proximity to dangerous animals is extremely dangerous for humans and therefore robots must be able to perform these tasks without any physical intervention from the human. Here we show that through testing and design iterations, advanced search-and-rescue missions can be carried out completely without putting any humans at risk. Having such a result proves that through the advancement in robotic technology we are able to create a safer work environment and allow robots to complete tasks that would have normally put humans at risk. This also paves the way for allowing robots into the work force without the fear of unemployment as robots can be used to complete previously difficult of impossible tasks. Our results demonstrate how robots are advancing and how they can be implemented safely to complete tasks mostly autonomously to completely remove the risks from some tasks.**

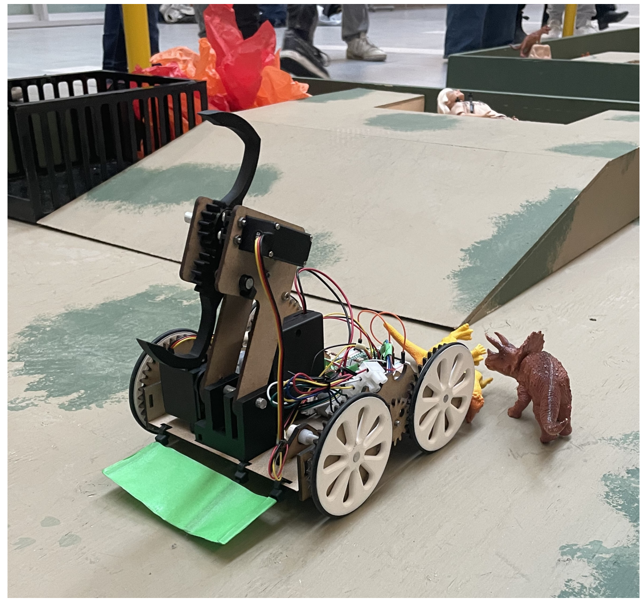


Fig. 1: Close-up isometric view of the Bot robot in the competition arena.

I. INTRODUCTION

To evaluate the robot's capabilities for corralling dinosaurs and rescuing individuals in distress, a scaled competition dubbed ”Tronassic Park” was designed for the robot to compete. The competition arena is split into two sections; the entrance section to be traversed autonomously, and the habitat section scattered with small dinosaurs needing to be corralled into their cage under the manual control of the robot operator. The habitat section also includes a Ken doll stuck in a small pit, who must be saved from the dinosaurs and taken to a helipad for evacuation. To quantitatively analyze performance, the competition was organized to award points for tasks of varying difficulty, with more complex tasks garnering more points. The system was to be designed using minimal materials including but not limited to, a processor (Raspberry Pi Pico W), electronic actuators (DC and Servo motors), sensors (Optic reflective sensors), and raw materials (ABS plasitc and MDF board).

The robotic solution to this endeavor, nicknamed ”Bot”, drew inspiration from Smith Engineering Design courses Mechatronics and Robotics Design I and II. These course featured the design and programming of small mobile systems that completed similar tasks of autonomy and manipulation, including line following, object pick-up, and interfacing electronic sensors with microprocessors. Industry robots such as the Clearpath Husky also offered inspiration for how a mobile platform can be fitted with additional mechanisms to accomplish complex feats [1]. Ideas form these sources lead to the development of the Bot as a four-wheel platform mounted with a two degree of freedom manipulator shown in Figure 1.

The Bot's expected performance in the competition was predicted to be a 8-13 point mean score. This was founded in the assumption that the agent would be able to reliably complete line following (4 points), would be able to collect 2-4 dinosaurs (2-4 points), and would be able to safely rescue Ken with some acceleration in the remaining time (2-5 points).

The authors are enrolled in MREN303: Mechatronics and Robotics Design III, taught by Amy Wu P.L.Eng, PhD. within the Smith Engineering Faculty at Queen's University. E-mails: 20ntd1@queensu.ca, 20awm@queensu.ca.

II. METHODOLOGY

Given the system's design requirements, the Bot's design team set out to create the agent using an agile project management approach. Over twelve weeks the design was iterated through various mechanical, electrical and software prototypes to achieve prioritized design goals.

A. STRATEGY

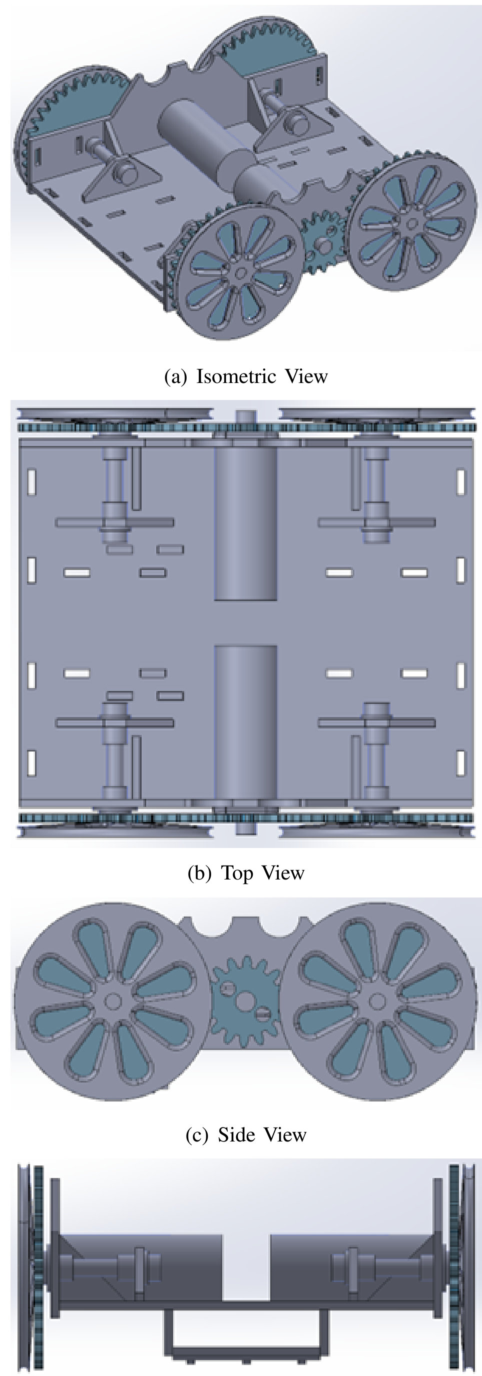
Throughout the design of the robot, the strategy was of the utmost importance. It was important that the robot was designed to be small and extremely maneuverable so that it could navigate through the rocks quickly so that it could spend more time picking up the dinosaurs and less time getting stuck on the rocks. Another important aspect to the strategy was to do game day scouting of the competition to see if the strategy should change to have the best chance at winning. This scouting included the pros and cons of the other robots and general game strategy such as of they go for Ken or picked up dinosaurs instead. It was this day scouting and seeing how few other teams went for Ken that caused the team to switch their strategy and try and pick up dinosaurs instead. With most other groups trying to pickup dinosaurs it meant that most matches were only getting up to about 5 or 6 points if they had a working line following. This meant that the team could rely on their line following to get 4 easy as fast points as they had planned and then would just need to add one dinosaur to their score to seal most matches away.

B. CHASSIS

Various means to drive small robotic vehicles exist including two-wheel drive, Ackerman steering, and Mecanum drive [2]. After exploring these styles and their implementations in other mobile robotic systems, the decided drive method of the Bot was a differential two-wheel drive, sometimes referred to as ”tank drive”. This style incorporates two drive motors, for the right and left sides of the robot, which are are connected to a small drive gear powering two larger pinions fastened directly to the robot's wheels. A differential two-wheel drive allows for two important qualities in the design of the Bot: power to all wheels, so that even if the robot is on uneven terrain or if mass is distributed abnormally above the wheels the robot will still have traction; and pivot-in-place, which will allow the motor to turn within a small turning radius when the motors drive in opposite directions. The Bot's width was determined as 70% of the competition arena's gate to allow sufficient room for the robot to pass. The robot track was set to as similar length as a square wheelbase facilitates the pivot-in-place feature. Other features including a line sensor mount, ultrasonic mount, and open platform space are shown in the CAD model of the Bot, displayed in Figure 2.

Wheel axles were constructed using 1/4” aluminum rod, while the wheel rims and bearing were made of plastic. The remainder of chassis frame and supports were constructed using medium density fibreboard assembled using slot joints and wood glue. The gears were also manufactured from MDF as we had ample amounts and had believed it would have a similar strength to PLC plastics. However during early testing there was obvious wear around the motor's drive shaft in the central gear. Rather than switch materials, the part was modified to have two small holes to access the motor mount screws (shown in 2(c)), allowing the gear to be quickly removed and replaced whenever it wore.

Dynamics of the Bot were modeled in software based on



(a) Isometric View

(b) Top View

(c) Side View

(d) Front View

Fig. 2: Principle views of the Bot robot's chassis model designed in SolidWorks.

the differential drive robot used in [1],

$$v = (v_r + v_l)/2 \tag{1}$$

$$\omega = (v_r - v_l)/W \tag{2}$$

where v represents the instantaneous transnational speed of the robot and ω the instantaneous rotational speed. v_r and v_l are the right and left wheel velocities, respectively. W is the effective track of the robot, 18.6 cm.
Manual operation of the chassis was programmed using a tank drive program similar to [3] to proportionally map commands for the right and left joysticks of the game-pad to drive signals sent to the right and left motors of the Bot respectively. In autonomous mode, actions were dictated by a finite state machine controller, adjusting the motor commands based on the state of the three line colour sensors and the previous state of the robot. The line following program was adapted from the line sensor manufacture's sample code with the desired state straddling the line, with the mid sensor detecting the line and the outer two sensors not [4].

C. MANIPULATOR

When designing the arm manipulator for the Bot it was important to consider the size and weight of not only the manipulator itself but also the size and weight of what the bot was trying to pickup. The arm was designed to be small enough to not increase the size of the robot but also large enough to where it was able to pick up Ken without any issues. The calculations for the arm with one servo motor can be see below in Equation 3 and were used to determine how far the team could make the manipulator reach while still having enough force to lift it.

$$L_t = \tau / W_t \tag{3}$$

where L_t is the total length of the arm linkage and W_t is the total weight of the expected payload. τ is the Servomotor torque, specified by the manufacturer as 0.32 N*m [5].

Using the Equation 3, the team could make the arm 13.35 cm long while still being able to pick up Ken which had a weight of 181 grams. After getting the calculations a CAD file was design and then manufactured by the team. After the robot was built it was tested and worked great. The claw was long enough to grab Ken and even long enough to knock the high Dinosaurs off of the rocks, while still able to have the force to lift Ken. The only issue that the team ran into when trying to pick up ken was that the front of the robot was not heavy enough and the robot would "pop a wheelie" when trying to pull Ken out of the hole. When testing it was able to do this but in future designs it might be easier to add weight to the front so the robot is able to take advantage of the 4 wheel drive that was implemented. The claw was also designed to use only 2 servo motors to allow a third one to be used for the front manipulator. Unfortunately due to unforeseen delays the team was unable to manufacture the front flipper design but in the future this could be implemented.

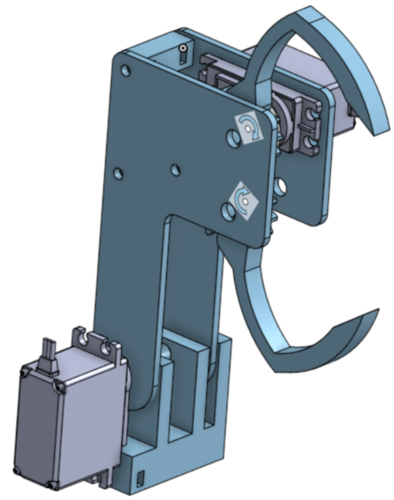


Fig. 3: Isometric View of the entire Manipulator Mechanism.

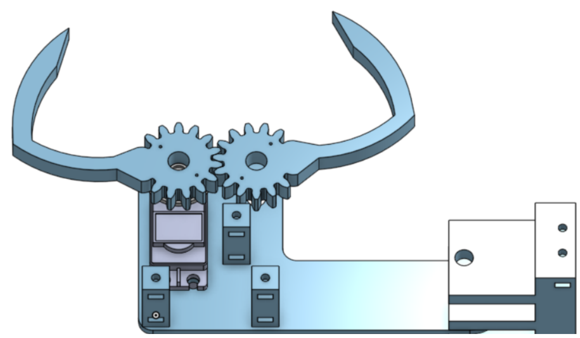


Fig. 4: Section View of the Claw Mechanism.

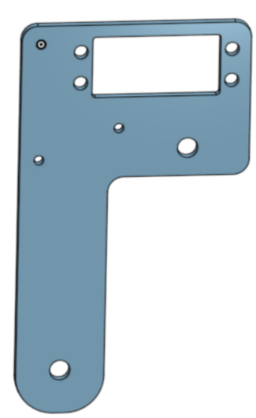


Fig. 5: Close-up View of the Manipulators Arm.

III. RESULTS

The final prototype evaluation was completed the week of April 1-5 2024. The event was hosted in Mitchell Hall and featured two arenas where competitors could compete head to head. A partial view of one arena is shown in Figure 6.

The Bot prototype successfully met all competition requirements, demonstrating robust mechanics and intelligent design allowing the agent to complete competition objectives with sufficient precision and efficiency. The final design held within material constraints, utilizing approximately 80% of the 3D printing budget and only 40% of the available medium-density fibreboard. The robot achieved linear speeds up to 0.3 m/s and angular speeds up to 3 rad/s. These speeds coupled with the finite state machine controller and feedback from the line sensor enabled the robot to navigate the autonomous mode reliably in under eight seconds.

Fig. 6: A large crowd including robot operators Nathan Duncan and Avery McFadden (center) gather round the Tronassic Park arena to watch the Bot complete a test of the autonomous navigation on the day of competition.

a) Qualifier 1: A late change in the competition requirements allowed the robot to access a third analog input on the Raspberry Pi Pico. To make use of the third line sensor, adjustments were made to the physical placement of the sensor and an updated autonomous controller was created. Theses late changes were not complete for the first qualifier, and along with communication issues between the computer and Pico lead to the Bot's first and only zero performance. The Bot was also not yet equipped with its manipulator due to manufacturing delays and so a front bumper pushing strategy was utilized to corral the dinosaurs. Despite proving to be a viable strategy during trial runs, there was not sufficient time following the communication timeout to corral any dinosaurs.

b) Qualifier 2: By Qualifier 2, the autonomous line following program had been completed and the agent was successful in navigating from the starting point into the manual arena. By this event the two degree of mobility manipulator, was mounted to the Bot. As joystick commands were already mapped to the robots chassis, arm and gripper controls were mapped to the right and left triggers of the game pad. This mapping along with lack of practice with the operator caused difficulties holding either joint in partial positions and complicated the placement of the dinosaur in the cage as it required holding the dinosaur at a height midway between the upper and lower bars of the cage. Due to these complications, the Bot scored no additional points in manual mode.

c) Round 1: The Bot was able to score for points in Round 1 for successful line following though its controller was not as smooth as usual perhaps due to an misaligned starting position. The Bot approached the gate with a high angle of incidence and its left front wheel caught the left hinge of the gate. Fortunately, due to the Bot's small wheel base it was able to pivot through the gate and when it reached half mass through the gates, the operator was able to take over manual mode and quickly exit the gate.
By The day of competition the team had mapped new controls from the game-pad to the Bot's arm to enable more easier control including a hold at 100 degrees button that, once a dinosaur was grabbed it could be held at the appropriate height to be carried straight into the cage and released without further arm commands. Despite these modifications the Bot still had difficulties making the initial grab of the dinosaur. These difficulties were further amplified by not only control signal timeouts but also a peculiar one second delay in control signals. The cause of these signal delays is undetermined and following the Round 1 event, they were never observed again.

d) Round 2: After a success in Round 1 the team progressed to Round 2. Once again the autonomous mode was completed flawlessly, earning the Bot four points.

The Bot was eliminated in this event by its opponent "Raptor Rescue" who scored 7 points, and would go on to place third overall.

The results of these events are summarized in Table I.

Event	Total Points	Autonomous Mode	Manual Mode	Time
Qualifier 1	0	0	0	2:00
Qualifier 2	4	4	0	2:00
Round 1	4	4	0	2:00
Round 2	4	4	0	2:00

TABLE I: Competition performance summarized with points and time recorded for each event. The median score of the agent is four points, with a point per minute average of 1.5 ppm. Following the agent's autonomous controller update in Qualifier 2, the Bot was able to reliably score full points for line following in autonomous mode. Manual performance of the agent was poor, scoring zero points in all events. The agent competed for the full two minutes in each event.

The average score of each team in the competition was 2.65 points [6]. This put the Bot in the 76^{th} percentile of mean scores for all robots.

IV. DISCUSSION & CONCLUSION

Based on the competition evaluation of our final prototype, we are satisfied with the outcome aligning with the competition objectives. The Bot prototype demonstrated reliable and efficient operation in the autonomous portion, and showed great capability for completing manipulation tasks in manual mode, though this potential was not realized during the competition.

The agent showed great maneuverability and handling during the competition. Its ability to pivot in place, proved useful during the Round 1 event when the Bot found itself positioned sideways in the gate way, as well easing the approach of the agent towards a dinosaur as its heading could be adjusted even when a dinosaur lay directly to the agent's side. Turning maneuvers were also reliable and aided for a stable completion of the line following. The speed and torque produced by the DC motors and attached transmission gears was an appropriate balance of both qualities, being able to easily climb the arena's inclined plane while carrying high loads while still offering sufficient speed. Reflecting on the design of the chassis, the only change recommended would be shortening the wheel axle length and moving the internal support nearer to the chassis side wall. This change is based on course learnings of bearings, which dictate best practice for the separation of radial supports should be calculated as $L = 3D$, where L is the support separation and D is the axle diameter. Moving this support would increase structural efficiency, shorten the wheel axle length, consume less aluminum material and open more space for mounting electronics and other components.

At the competition the manipulator preformed well and the team was able to pick up dinosaurs and move them towards the cage for collection. The manipulator also worked to pick up Ken and when testing the claw it was able to pick up Ken and move him out of the hole. The claw also stay true to the initial plan with keeping a small but powerful design while only using two servo motors on the design. Looking back there was a few improvements that could be made to the manipulator to improve the function and performance in competition. The first of which would be to add bearing shafts to help hold the second claw arm in place better. The bottom half of the claw was only locked in place by a zip-tie which allowed for some flop in the design which meant that it was harder for the bottom half of the claw to get a good grip on Ken to pick him up safely. Another improvement to the manipulator arm would be to d more testing to better refine the stop angle to put the dinosaur into the cage. At the front of the cage there was a lip which made it hard to lift dinosaurs into it. To combat this the team had a stop button where the claw would stop at a specific angle to place the dinosaur into the cage. In competition this angle was a little small and the dinosaurs legs would get stuck on the bottom of the cage and we would be unable to lift the dinosaur into the cage. Overall the teams general strategy worked well and allowed the team to make it into the second round. The strategy to have a small and fast robot paid off as it allowed the team to very quickly navigate the rocks to bring the dinosaurs to the front of the cage. The strategy to go with the line following instead of the button press also paid off any many teams focused on the button pressing for too long and were unable to get an efficient line following which allowed the team to get a quick 4 point advantage over their competitors. Although the strategy helped the team in many ways it also could have been improved to help with efficiently grabbing Ken. The teams goal to have a small and fast bot worked well to move around the game board quickly but when it came to picking up Ken the robot was not heavy enough to keep four wheels on the game board. The weight of Ken was to much for the robot to be able to keep all four wheels on the ground when dragging him out which made it way harder to get Ken out of the pit. For future designs more considerations should be put on where the heavy components (e.g the motors and batteries) of the robot go, to make sure that the robot has enough weight on the front to be able to lift Ken without throwing the robot off balance.

Wireless communication between the agent and the operator's computer presented a recurring timeout issue that caused control signals to not be received properly, resulting in a continual execution of the last correctly received command. The issue presented on multiple wireless networks including competitor's home network as well as the provided MREN303_wifi. It is our assumption that this problem is related to the nature of the UDP transmission protocol used for communication, but there has been no success in attempts of remediation.

V. Acknowledgements

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