Friday, March 27, 2015

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To Professor Bill Owen,

We, Group 8 (Benjamin Eckert, Ye Guan, Mathew Mendelsohn, Dan Prodan & Ben Vander Schaaf), are submitting the report entitled "Autonomous Retrieval Robot For Search And Rescue Final Report" for the MTE380 - Mechatronics Engineering Design Workshop Report #3 Final Report.

This report will outline the implementation and results of Group 8's selected conceptual design. This will include details from a Mechanical, Electrical and Controls standpoint relating to construction, testing and modifications. The final competition results and recommendations will be included as well as the final budget.

"We are the sole authors of this report and, unless otherwise stated and properly referenced in the report, the entire content of this report is original work done by us. We have all read the report and are aware of the content. The content of this report has not received credit in this or any other course that we have taken in the past or are currently taking at this time."

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Autonomous Retrieval Robot for Search and Rescue Final Report

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Executive Summary

This project aims to build an autonomous search and rescue robot. The robot navigates over a mountain range to pick up a person and return them to a base. The mountain range is represented by a plywood wall, and the person is represented by a Lego minifigure. The implemented design is the Climbing Bull from the "Autonomous Retrieval Robot for Search and Rescue Detailed Design" report and modifications from two formal design change requests.

The final design of the robot utilizes bump sensors, IR sensors, an accelerometer and a LIDAR to obtain information about its environment. It navigates with two rear rubber wheels for locomotion and two 2-degree-of-freedom arms which are used to perform accurate turns, tackle base edges and traverse the ramp. An arm with a sticky mouse trap is used to collect the Lego minifigure.

Component failures led to design modifications which set the project over budget and behind schedule due to the lead time of attaining additional sensors and designing around broken sensors. However, a final working design was completed by the project deadline. The project concluded with a cost of $415.77, exceeding the initial budget of $225 and auxiliary budget of $100 by $90.77, largely due to the cost of the high quality LIDAR sensor.

The robot is able to meet most objectives outlined in this report. The robot meets the goal for mass, weighing in at 1.3 [kg]. It can collect at least a 20 [g] target, identify the base 95 [%] or more of the time, climb the 45 [degree] ramp and fit within the 0.6 [m] cube. The robot does not meet the objectives for budget as outlined above, and does not return within the performance time of under two [minutes]. The final design performed in 4 [minutes] and 40 [seconds]. Overall, this design is considered successful by the group because it is able to accomplish all tasks with minimal interaction during testing.

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Introduction

General Background

Search and rescue teams are responsible for the safe recovery of individuals in need of assistance in remote locations. Adventurous individuals who explore the wilderness sometimes get lost or sick in places where no help is available. The delay between a person needing help and alerting the authorities can be critical to returning to safety; the longer the delay is, the further the person could have travelled. Large areas need to be searched quickly to identify a human amidst the terrain. It can be very difficult to identify people in the middle of dense foliage, tall canyons or around other obstacles. Once a person is found, help is provided to them and they are returned to safety.

It is no surprise that machines can assist humans in this context. An autonomous search and rescue robot can be designed to assist with these tasks, providing more manpower to critical needs such as medical assistance. Smart algorithms can process a lot of data from sensors on the robot, spotting humans and points of interest very quickly. The robot can be built to travel across the terrain faster than humans are able. These robots may not replace human workers in the search and rescue field, but instead act as valuable tools that can save lives and provide aid faster than ever before.

This project is designed to emulate an autonomous robot retrieving an individual in need of help. A robot controlled by an Arduino microcontroller starts from a home base and sets out to recover the target individual, a Lego minifigure. A vertical wall blocks the path to the Lego target, creating an obstacle that must be traversed. The centre of the wall has a sheet of steel, and the end of the wall has a 45 [degree] ramp to use to drive over. Once the robot is on the other side of the obstacle, it will retrieve the target Lego man from the base at an uncertain location, return to the starting side and carry it safely back onto the home base.

Improving the system used by search and rescue personnel can speed up target recovery time and save human resources for other tasks. A robotic system may be more capable and cheaper to use to identify or rescue a lost person. Smart investments in this field helps to innovate the technologies used to save lives. Incorporating robotics to assist with these tasks is an integral part in developing new methods to tackle search and rescue missions.

Needs Assessment

The Lego minifigure is stranded at an unknown location and obstructed by a wall. A method is required to traverse this obstacle, and locate, collect, and return the Lego target to its home base.

Problem Formulation

Problem Statement

Design an autonomous system that is able to identify the target integrated with a mechanical design capable of traversing the obstacle, collecting the target and returning it to the home base.

Objectives

The performance value of this craft depends on weight, so minimizing this value will increase performance. The ideal weight for the robot will be stated as 7 [kg] or lower which is an ideal carrying weight of the robot. Most people are able to lift up to 7 [kg] with ease. Additionally, a short retrieval time increases the performance index. The robot should be able to return the Lego target within 2 [minutes] to ensure a good performance index while providing enough time for the robot to travel. The size of the course and the anticipated speed of the motors driving the robot lead to an estimated retrieval time of 2 [minutes]. Also, even once fully autonomous, the robot can make mistakes identifying objects. These mistakes take time and therefore affect performance. Target identification errors should occur fewer than 5 [%] of the time. Finally, the project budget promotes a frugal design; the design should fit within the allotted budget, costing less than $225 to construct.

Constraints

The project outlines some key constraints with regards to the design of the robot. As per project design criteria, the size of the robot is not to exceed the dimensions of a 0.6 [m] x 0.6 [m] x 0.6 [m] box. Additionally, the approach that the robot will use to travel must be able to traverse over a 1 [m] tall obstacle or be able to climb a 45 [degree] wooden ramp. The design will be rejected if it is unable to return the target Lego man to the home base. When in operation, the robot will operate completely autonomously and will not require interaction to receive instructions.

A Lego minifigure does not weigh much, only about 2 [g]. The device used by the robot should be strong enough to lift the target with a factor of safety. The minimum weight the device should lift is 20 [g], 10 times heavier than the target.

Design Selection Criteria

The design is chosen by comparing it to the defined objectives and constraints of the project. The weight [kg] of the design will be considered as a major factor favouring lighter solutions. Designs will be compared by estimating reliability [%] of target identification sensors and target collection devices. Algorithms will be selected based on how likely [%] they are to make identification errors from sensor data. The cost of parts [$] will also be a determining factor in design selection. Cheaper parts and expenses fit the budget more appropriately.

Rejected designs violate project constraints. These design either does not fit the constraint size of a 60 [cm] box, or cannot perform as expected. This may include not traversing the obstacle or climbing the ramp, not operating autonomously, or not lifting a minimum of 20 [g]. Rejected designs are not considered unless they can be altered to not violate constraints.

Deliverables

The first report for this project has been submitted February 2nd, 2015 and construction check one took place on February 4th, 2015. Other completed deliverables include the design report, submitted March 2, 2015, Construction Check 2 on March 6th, 2015 and the presentation March 13th, 2015. The final competition was completed on March 20th, 2015. The current deliverable is the final report, report 3, due on March 27th, 2015.

Design Overview

An overview of the system consists of a robotic vehicle that navigates from the home base to the piping adjacent to the ramp. At this time the robot rotates and mounts the ramp. The ramp is scaled using various methods to conquer the numerous challenges it presents. On the other side of the wall, the robot travels parallel to the piping while scanning the arena perpendicular to the direction of travel. Once the away base is detected, the robot travels directly towards it and retrieves the figurine. Following this the robot navigates back to the ramp, scale the ramp and return back to the home base with the rescued figure.

This system is implemented with a two-wheel, rear-wheel drive robotic car that is previously described in the report titled “Autonomous Retrieval Robot for Search and Rescue Detailed Design”. This car is designed in order to scale the 45 [degree] ramp to make it to the other side of the wall and perform the search and rescue operation. The wheels are driven by modified servos that provide continuous motion and the capability for differential steering. The chassis is built using two aluminium plates. Modifications to the initial design include two 2-degree-of-freedom mechanical servo controlled arms with rubber wheels on the end. These arms assists in ramp scaling and turning and allow for the robot to transform into a four wheel design which can assist in forward movements.

Additionally, the robot is equipped with a front facing bump sensor, two downwards facing IR sensors, a combination compass and accelerometer and a side facing LIDAR. This array of sensors allows the robot to properly interact and navigate through its environments, detect obstacles and key locations and perform the search and rescue operation.

The pickup mechanisms for claiming the Lego figure is a sticky mouse/insect trap mounted on a servo controlled arm. The figurine remains stuck to the trap during the return trip to the home base.

This design is selected to achieve all constraints and objectives set out in this search and rescue operation.

Design Implementation

Mechanical

Modifications

The major modification made to the robot is the addition of two top mounted clamping arms, each with two degrees-of-freedom, shown in Figure 1. These arms are added because during testing it is discovered that the drive wheels alone cannot provide enough friction for the robot to climb the ramp. This is due to both an overestimation of the amount of traction the wheels can provide and an under estimation of the steepness of the ramp. The additional clamping arms provide a way for the robot to increase friction by clamping to the underside of the ramp pushing against the drive wheels, effectively pinching the robot in place on the ramp, as shown in Figure 2.

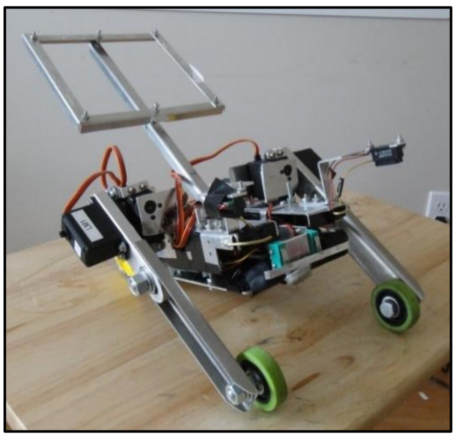

Figure 1: Two clamp arms each with two degree of freedom

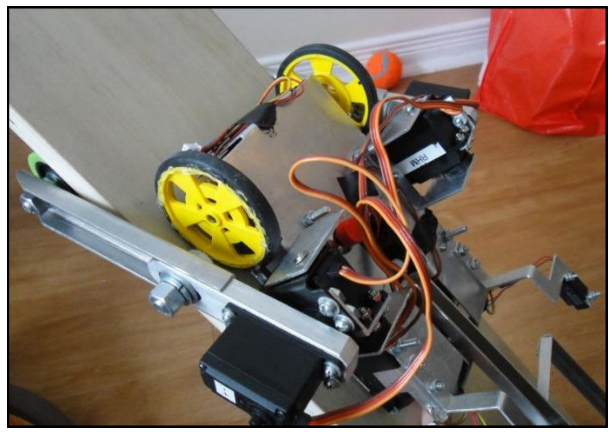

Figure 2: Clamping to the ramp

Another modification is the bumper system. The original plan calls for two bumpers that are spaced one above the other. The position of the bottom bump sensor allows it to be pressed by the ¾ inch base. In contrast, the design for the top bump sensor ensures that only the boundary pipes and walls can trigger it. This provides more situational awareness for the robot. In practice, the two individual bump sensors are difficult to build so that they perform as desired. Thus, the upper bumper is removed and the robot relies on more careful path planning and IR assistance to determine the appropriate reaction to each bump.

Construction

The construction of robot is done in three separate stages. The first stage builds the chassis and drive system. The overarching principle during the first stage is to reduce the number of parts in the design. Therefore the chassis mainly consists of two pieces of sheet aluminum. The second stage is the implementation of the sensors and capturing mechanism. Some compromises and adjustments are made to provide more space for wiring and assembly flexibility. The third stage is necessary due to inadequacies in the original design that occur during testing, such as the need to add clamping arms. The third stage is the most challenging because the original design tries to minimize space, thus making the task of adding additional features increasingly difficult.

The clamping arms are cannibalized from another robot designed for bipedal motion. The hip portion of the bipedal robot is removed and added to the top of ramp climbing robot to act as the clamping arms, shown in Figure 3. This significantly reduces the amount of work required to manufacture the clamping arms from scratch.

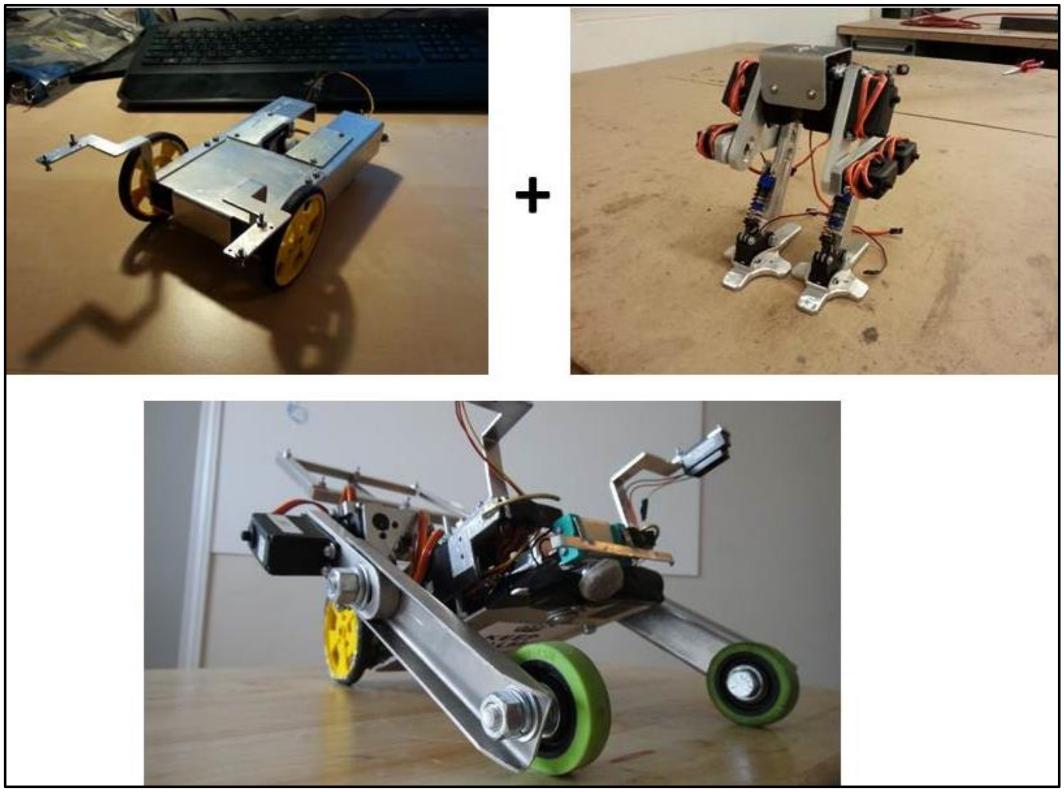

Figure 3: The merging of two robots

Results vs. Expectations

Testing shows the clamping arms perform beyond all expectations. The amount of versatility and flexibility two independent clamping arms provide was critical to the overall success of the design. In addition to providing extra normal force on the ramp, the clamping arms also serve as; the front wheels, the turning mechanisms and a means to align the robot on the ramp.

Electrical

Construction

The electrical construction process is fairly straight forward. The signal processing board for the custom LIDAR is the first item built. A part layout is done on grid paper by hand, and then the prototyping board is cut to size and the parts are mounted and soldered to it.

The second subsystem built is the power distribution. Approximate locations on the chassis are marked out for the battery and voltage regulator while the servos and off switch are installed onto the chassis. The battery cell tap for charging is cut and re-spliced with a longer wire which is necessary to reach the charger. The battery barrel jack is cut off and the leads are connected to the power switch and the voltage regulator. Another power line is attached to the Arduino so it can draw power directly from the battery. This Arduino feed line is left longer so that the bottom half of the chassis (onto which the Arduino is mounted) may be separated from the top half (where the battery and power regulator reside) with enough slack so that the robot may be worked on. Lastly, the standard connectors from the servos are removed and the three wires are separated. The power wires are cut to length, with little slack as these servos and the power regulator both reside on the top half of the chassis. After all of the wires are soldered and heatshrunk to the power regulator, the power regulator itself is attached to the chassis using high strength double sided tape.

The next part of the electrical system to be attached is the control wiring. The remaining servo wires, which are for the PWM input, are cut with a similar amount of slack to the power cable and soldered to header pins which can be inserted and removed from the Arduino. The sensors are also wired in at this stage as they all draw power from the Arduino on-board power regulator. The IR sensors are wired to analog pins, the accelerometer/compass package is wired to the I2C bus and the bump sensors are wired to general IO pins.

Lastly, upon assembling to upper and lower half of the chassis, a thin screwdriver is used to move the wires around the available space to avoid damaging the insulation with pins or by being pinched when the bolts are tightened. Electrical tape is applied to all metal edges that come in contact with wires.

Testing

LIDAR testing is done separate from the main robot, as this is a high risk item. Using an oscilloscope, the comparison potentiometer is adjusted on the fan signal conditioning circuit until a clean square wave is achieved on the output. The potentiometer can be seen circled in Figure 4. This part of the circuit works as expected and tuning takes little time.

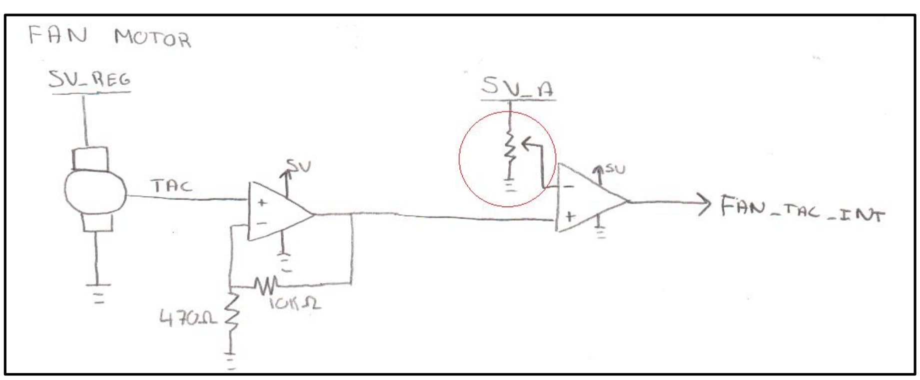

Figure 4: Fan signal conditioning circuit

The next phase of LIDAR testing is to adjust the comparison potentiometer on the photodiode signal conditioning circuit. The comparison potentiometer can be seen circled in Figure 5. Despite being bottomed out, no signal can be detected. Measurements taken at point A in Figure 5 shows a voltage level of about 43 [mV] when the photodiode is exposed to ambient light. The feedback resistor in the amplifier is increased to 20 [MΩ], effectively increasing the amplification by 20x. This increase provides a signal of about 1.45 [V] in ambient light, which is an adequate level. The comparison potentiometer is adjusted until the interrupt signal goes low in ambient light. The laser diode and mirror motor are turned on and a target is placed close to the LIDAR. An interrupt signal on the output can only be generated at a distance of less than 80 [cm] under ideal conditions, such as a dark room. In bright sunlight, it is difficult to consistently generate an interrupt, even at close distances. Examining the location of the laser on the target as it moves further away reveals that its alignment is incorrect, causing it to drift from where the photodiode points. The sensitivity issues and the alignment problems are deemed too difficult to solve in a timely manner and the custom LIDAR is abandoned in favor of an off-the-shelf solution.

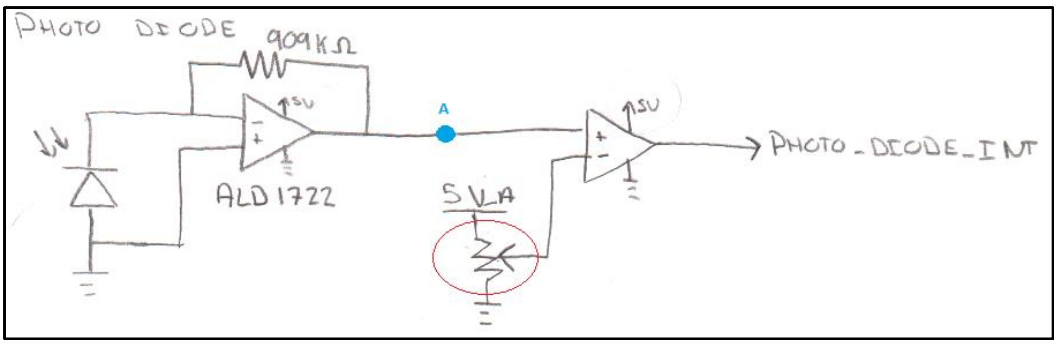

Figure 5: Photodiode conditioning circuit

The power and servo system is tested next. While monitoring the voltage regulator output, the power is turned on. The arm servo snaps to a default position and there is no voltage drop on the output of the voltage regulator, indicating there is no serious short circuits. The voltage of the battery is checked next, and again no significant voltage drop is observed. The servo control lines are tested next, with the software team writing code to cycle each servo slightly off center. Each servo moves in turn, and each are attached to their expected pin on the Arduino. The battery life is difficult to test accurately due to varying runs done during software testing, however on average it lasts over 4 hours, significantly greater than the initial goal by a factor of 12.

The last parts to be tested are the sensors. Bump sensor input is tested by pressing the bump sensor and checking that the Arduino software receives the signal. The IR sensors are tested by moving a paper target in front of them. The IRs are found to be slightly inaccurate and highly dependent on ambient light, but are deemed adequate for detecting sudden, large changes such as those seen when a sensor peaks over the edge of the ramp or over the crest of the ramp. Communication over the I2C bus works without errors and data from both the compass and the accelerometers is received.

Modifications

The first major modification required is the use of an off-the-shelf LIDAR instead of a custom built solution. The LIDAR Lite is the only product encountered within the budget of this project. Wiring consists of a power and ground line, which are connected to the Arduino on-board voltage regulator, and a PWM input signal. The LIDAR mounting bracket angle is adjusted after it is wired to the Arduino. This is done by setting up the LIDAR at a 3 [m] distance from a wall with the aim being set too low. The angle is adjusted upwards little by little while the LIDAR is moved back and forth. When the distance measurement changes, the correct angle has been reached whereby the LIDAR points at the bottom of the wall.

The second major modification is the addition of arm servos. These are directly wired into the voltage regulator and Arduino PWM pins in an identical fashion to the drive and arm servos. The main concern with this modification is the current draw on the voltage regulator. Due to the need to use the robot in software development, the exact current draw is not tested. Instead, the previous voltage drop test is done. Additionally, although the voltage regulator does not have a specified max temperature, it is known that the temperature of MOSFET silicon junctions should not exceed 150 [°C] [1]. It is difficult to get an accurate temperature measurement of the tucked-in voltage regulator, but a ballpark indicator is that it should never feel hot to the touch. During all of the early software testing runs, regular touch tests ensure that the voltage regulator runs safely.

Results vs. Expectations

The custom LIDAR actual performance is nowhere near good enough to be able to reach the 95 [%] detection rate objective. Once properly tuned, the LIDAR Lite is able to detect the base with a 100% success rate after a 12 run sample.

The final product is able to beat the 20 [min] runtime between battery charges objective by a 12-fold margin. This is due to the battery capacity being almost twice the original calculated value, and that calculation being based off a conservative power draw estimate, and continuous maximum draw assumption.

Control

The first code for the control system is made with the original Climbing Bull electromechanical design in mind. This original design incorporates a differential drive, two infrared sensors, a front bump sensor, a tilt-compensated compass and a LIDAR distance scanner. This concept is developed prior to the completion of the electrical and mechanical components. The first draft of the code assumes that everything about the initial mechanical and electrical design works perfectly.

The first draft of the code consists of several modular sections that can be tested independently. The beginning of the code execution consists of driving parallel to the wall until the bump sensor hit the boundary. The robot then uses the compass to turn until it is aimed at the ramp and then moves forward. It stops moving forward when the accelerometer measures a 45 [degree] angle, indicating that that robot is on the ramp. It is then that the ramp driving section of the code executes. The first draft of code drives the robot forward up the ramp, adjusting as required to remain on the ramp. It senses the sides of the ramp through the use of its infrared sensors which measure distance to the floor on either side of the robot. When the accelerometer detects that the robot reaches flat ground, the robot uses its LIDAR sensor to make a sweeping scan for the target base. When the base is found, the robot heads straight in the direction of the target base until the bottom front bump sensor is hit. This is when the capture mechanism is deployed in the first draft of the code. Following this, the robot returns to the home base by the same ramp climbing method it uses to get to the target base.

It is not possible to completely test this code until the completion of electrical and mechanical prototyping phases. Testing of the first draft of code occurs after the completion of the initial prototype. Testing reveals that the robot is unable to traverse the steep inclined ramp with the current design due to a lack of traction. Resolving this issue with the addition of double-sided tape provides unreliable results because the stickiness of the tape degrades as dirt collects from the dirty floor. This is a mechanical issue requiring a mechanical redesign which results in a heavily modified control system. The robot cannot climb the ramp with the initial idea of driving up the ramp.

The next major revision is shown in the second stage of development incorporating arms onto the robot to assist with ramp climbing. The arms add a total of four servos to the robot. There are two actuators on each arm. One actuator is a hinge that attaches the arm to the robot and the other actuator on each arm swings the arms of the robot. Together, these arms grip the underside of the ramp in order to provide enough traction to drive up the ramp. The initial phases of the design do not use the arms for any additional purposes aside from climbing the ramp.

A change to the electromechanical design affects many aspects of the control software. Modifications to the initial design includes a change of location for the LIDAR sensor, moving from the front to the left side of the robot. Also, the LIDAR no longer uses a swivel arm to perform a sweep of the course and instead mounts directly to the robot chassis. This is done to simplify the construction of the robot to reduce the amount of servo motors and to simplify the controls aspect of the software design. This component modification changes the searching algorithm. The algorithm does not scan and travel directly to the base in a straight line. Instead, it performs a perimeter search to detect close objects. The robot travels along the edge of the wall after exiting the ramp until it detects the base or it hits the front bump sensor. This indicates a wall is in front of the robot, so it will rotate to follow the wall and continue its perimeter search. This repeats until the LIDAR reports an object is within a tolerance distance.

The tolerance distance is set to account for the dimensions of the course, the base and the robot.

Testing this new search pattern and method of climbing the ramp over the wall proves the new algorithms successfully accomplish their challenges. However the addition of the clamping arms introduce a new control problem; the protruding arms interfere with the navigation of the robot as it approaches and travels next to objects such as the walls of the course. The original control design does not account for this issue and requires modification in sections to accommodate this protrusion. Aligning with the ramp requires pressing against the boundaries and the arms prevent this. Resolving this issue requires utilizing the arms to align the robot with the ramp once it is close to the ramp. The arms also provide a means to climb the ramp by lifting the robot into a vertical position when mounting the ramp to increase friction on the high grip wheels. The robot then transitions into a forward position to traverse over the apex of the ramp using the arms to remain attached to the ramp. These climbing modes are illustrated in Figure 6 and Figure 7 below.

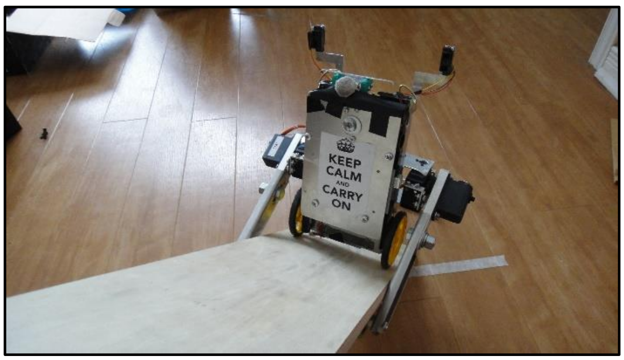

Figure 6: Segway climbing mode

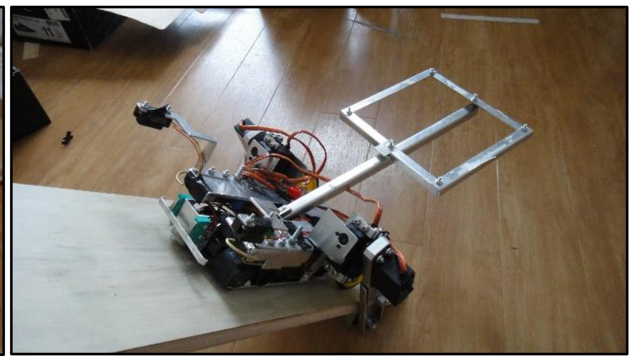

Figure 7: Forward climbing mode

A last minute failure of the tilt-compensated compass on the day before the competition results in a revision to the controls of the robot. As the robot crests the top of the ramp, it lands on the opposite site of the ramp with a noticeable impact. This is thought to be the cause of the tilt-compensated compass breaking. The initial control system for the robot uses the compass to be able to turn accurately in different directions. The driving motors do not have encoders attached to be able to detect how much the robot it turning. Without the compass providing an external heading, the turning of the robot with this control system is very inaccurate. The dirt buildup on the wheels causes dead reckoning to be very inaccurate because the same timing results in different amounts of rotation on different runs. Previous testing shows the robot successfully navigating the course, however the failure of the compass results in an improvised control solution the night prior to the competition. The lead time that is required to attain a new replacement compass in this short time is not feasible.

The final control system uses the arms of the robot in order to dead reckon all of the turns. The arms are used to push off of the ground to orientate the robot to the desired direction. Some of the turning maneuvers involve grabbing onto the boundary and others involve moving the robot in a series of smaller steps. Testing shows that this technique works better than initial expectations indicate. This is not a planned change in controls, which is the reason the members of the team initially do not give this solution a high chance of success. The robot manages to complete all stages of the course with the new turning control scheme.

This new turning method has the unfortunate side effect of greatly damaging the wheels. Excessive testing of this technique causes rapid wear on the wheels, resulting in requiring replacement wheels on the morning of the competition. These new wheels cause slightly different turning angles due to different levels of wear. This results in uncalibrated controls without adequate testing before the competition, causing the robot to perform poorer in the competition than in previous tests. However, the robot does manage to perform all of the tasks with minimal assistance, so the last minute changes are considered a success.

Budget

Due to modifications to the initial design the project exceeds the initially outlined budget of $225.00. The auxiliary budget of $100.00 is also depleted. The final cost which includes designing, prototyping and construction is $415.77, which then requires a contribution of $63.15 per group member.

A spending breakdown for each department shows the mechanical department spending $51.59, the electrical department spending $364.18 and the software department spending $0.00. In correspondence with the original budget, the mechanical is under their $67.50 (30%) budget by $15.91 and the electrical is over its $157.50 (70%) budget by $206.68. This is shown in the following figures, Figure 8: Departmental spending and Figure 9: Money spent vs. allocated budget. Together the figures illustrate that the bulk of the spending is in the electrical department and the significant amount the electrical spending exceeds the allocated budget.

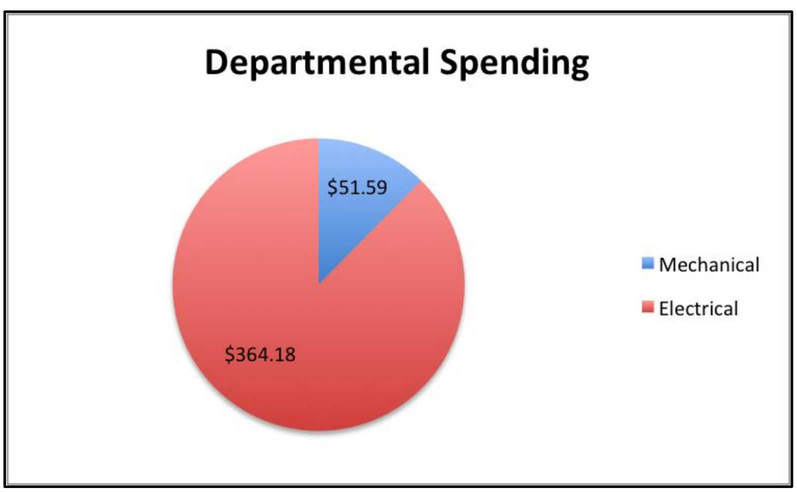

Figure 8: Departmental spending

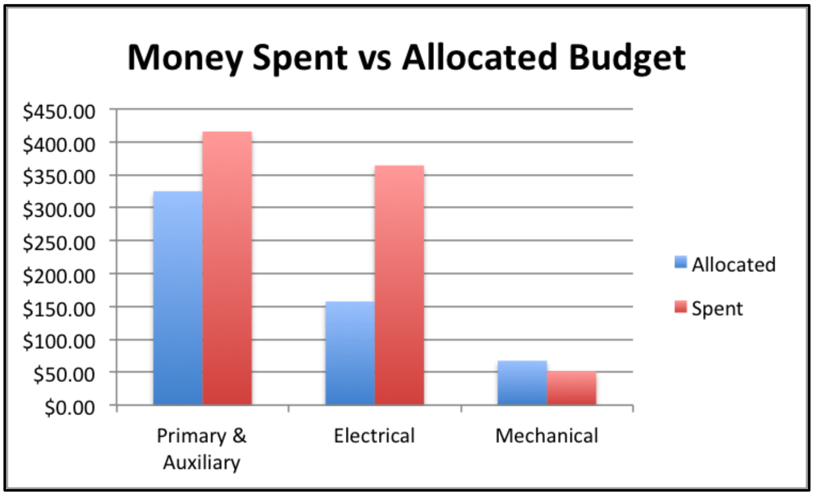

Figure 9: Money spent vs. allocated budget

The bulk of the overage is due to the design modification that consists of replacing the home-built LIDAR with the LIDAR Lite designed by Pulsed Light. This is a necessary change due to difficulties with the accuracy and range of the home built sensor. The LIDAR Lite is a high accuracy, long distance sensor which satisfies the requirements of the application and control system. This concern is noted in the original budget consideration leading to the creation of the auxiliary budget which is able to absorb the cost of the LIDAR Lite. Unfortunately, express shipping is required to counter the delays in electrical prototyping so that the sensor is received in time for the competition. Additionally, stock issues with the Canadian supplier requires an American supplier to be used, thus higher costs are inherited due to exchange rate, shipping and duties. These issues lead to this purchase costing roughly $200, which is $100 more that the anticipated costs.

Other major design modifications including the arms attached to the side of the robot have minimal effects on the budget due to the costly materials being already on hand. If this was not the case, the addition of the arms would be a costly design change due to using four high torque metal gear servos. From a budget perspective, this would not be a feasible modification and design change.

A full breakdown of spending by supplier can be found in Appendix A. This consists of all of the materials that are purchased to create this robotic vehicle.

Schedule

The original set schedule that is designed to ensure the timely completion of this project is documented in the Gantt charts in Appendix B. Some elements of the timeline are delayed due to the multiple design changes and modifications, along with equipment failures which affected the timely completion of this project.

Even though some of the changes require minimal monetary support, they require a significant amount of time for designing and constructing. Modifications, such as the arms, require new

CAD models to be created. Then, the robot needs to be taken apart and the electronics removed so that the arms can be attached. Following this, everything needs to be put back together and re-tested with a newly developed control system. This is a multi-day endeavour and limits the amount of time the controls team has to test, debug and develop with the robot.

Additionally, hardware failures such as the LSM303D Compass and Accelerometer module late in the development stage forces the redesign of the control system. This is time that should be spent doing final testing and polishing of the complete system rather than redeveloping navigation algorithms.

Overall these issues, accompanied by procurement delays earlier in the process, lead to the conclusion that time can be better allocated earlier on and an improved schedule could be created. It is important to note that despite various issues, all key milestones and deliverables are met and a final working model is delivered.

Design Results

The design results are based on the objectives and criteria discussed in the second report entitled “Autonomous Retrieval Robot for Search and Rescue Detailed Design”. The original performance index is shown in Equation 1 below.

$$PI = \frac{F_f V^2}{m}$$

Equation 1: Performance index

The objective mass of the robot is 7 [kg] or less. The final design of the robot weighs in at 1.331 [kg]. This means that the robot accomplishes the mass objective. The target objective time is 2 [minutes]. The final run time for the robot during the competition as recorded by a group member is 4 [minutes] and 40 [seconds]. This means that the robot does not achieve the time objective. This is largely the result of the last minute changes to the turning algorithms of the robot. The new method of using the servos on the arms to turn requires additional time that is not factored into the objective at the time of the second report. Another objective given for the robot is identifying the target base correctly at least 95 [%] of the time. This objective is achieved due to accuracy of the LIDAR scanner. A final objective given is to have a frugal design that comes in under the budget of $225. This objective cannot be achieved because expenses, primarily from the LIDAR, cause the project to go over the allocated budget.

There are some key constraints that the device has to follow. One of these constraints is that the robot is no larger than a 0.6 [m] x 0.6 [m] x 0.6 [m] cube. The Climbing Bull robot easily fits within these dimensions. The robot is able to climb the 45 [degree] ramp and return the Lego man to the home base. When in operation, the robot is autonomous and does not require interaction to give additional instructions. The Lego figurine does not weigh a large amount so the capture mechanism easily fills the constraint of being able to lift a 20 [g] target.

The final design of the robot can traverse individual sections of the course autonomously. However, the competition run of the robot fails to fully navigate the course without assistance in the form of turning the robot in the right direction at a couple of points. This results in mixed successes for the robot. Overall, the group considers this design successful because it accomplishes the goals of the project in testing, even with only partial success in the final run.

Conclusions and Recommendations

In conclusion, this project successfully integrates all aspects of the project design cycle. Throughout the development of an autonomous search and rescue robot, aspects such as component selection, cross-discipline integration, design and troubleshooting techniques are explored. These techniques will assist with future projects and develop the skills of all group members.

Over the course of this project, several important lessons are discovered. This project effectively teaches the rapid prototyping development cycle. There is limited testing time after the completion of the electrical and mechanical parts. Not having enough time to properly test the system outlines the importance of properly designing and following a schedule. Another lesson taught by this project is the importance of having spare parts in case of an emergency. The value of having replacement parts is discovered as sensors fail and improvised solutions require additional adjustments to the controls with minimal time. The reduction in overall performance is due to the loss of these sensors, outlining their importance in the successful performance of the robot. Once a sensor has been tested and approved for use, it is concluded that attaining additional backup components for high priority sensors will greatly reduce troubleshooting issues.

The selected design, while not cost effective, is able to successfully retrieve the Lego target with moderate success. Additional iterations to this design may help to improve the consistency of its performance.

The self-built sensor proved to be a bad idea due to the failure of its sensing abilities and the cost of additional man-hours required to construct it. The ambitious approach proved to take too much effort to complete within the allotted time. Constructing custom sensors without precise high-quality equipment is not a good idea.

Future teams would benefit from frontloading as many aspects of the project as possible to provide as much time as needed to test and redesign the robot. Testing early and often leads to a more consistent performance.

References

[1] Dr. Reinhold Bayerer, ‘Higher Junction Temperature in Power Modules – a demand from hybrid cars, a potential for the next step increase in power density for various Variable Speed Drives’, [Online]. Available: https://www.infineon.com/dgdl/Infineon-PCIM_2008_Higher_Junction_Temperature-ED-v1.0-en.pdf?fileId=db3a30431a5c32f2011a5de9861700a3 [Date Accessed: March 25, 2015]

Appendix A – Spending

The follow table documents all purchases made for the prototyping, designing and construction of the Climbing Bull.

Spaenaur	**Qt**	**Cost Per Unit**	**Final**
M4 Screw	6	$0.32	$1.92
M4 Hex Nut	20	$0.13	$2.68
M4 Flat Washer	10	$0.04	$0.35
M4 Lockwasher	10	$0.03	$0.33
HST			$0.69
Total			**$5.97**
Student Design Shop	**Qt**	**Cost Per Unit**	**Final**
Misc Material			$2.94
Misc Material			$2.54
Aluminum			$8.84
Total			**$14.32**
Digikey 1	**Qt**	**Cost Per Unit**	**Final**
IR Distance Sensor	2	$9.69	$19.38
Photo Diode	1	$9.78	$9.78
Low Offset Opamp	2	$3.37	$6.74
Res 909K	3	$0.13	$0.39
Res 14	1	$0.57	$0.57
Res 13.3	1	$0.57	$0.57
HST			$4.87
Shipping			$8.00
Total			**$50.30**
Digikey 2	**Qt**	**Cost Per Unit**	**Final**
IC OPAMP	4	$0.52	$2.08
Res 470	2	$0.17	$0.34
Crimp	18	$0.05	$0.85
Housing	6	$0.13	$0.78
HST			$0.53
Shipping			$8.00
Total			**$12.58**
Trossen Robotics	**Qt**	**Cost Per Unit**	**Final**
Lidar Lite	1	$89.00	$89.00
Shipping			$51.27
Total			$140.27
Total CAD			$180.26
Duties			$25.71
Total			**$205.97**
Robot Shop	**Qt**	**Cost Per Unit**	**Final**
HS-422 Servo	3	$11.98	$35.94
LSM303D Compass/Acceler	1	$11.70	$11.70
SPDT Lever	2	$2.93	$5.86
M3 Standoffs (10)	1	$1.94	$1.94
7.4V, 1A, LIPO	1	$17.60	$17.60
Protoboard	1	$3.90	$3.90
LynxMotion Servo Wheel	1	$8.82	$8.82
HST			$11.98
Shipping			$6.41
Total			**$104.15**
Sayal	**Qt**	**Cost Per Unit**	**Final**
Wheel Rubber	2	$9.95	$19.90
HST			$2.59
Total			**$22.49**
Total Spending			**$415.77**

Figure A - 1: Supplier spending breakdown

Appendix B – Gantt Chart

The project has followed most of the timelines that are shown in the Gantt charts. The full Gantt chart for the Climbing Bull project can be found in Figure B - 1 and Figure B - 2.

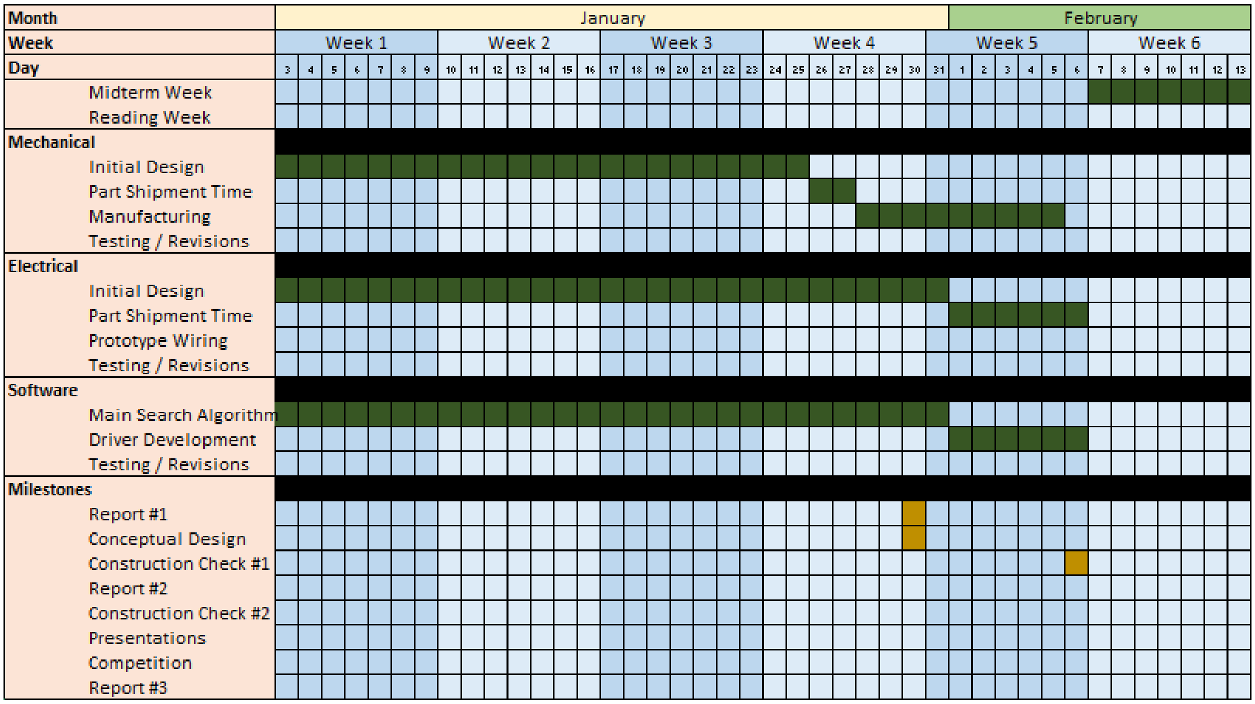

Figure B - 1: Gantt chart for weeks 1-6

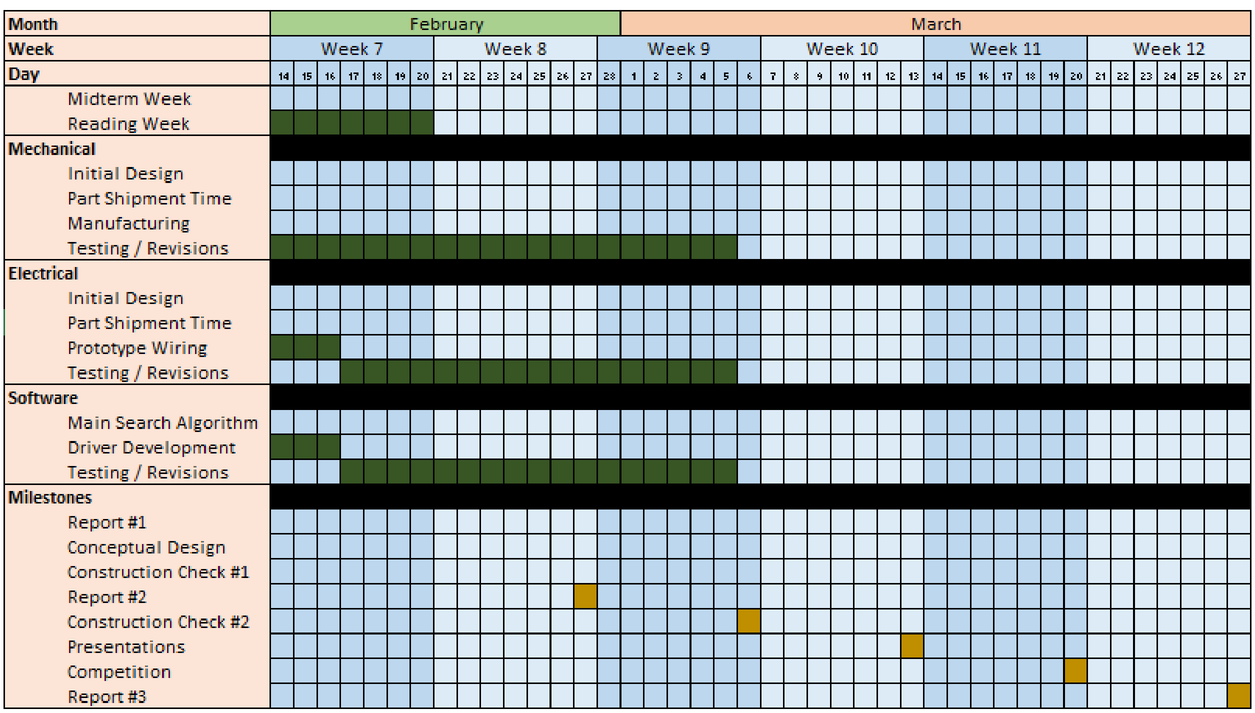

Figure B - 2: Gantt chart for weeks 7-12