Design and Implementation of Building Navigational Tools for the PantherBot Mobile Robot

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ABSTRACT

This paper presents the design and development of tools and a tool changer system that enable the PantherBot to navigate the interior of typical university buildings. The PantherBot is a $MobileRobots^{TM}$ PowerBot mobile robot platform equipped with a laser navigation system and a Schunk 6-DOF robot arm. The tools presented here enable the PantherBot to use its robot arm to open and close doors, operate elevators, and press accessibility buttons to facilitate movement into and throughout a building. One tool serves to rotate door handles and maintain door clearance while the robot passes through, while the second tool allows for the robot to safely press elevator and accessibility buttons. The robot is programmed to autonomously perform these tool operations and access or store the tools as needed.

Keywords

MobileRobot, Autonomous Navigation Tools, MobileRobot Tools.

1. INTRODUCTION

1.1 Project Overview

The team was tasked with the objective of designing tools to assist the autonomous functions of the PantherBot such that it may open doors and press elevator buttons and access panels as necessary to maneuver in and around the F. W. Olin Engineering Complex.

1.2 Project Goals

The team had two main goals to accomplish during the entire design process:

- To operate safely while protecting the PantherBot, its operator(s), and any persons or objects the PantherBot may come in contact with
- To research on appropriate tools for the defined objectives and to adapt to Schunk robotic arm
- To ensure that the process is repeatable
- To have the PantherBot remain positive control of the designed tools

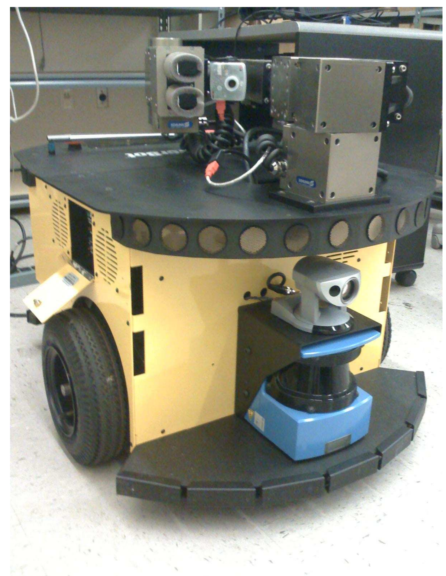

Figure 1: PantherBot with Schunk Robotic Arm

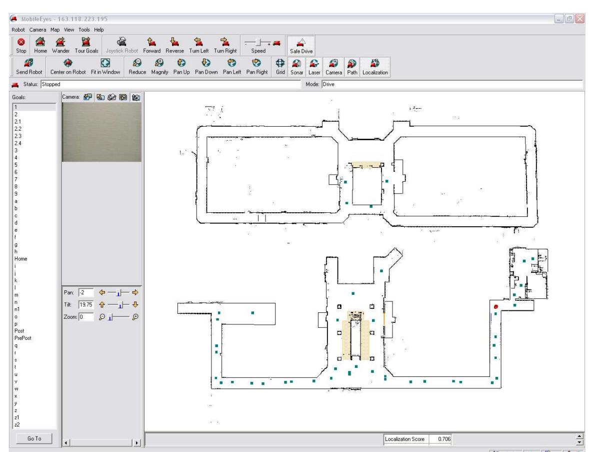

Figure 2: $MobileRobotics, Inc.^{TM}$'s $MobileEyes$ software with Olin Engineering Complex map

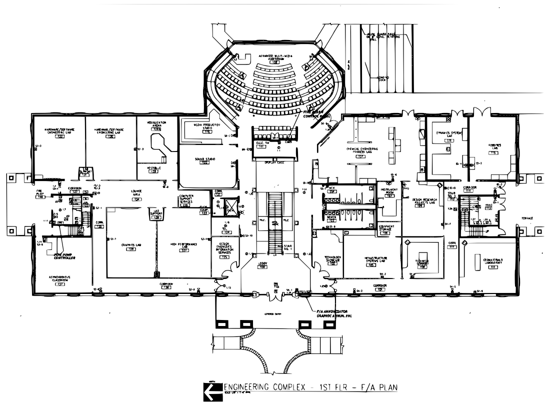

Figure 3: F. W. Olin Engineering Complex floor plan

Figure 4: F. W. Olin Engineering Complex

1.3 Project Background

1.3.1 PantherBot

The PantherBot consists of the PowerBot mobile robot base, manufactured by $MobileRobotics, Inc.^{TM}$[5], and a 6-DOF robotic arm, manufactured by Schunk Intec[2], shown in Figure 1. The PantherBot base has the ability to autonomously map terrain, plot coordinates, as well as performing miscellaneous functions at a certain location after a full map is acquired by using the $MobilEyes^{TM}$[4], shown in Figure 2, and $Mapper3^{TM}$ software [3] in conjunction with its on-board sonar sensors and laser range finder. The software can also stream live footage from the PantherBot's two cameras mounted on board, one on the PantherBot's base, one adjacent to the parallel gripper on the robotic arm to monitor the arm's movements remotely over 802.11b WiFi.

To give the PantherBot the ability to map out to a building, it must be able to gain access to doors and be able to travel between floors. To do that, two tools were designed to perform two basic tasks - one to push buttons and one to open doors. The tools were designed such that they would be tailored to the hardware of the F. W. Olin Engineering Complex at Florida Institute of Technology for ensured repeatability.

1.3.2 F. W. Olin Engineering Complex

F. W. Olin Engineering Complex was established via a grant from the F. W. Olin Foundation in 1997. The three-story building contains several classrooms, a 142-seat multimedia auditorium, and 26 specialized laboratories[7], including the Robotics and Spatial Systems Laboratory.

Figure 3 shows the floor plan of the first floor of Olin Engineering Complex in relation to Figure 2, which shows what the PantherBot maps through its laser range finder and sonar sensors.

2. PRESSING BUTTONS AND PANELS

Handicap access panels, such as those in Figure 8, have become common in many modern buildings, including F. W. Olin Engineering Complex. These are normally placed at entrances and exits to the building which allows PantherBot

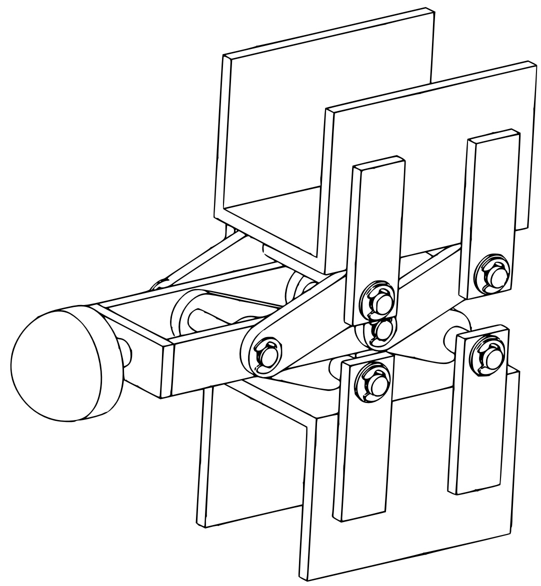

Figure 5: The Prod - used for pressing buttons

access to the building. The elevator in the Olin Engineering Complex allows the PantherBot to travel between floors. The elevator buttons shown in Figure 7 are smaller than the handicap access panels and are grouped close together, so the PantherBot will need to be able to select the correct button and press it while not hitting other buttons[6].

There are several things to consider when designing a mechanism to press buttons:

- Force required to press elevator/handicap buttons
- Motion required for PantherBot to press buttons
- Ways to prevent damage to the buttons being pressed
- Ability to hit desired button and avoid hitting other buttons

2.1 Human Motion

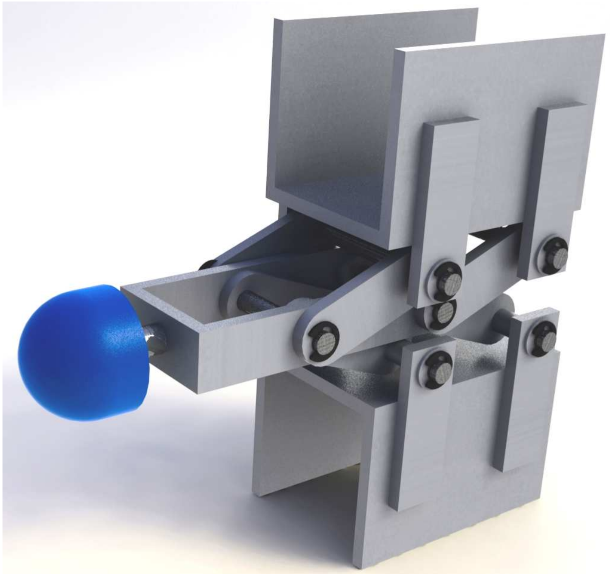

Figure 6: The Prod - used for pressing buttons

Figure 7: Elevator buttons in the F. W. Olin Engineering Complex

The motion to press a button involves extending a human arm such that an extended finger may poke the desired button, causing the button to be activated. Once pressed, the arm may be withdrawn. This simple motion may be translated into a simple mechanism to replicate this motion.

2.2 Design Process of the Prod

The goal of this tool was to convert the motion of the arm's gripper into a safe way to actuate buttons. We looked at several alternatives including a gear system and determined that direct links was the best option for the range of motion we needed. The design started with concept sketching and rough CAD modeling and quickly progressed to computer analysis and physical prototyping. Once the design was found to meet physical requirements and pass initial finite element analysis testing we then returned to the CAD model to optimize the design for production.

Figure 8: Handicap access panels to operate main doors

2.3 Design of the Prod

The Prod's design uses spring supported symmetric four-bar mechanisms to press buttons, shown in Figure 5. The PantherBot is able to make use of its parallel grippers to drive the poking end of the Prod forward, mimicking the motion of a human finger reaching out and pressing a button. Once the button has been pressed, the spring allows for easy retraction of the tool and even deployment of the mechanism. A foam tip minimizes any damage dealt to the button. Once the button has been pressed, the PantherBot can continue its autonomous navigation.

2.3.1 Accuracy and Dependencies

The effectiveness of the tool relies on the PantherBot's ability to correctly identify the button it needs to press and the distance that it is from the button. If the PantherBot is positioned at the wrong distance it may not be able to press the button or possibly damage its operating setting. The lack of sensors installed on the robotic arm that could be used to identify if the button has been pressed means that the on-board camera on the parallel gripper must show the operator successful deployment of the tool.

2.4 Analysis of the Prod

Analysis of our tools was performed using the COSMOSWorks finite element analysis package by DS Solidworks, shown in Figure 9. Forces of actuation were found for both elevator and access buttons using manufacturer's specifications and then applied to contact surface of the analysis model with a 1.5 multiplier. From this analysis it was determined that a solid contact point would easily exceed the breaking point of the push buttons. To prevent this, a foam rubber contact point was added to the tool to help cushion the contact as well as increasing the contact area, which simplifies the machine's approach to the button.

3. OPENING DOORS

In most modern buildings, including the F. W. Olin Engineering Complex, doors are equipped with a door closer. This simplifies the door clearing process, as the PantherBot is only required to open the door and clear the doorway and the door will close itself. There are a total of four ways of opening a door, depending on whether the door needs to be pulled or pushed to open, and whether the door hinges are mounted on the left or right side of the door frame[8].

There are several key points to consider when designing a mechanism to open doors:

- Forces required to open door
- Force tolerances in the Schunk robotic arm
- Size tolerances of the PantherBot when clearing a doorway
- The motion of the Schunk robotic arm needed to open a door

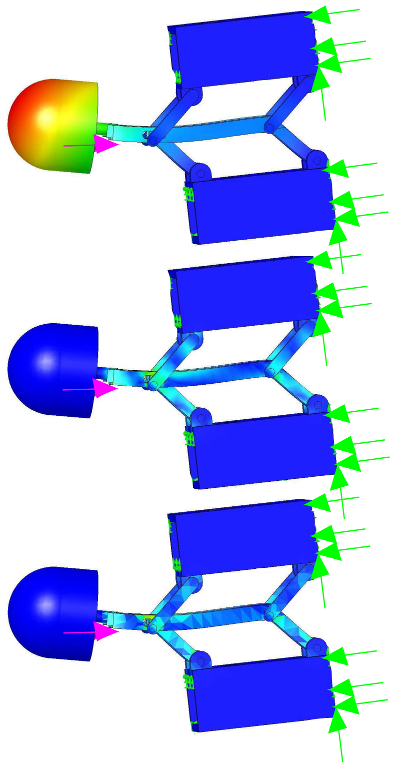

Figure 9: Analysis results on the Prod, showing displacement, stress, and strain results

- Methods to minimize damage to the robot by open opening process as the door closer attempts to close the door on the robot

3.1 Human Motion

The motion required to open a door by a human arm is relatively simple. The hand twists the door knob or door handle, resulting in the unlocking of the door mechanism. Then, the arm pulls back the door and as the door clears enough width for the person to pass through, the hand lets go of the door handle and holds door until the person clears the doorway. Understanding this three-step process, tools were designed to replicate this process, combining as much of the process into one tool as possible to minimize extraneous tools. Eventually the team developed one tool which will perform all three functions.

3.2 Design Process of the Enterprise

This tool was designed to manipulate door handles and hold doors open while the machine transitions through them. This tool started as two independent tools, one for door handle manipulation and one for maintaining door clearance. The design of these tools proceeded to the point of prototyping where we determined that both tools could be combined to simplify manufacturing as well as operation. The new combined tool was then prototyped and after proving functionality and passing computer analysis it moved to production.

3.3 Design of the Enterprise

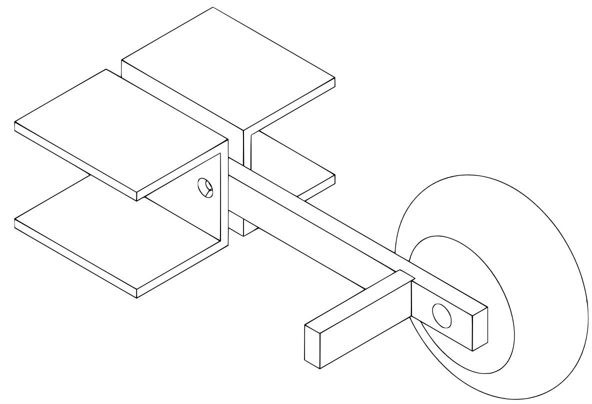

Figure 10: The Enterprise, used to open doors

Figure 10, nicknamed the $Enterprise^{TM}$ [1], shows how the PantherBot would be able to accomplish opening doors. To pull a door open, the T-shape allows the PantherBot to unlock the door handle, then as the PantherBot backs up, the door can be pulled open. Once the door is open, the arm will let go of the door handle and the door closer will spring back against the robot. As this is going on, the arm will reposition itself such that the wheel of the Enterprise, is pressed against the door, clearing the doorway allowing the PantherBot passes through.

To push a door open, the PantherBot utilizes the T-shape of the Enterprise to unlock the door and then will tilt the PantherBot's arm such that the wheel is pressed against the door. As the robotic arm opens the door the arm on the PantherBot will lift off of the door handle and reposition itself so that the wheel is pressed against the door, but not locked in place by the door handle. The wheel provides a continuous contact point for the PantherBot so it can clear the doorway. Once the PantherBot has cleared the doorway, its autonomous navigation may resume.

3.3.1 *Accuracy and Dependencies*

The tool's ability to achieve the goal of opening the door and clearing the doorway will depend on the accuracy of the entry angle of the robot relative to the door. If the PantherBot approaches the door at an angle which the robotic arm will have inadequate space to maneuver, there may be a possibility that the arm could crash into the door. Since sensor arrays are not built into the robotic arm, it is not currently possible to prevent this from occurring except close monitoring of the PantherBot's movements.

3.4 Analysis of the Enterprise

Due to the design history and evolution of this tool, analysis was performed first on the two independent tools and then on the final combined design. To properly test this tool analysis was performed for both of its functions with loads set at 1.5 times the measured forces of average building door handles and automatic door closing devices. The tool was found to successfully pass this analysis, shown in Figure 12.

[1] $U.S.S.Enterprise^{TM}$ is a registered trademark of Paramount Pictures Corporation.

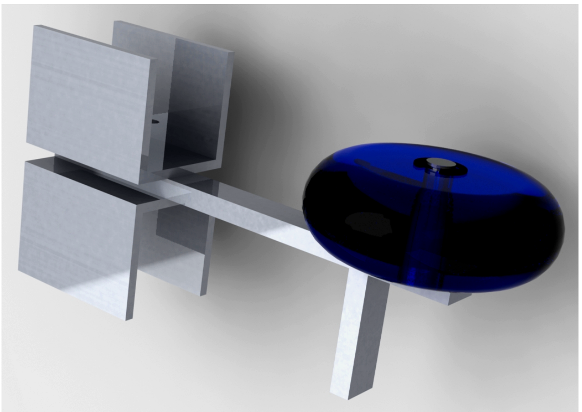

Figure 11: The Enterprise, used to open doors

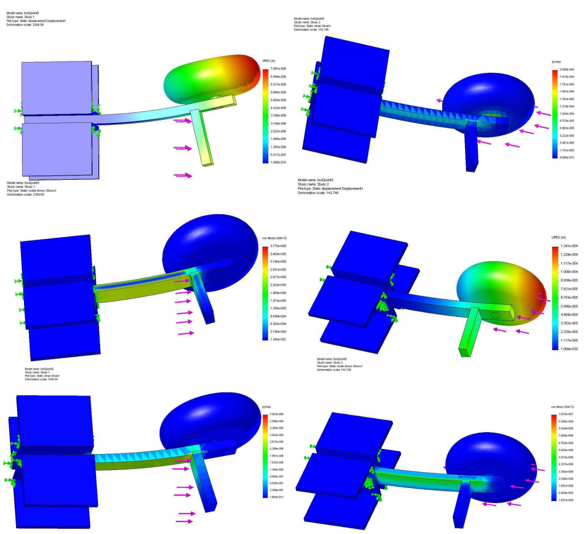

Figure 12: Analysis results on the Enterprise, the left column shows displacement, stress, and strain while opening the door, and the right column showing the respective data when clearing the doorway.

4. SAFETY CONSIDERATIONS

Keeping in mind that the PantherBot should be able to operate and change tools autonomously, it is still necessary to have safety features in place in case PantherBot or its robotic arm malfunctions or operates outside of its intended parameters. There are two emergency stop buttons near the rear of the PantherBot base which will stop all robot functions, including the robotic arm. Bumpers located in front and rear of the PantherBot also serves as collision sensors and will serve as emergency stops as the PantherBot navigates. The sonar sensors and laser range finder on the PantherBot also serves as a safety device to help avoid obstacles and to properly plot alternative routes to the prescribed destination. These safety features help keep PantherBot safe from its surroundings[1].

5. APPLICATIONS AND FUTURE WORK

This project's scope can be applied in many assistive technologies today. Adapting a similar technique on a wheelchair, motorized scooter, or on a mechanical prosthesis may significantly improve the quality of life of an individual. A similar method may also be applied towards future projects where other mobile robots may be employed to perform similar functions, utilizing autonomously mapping terrain and open doors and access areas of a building otherwise inaccessible without passing through closed corridors.

There are several key issues to improve upon in the future, which include the robotic arm, software integration, and the addition of autonomous recognition of appropriate buttons, panels, and door handles. The robotic arm should be improved upon such that there are more safety features, including addition of sensors, limit switches, and/or replacing the 2-D laser range finder with a 3-D laser range finder in conjunction with PantherBot automatically calculating the total height of the robotic arm and the PantherBot base[1]. Software could also be developed to trip a resistance switch if the arm does hit a wall, door, or gets stuck in a certain position. Since the PantherBot and the Schunk robotic arm were developed separately, execution of arm commands cannot be seemlessly integrated into the *MobileEyes* software. Future software development using the ARIA library could improve ease of development in manipulating the PantherBot to expand on its directives in addition to opening doors and pressing buttons. Development in computer vision and autonomous recognition of basic known objects, such as handicap access panels, elevator buttons, doors, doorways and door handles could help the PantherBot automatically adjust the approach angle of the robotic arm or the PantherBot base itself to avoid collision, harm to its operating environment, or itself.

6. CONCLUSIONS

We have completed the task of designing and implementing a tool changer for the PantherBot such that it may open doors, as well as press buttons and access panels in the F. W. Olin Engineering Complex. The Prod was created with an objective of pressing buttons by utilizing the PantherBot's parallel gripper on its robotic arm for input. The Enterprise was created with objective of opening doors by fully utilizing the PantherBot and its robotic arm. As a result, the team was able to successfully give the PantherBot the means of autonomously navigating into additional sections of the F. W. Olin Engineering Complex.

7. ACKNOWLEDGMENTS

The PantherBot Tool Changer team would like to thank the Florida Institute of Technology College of Engineering for funding the project, DrẎoungsik Choi for instructing the Mechanical Design course, and DrṖierre Larochelle for approving and facilitating this design project at the Robotics and Spatial Systems Laboratory. Specifications of the PantherBot courtesy MobileRobotics, Inc. and Schunk Intec, Inc. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of these two companies.

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