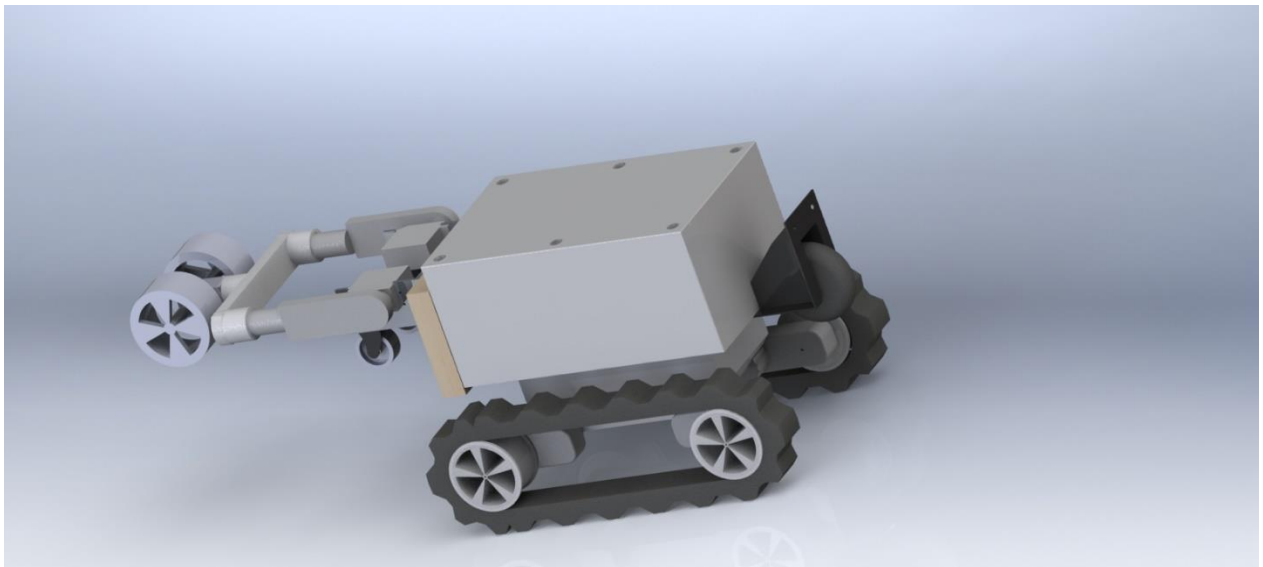


ENGR2001 - Engineering Design
Group Project Report

Stair Climbing Robot



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1 Introduction

1.1 Rationale

The science and technology behind the engineering of robots has been a topic continuously being refined and researched over the last few decades. Modern day applications such as drones for delivery as well as in search and rescue are becoming less science fiction and more reality. In fact, it is relatively affordable for the average consumer to purchase and utilize these for leisurely purposes. However, it remains that most terrestrial-type robots – that is those which are confined to the land’s surface, as opposed to aquatic and aerial types which are developed for use in the ocean and air respectively, are frequently limited by their technology and ability to scale across uneven terrain. Few notable exceptions include the Mars Rovers ranging from Sojourner to Curiosity.

1.2 Problem Statement

- To implement a prototype robot model capable of climbing steps as proof of concept to traversing uneven terrain.

1.3 Project Objectives

- To build a terrestrial robot able to climb a series of stairs.

1.4 Project Scope

1. To research and understand methods for traversing uneven terrain.
2. To design a model capable of climbing a series of steps.
3. To implement and test the model as a functional prototype.

1.5 Literature Review

On researching various methods of mechanisms for climbing over obstacles, data was found from many viable sources mainly from hobbyists and military concepts to name a few. The various issues the team felt needed to be elaborated were itemized and evaluated against the possibility of the models providing effective solutions in those cases specifically. The most relevant robot concepts found included the Articulated Traction System (Ferguson, Articulated Traction Control, 2014), the Curiosity Mars Rover (Jet Propulsion Laboratory, 2013) and the ISR Urban Robot (nicknamed Urbie) (Pierce II, 2000).

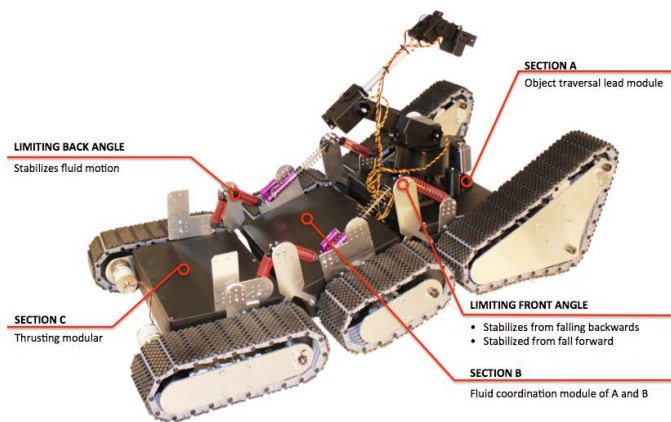


Figure 1.UTS



Figure 2. Urbie

To begin, the Articulated Traction System (referred henceforth as ATS) offers a unique three-cab type chassis. Each cab or bus is able to articulate itself relative to the other allowing for an effective climb solution on virtually any terrain. It operates similarly to the segmentation as found commonly on arthropods, as seems to be the case with most robots. This has been accounted for as a more efficient means while providing some form of compensation in the event of some form of failure in one aspect of the articulation (Ranganathan , 2004). The climb height is rather unique as for uniform staircase scenarios, the ATS can climb as high as its second cabs pivot to the third reaches measured from the front of its forward traction system. It is even more unique in the sense that a sub obstacle for a non-uniform staircase, that is an extra zone of elevation relative to the already existing height of a single step from the ground can be overcome with ease, however the limitation now falls on the height the first cab can escalate relative to the first pivot point joining the first two cabs. Despite this feature, it presents one crucial fall back as with any engineering trade-off. The processing power and input/output pins available in its control system increases the overall cost to the already limited electrical power, processing and financial aspects.

While that may be the case of the ATS, a similar system also is implemented in the case of the ISR Urban Robot, codenamed Urbie by the United States Department of Defence (Pierce II, 2000). Urbie while containing less segmentation characteristics (actually has two buses rather than more) is able to articulate and scale over an inclined or wall of height relative to the maximum length of its pivot in relation to the front of its forward traction system. This makes both the financial cost and processing cost requirement of Urbie to be less than the ATS. Urbie is able to escalate itself on most small steps and obstacles by the sheer length of its first cab. This allows it to traverse without issue, as the threaded belts hook onto the edges as well as are long enough to move across the imaginary hypotenuse formed from edge to edge of each step. This is especially useful as it requires less processing power and the robot will not be taxed with extra steps to readjust its angles to compensate for each step. However, in the event that it did encounter a height and hypotenuse of length greater than its first cab's overall reach, then it will force its front cab to rotate about its pivot while the second cab forces it to make contact with the surface. The traction formed from this and the wheels will then force the first cab upward

until it has lifted itself onto the next stair. Both methods are particularly useful and effective in terms of the resource use available.

While not considerably evaluated here, there is much to be admired of the Google subsidiary Boston Dynamics. They have designed several proof of concept prototypes on behalf of DARPA and the United States Defence Department, many which are capable of feats of overcoming some rather difficult types of terrain. Several robots were designed based on animal gait patterns including arthropods and canine subspecies of the mammal family (Boston Dynamics, 2013). These use the principle of maintaining an equivalent dynamic balancing system on all vertices of the robots, as described by Ranganathan (2004) in the manner: *“Each leg passes through a stance and a swing phase...reaction force for movement and the swing part involves the forward motion of the leg.”* This translates to the robot continuously monitoring each legs position relative to distance travelled and moment as well as impact force experienced in comparison to the other legs such that it can figure out how much force to apply based on its required motion. This type of articulation allows it to even jump vertically or leap at various angles. It is of key importance to realize that these despite using fundamentally different means of scaling over obstacles, the mechanics and methods are virtually required for advancement of the other means of climbing, including the prior two presented by Ferguson (2013) and Pierce II (2000).



Figure 3. Boston Dynamics

Finally, is the Curiosity Rover as designed by NASA's Jet Propulsion Labs (referred to as JPL). Curiosity was designed high enough to just slip between obstacles without difficulty or by going around them. In instances where the rover needs to absolutely go over some form of higher than usual rock formation, its wheels are able to be articulated individually like arms, while the rear part of the robot angles the overall body to tip its centre of gravity sufficiently allowing the rover to gain adequate grip or angle to pull itself up while the rear wheels can readjust the height to give it a push over. However, the rover prioritizes safety of its valuable payload over risky actions such as the scenario given.

In spite of the significant differences found in articulation methods, the underlying principles are somewhat familiar. Therefore, with the already available resources, a combination of favorable mechanisms which are evaluated to be more effective can be deduced as this report will show.

1.6 Method

Upon review of the various cited patents and designs, the team evaluated what designs were possible based on the resources and time available. As such, a range of steps were constructed and measured to provide some initial test data including potential torque values and a minimum output to the actuators. A basic prototype referred to as the "rover" was used to evaluate the maximum the device could handle before the centre of gravity shifted sufficiently to result in toppling and therefore failure. The resulting data from repetitive toppling provided adequate variations of the next step to implement a support system to give the rover ample ability to traverse its obstacles. Refer to Appendix I to find logs of the build and tests that were conducted.

1.7 Applications

Potential applications for the robot at its current scale and state include, but are not limited to:

1. Aides and projects within the scope of Science, Technology, Engineering and Mathematics (STEM) curriculum.
2. As an open-kit for hobbyists.
3. Projects/toys for both adults and children.

Further evaluation on the scaling and technologies included within the device would open up the application range significantly, especially to the following:

1. In use by Law Enforcement as a means for provision of surveillance and reconnaissance.
2. For Search and Rescue applications including expanding the capabilities to disarm and dispose dangerous explosives including bombs and other items deemed too dangerous for in-presence human interaction.
3. As an aide for structural inspection, especially when combined with LIDAR, IR and optical sensors.

2 Design

2.1 Description

Through various iterations and thought experiments conducted, the team evaluated what was deemed as the best effective concept possible with what was available within the scope and budget. On any scale, the model would contain a large single cab with threaded tracks around each pair of individually articulated actuator on both the left and right sides. These actuators would comprise of a combination of a servo and motor pairing, with the motors providing torque to tracks and the servos affecting the tension of the track belt as well as the height of approach of the cab. This cab would serve as a base to a housing containing all the required electronic devices and sensors as well as the power supply. The base would also be linked to a rear pair of motor-powered wheels, and articulated via a servo and shaft setup.

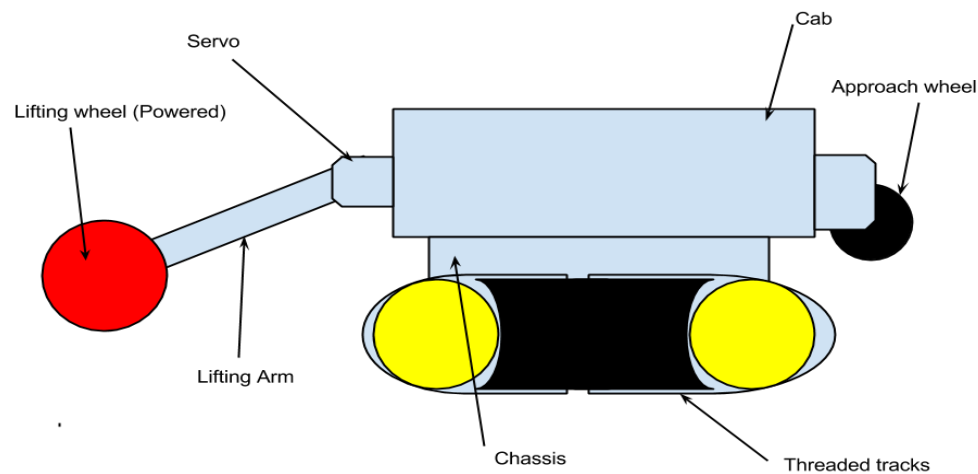


Figure 4. Basic Design Concept

2.2 Working of the Robot

On approach to the obstacle, mainly the stairs, the robot would push itself against the vertical wall and the tracks can revolve sufficiently to drag itself vertically. In instances where the height of the wall is approximately half the wheel base or less, the robot can traverse over with

ease and no need for additional assistance. However, in the event of the robot encountering a step much higher when compared to its wheelbase, it will push itself sufficiently upward until it can climb no more and the controllers will actuate the rear arm giving the front some leverage to continue its escalation. See figure 5 - 10 for a graphical representation of the above details.

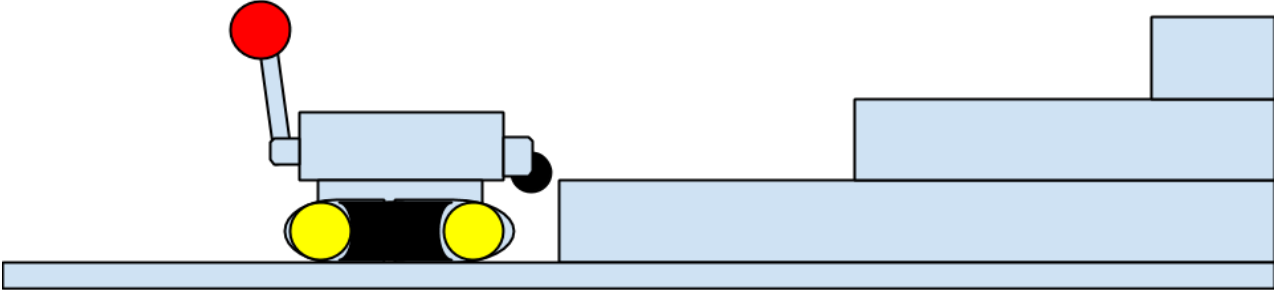


Figure 5. Step one - Robot approaches stairs

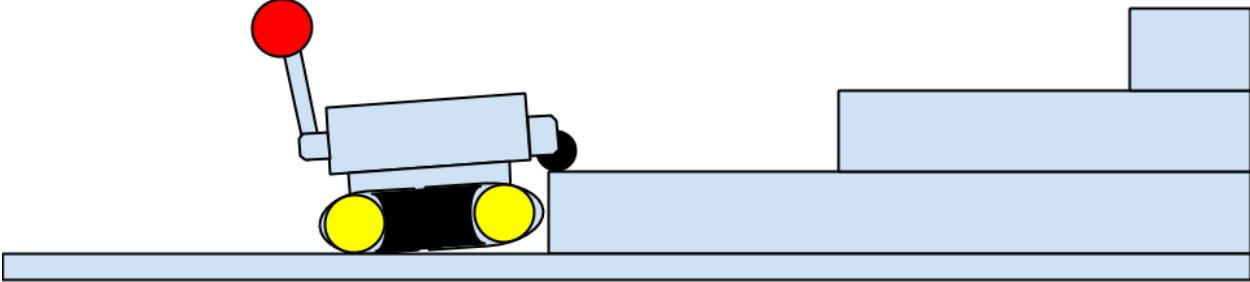


Figure 6. Step two - Robot pushes against the wall and begins to climb

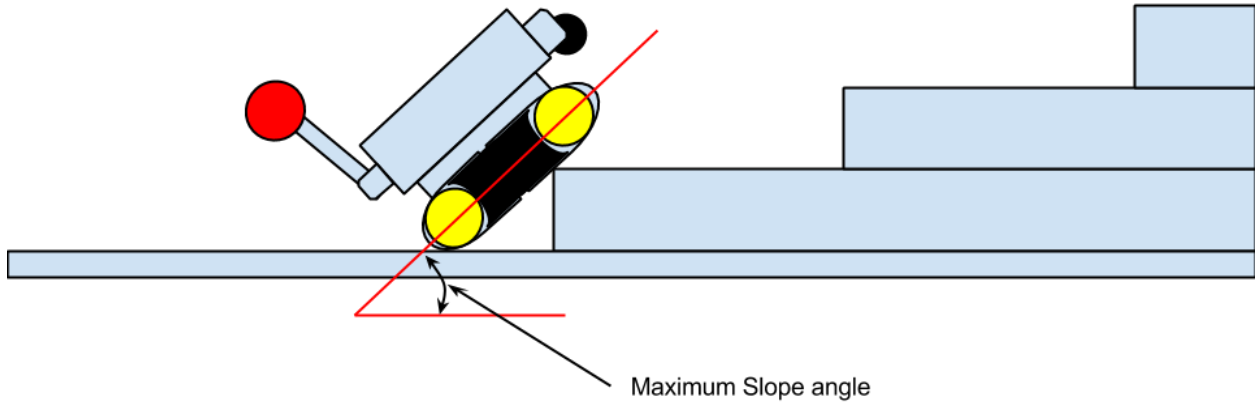


Figure 7. Step three - Robot reaches maximum limit of climb (40 deg)

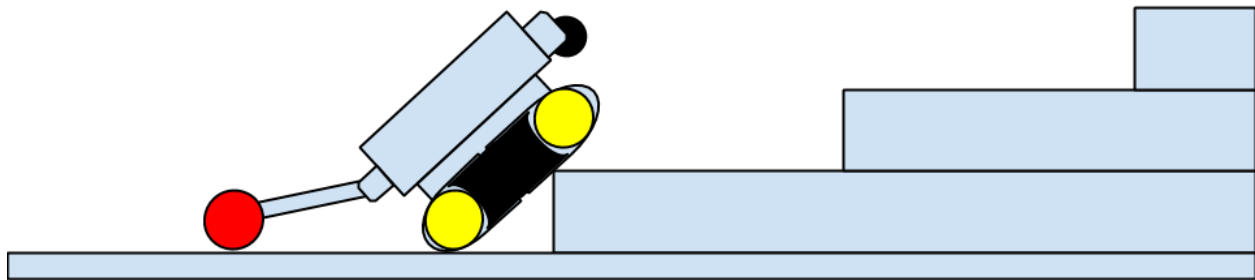


Figure 8. Step 4 part one - Lifting arm descends

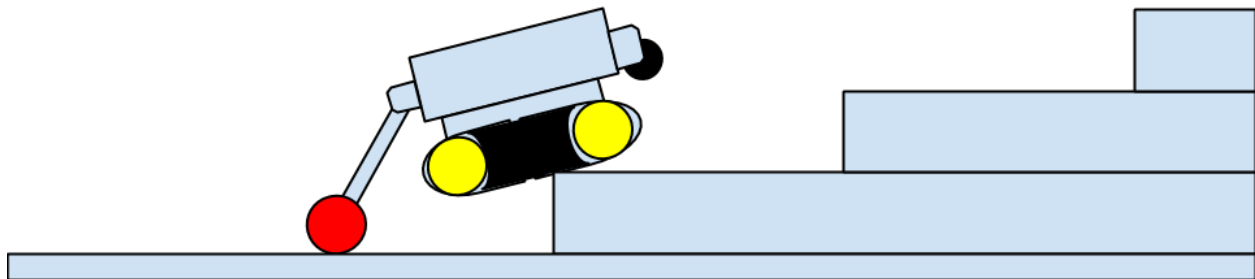


Figure 9. Step 4 part two - Lifting arm reduces Robot angle of tilt thereby allowing it to continue its ascent

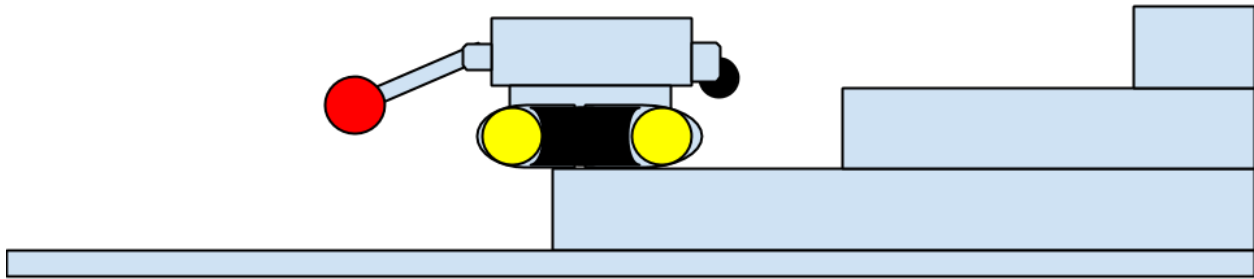


Figure 10. Step five - Robot completes climb

2.3 Control System Design

In order to achieve the above stated objectives and process operation, the following control system design concept was formulated, as illustrated in figure 11. A power source would provide power to a central power regulation/distribution board. This board will then regulate the power from the source and distribute the power to the various system components according to their power ratings. The main center of control will be a microcontroller.

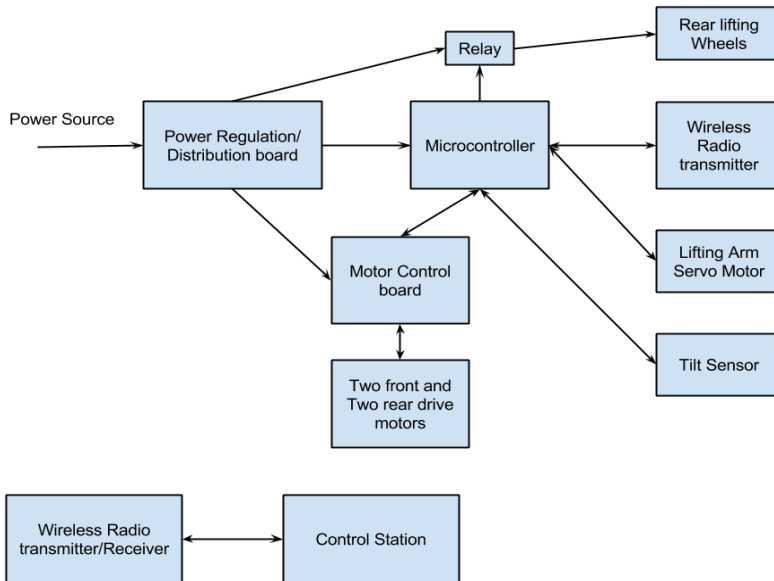


Figure 11. Control System Design

This microcontroller will receive and interpret system control signals from a wireless radio transmitter/receiver, tilt sensor and motor control board. Based on pre-programmed instructions, the microcontroller will then instruct the motor control board, which controls the four independent drive motors, to perform the required actions which will cause the Robot to move forward, backwards, to the left or to the right. It will also turn on and off the relay and the servo to activate the rear lifting arm and set the arm at the required angle for lifting the Robot up the stairs. During this the microcontroller will also send status update via the radio transmitter/receiver to a monitoring/control station.

2.4 Control Station Design

Figure 12 below shows the graphic user interface(GUI) design of the Robot Control Station computer application. This application was designed and programmed in Processing and compiled to run on the java virtual machine. The application is very simple and have the following features:

- 1) **The Serial Monitor** - The serial monitor displays all the data sent from the Robot to the control station. This information includes feedback information to inform when the Robot is moving forward, backwards, to the right or to the left; pid values when the Robot is climbing; orientation data from the onboard nine degree of freedom sensor (9DOF) and current usage information.
- 2) **The visual indicator** - This is a simple 3d model of the Robot which virtually shows the physical orientation of the Robot. This allow the operator to know if the Robot has turn over when it is out of sight.

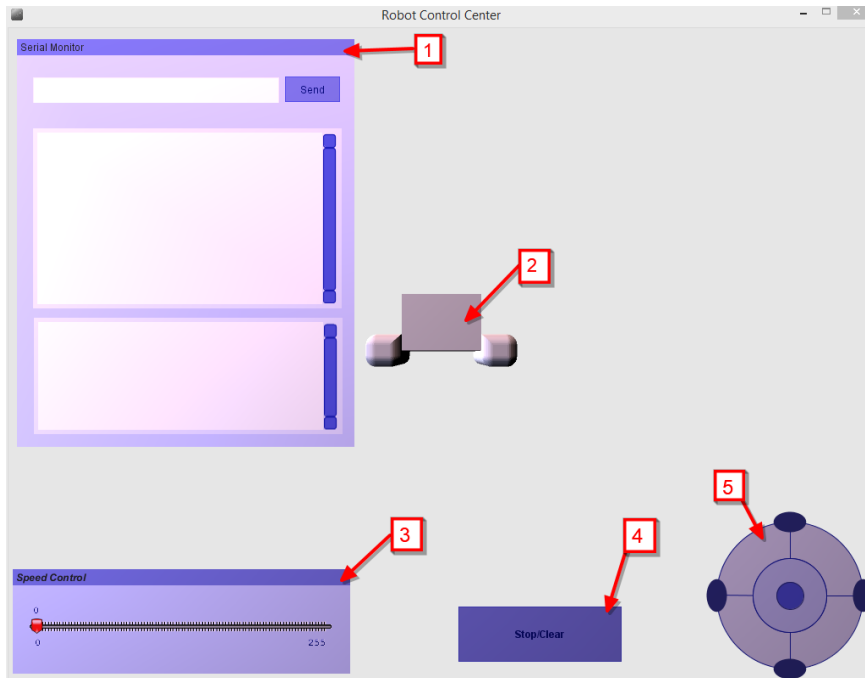
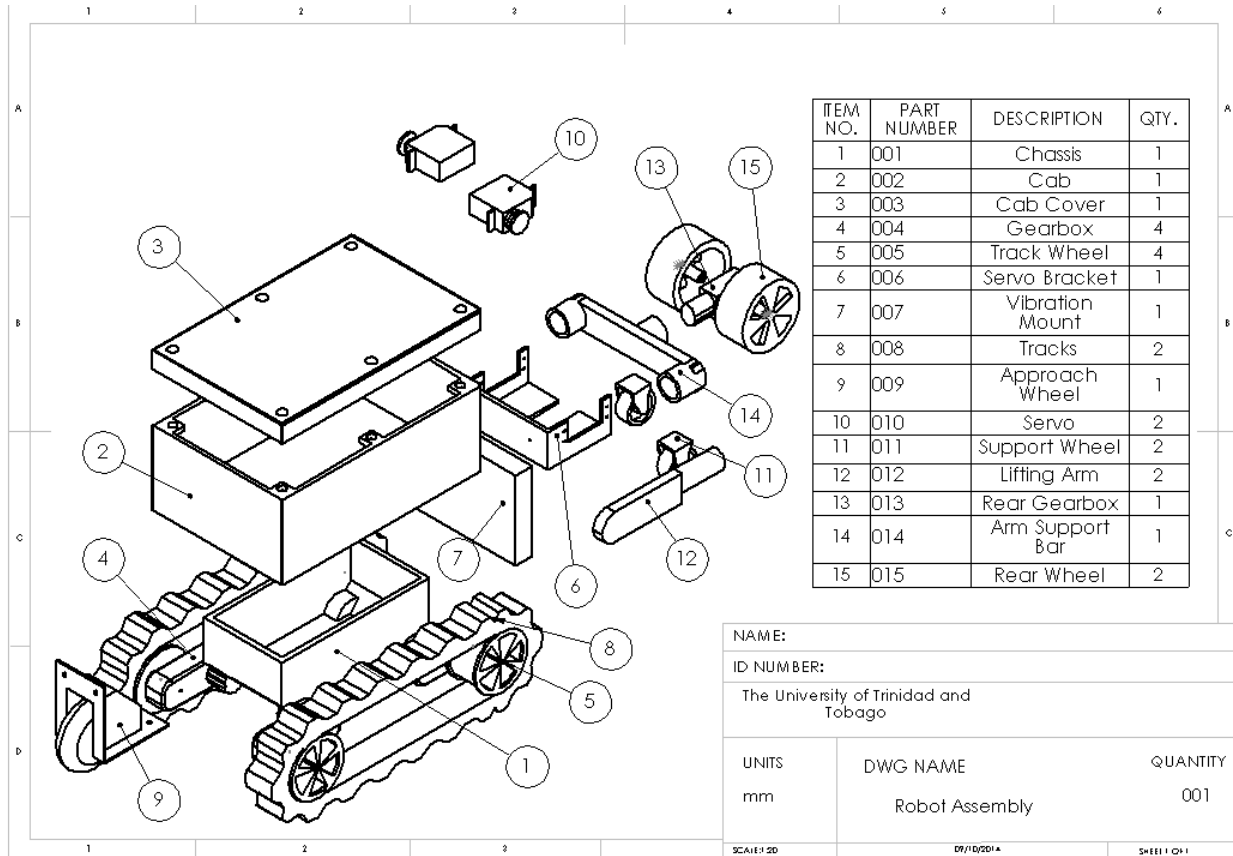
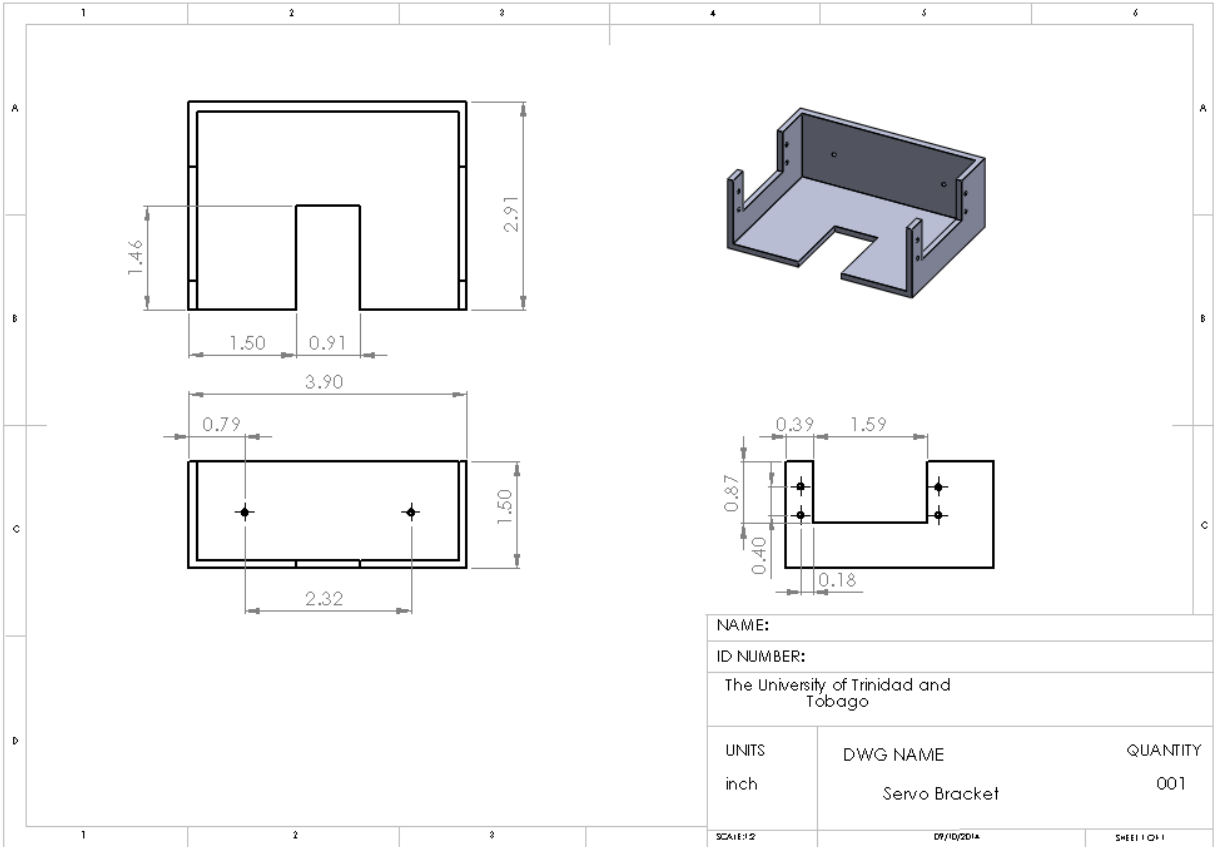


Figure 12. Robot Control Station GUI

- 3) **The Speed Control Slider** - This slider is use to set the Robot operating speed to digital speed value of 0 to 255.
- 4) **Stop/Clear Button** - This button stops the Robot and Clears the serial monitor window.
- 5) **The virtual Joystick** - This joystick allows the operator to control the direction of the Robot. By moving the center button to any of the four outer buttons the application will send a command to the Robot which will cause it to move in the desired direction.

2.5 Drawings





2.6 Calculations

2.7 Design Considerations

In choosing the components to use in the system the following factors/criteria were taken into consideration:

- a) **Simplicity** - The components must be simple and easy to use with minimal setup and configuration.
- b) **Versatility** - The components must have multiple uses thus reducing the overall system complexity.
- c) **Economical** - The overall cost of ownership should be minimal.
- d) **Accuracy** - The components must be accurate. Sensor values must accurately reflect the conditions they are measuring.
- e) **Reliability** - The components must operate with minimal failure over there intended range and design specification.

2.7.1 Components Selection

- 1) **Microcontroller** - There are several microcontrollers on the market that can be used in the project. The most popular one are: Arduino Uno, Arduino Mega, Parallax popular and PIC 16F877. Table 1 show a comparison of the above microcontrollers using a Pahl and Beitz Matrix. The results show that the Arduino Mega was the better choice.

- 2) **Control/Base station** - The choice of control station is critical to the overall system design. The following factors were taken into consideration in its selection:
- a) It must integrate well the above selected microcontroller.
 - b) It must work seamless with the choice of wireless transmitter/receiver unit.
 - c) It must be able to visually display the system status and errors produced by the microcontroller.
 - d) It must be able to store the data digitally.
 - e) With the above criterion in mind the best possible option would be to use a PC to serve as the control station. A simple custom software can then be written that will meet the above criterion.
- 3) **Wireless Transmitter** - There are many wireless transmitters and receivers on the market. The one selected must be able to work with the microcontroller selected above but also integrate with the control/base station. From research the XBee radios were the best choice. They meet the design considerations and integrates well with computers and the Arduino microcontroller.

Table 1. A comparison of Microcontrollers using Pahl and Beitz Matrix

		Arduino Uno		Arduino Mega (Reference)		Parallax popular		PIC 16F877	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Simplicity	10%	4	0.4	4	0.4	3	0.3	2	0.2
Versatility	15%	3	0.45	4	0.6	4	0.6	3	0.45
Economical	30%	4	1.2	4	1.2	3	0.9	3	0.9
Accuracy	10%	3	0.3	3	0.3	4	0.4	2	0.2
Reliability	35%	2	0.7	3	1.05	3	1.05	3	1.05
Total		3.05		3.55		3.25		2.8	
Rank		3		1		2		4	

Building the Robot according to the design specifications detailed in the engineering drawing above has its advantages and disadvantages. The design team was also time and resource constrained among other things therefore, it had to be decided what structural components should be made or purchased. The following criteria were used in the decision making process:

- Complexity - The less complex the part is the easier it would be to make given the current constrains.
- Flexibility - Being able to make adjustments to the structural components is necessary as part of the prototyping process.
- Resources - The materials, machines, equipment, manpower and cost show be low to meet the current operating constrains.
- Time to implement - The Robot must be build and tested within one-month time frame therefore, the decision made must allow for the meeting of this deadline.

These are the structural components under consideration: the cab, the lifting arm, the servo bracket and the robot chassis. Using a scale from one to three, with three being the most critical. Table 2 shows a matrix of the decision result.

Table 2. Make vs Buy Decision Matrix

Criteria	Weight	The Robot Cab	The Lifting Arm	Robot Chassis	Servo Bracket
Complexity	1	2	1	3	1
Flexibility	2	2(4)	2(4)	2(4)	3(6)
Resources	3	3(9)	1(3)	3(9)	2(6)
Time to implement	3	3(9)	2(6)	3(9)	1(3)
Total		24	14	25	16

2.7.2 Material Selection

1) **Material Selection for the Chassis, Lifting Arm and Cab (Primary)** - For the primary use, which is for prosumer experimentation and STEM based education applications, it was thought that a low cost, easily modifiable and moldable yet tough enclosure was desirable. As such, utilizing the CES Material Selection Tool (2014 Edu Pack), the following were found:

- a) Polypropylene (PP)
- b) Polyamides (Nylon, PA)
- c) Acrylonitrile Butadiene Styrene (ABS)

These were determined by using the criteria of: *Price* $\leq 15\text{USD/kg}$, *Young's Modulus* $\geq 2\text{GPa}$, *Shear Modulus* $\geq 1\text{GPa}$, *Melting Point* $> 150\text{ C}$, *Poor Thermal Conduction & Excellent Thermal Insulation*, *Excellent Electrical Insulator*. Since the results were all polymer based, a further criteria was added: *Moldability* ≥ 3 .

2) **Material Selection for the Chassis, Lifting Arm and Cab (Secondary)** - For any secondary use where a tougher assembly may be necessary, provided that more capable high-torque output actuators are used, the following materials may be considered (assuming low cost is less of a factor):

- a) Zinc Alloys
- b) Aluminium Alloys
- c) Titanium Alloys

These were determined by using criteria of: *Young's Modulus* $\geq 5\text{GPa}$, *Shear Modulus* $\geq 3\text{GPa}$, *Melting Point* $> 450\text{ C}$, *Acceptable to Excellent Environmental, Industrial & Chemical Durability Properties*. The results were then sorted graphed in software by *Price and Density*. This was further refined by *Formability and Castability* levels.

3) **Material Selection for the Wheels** - For the wheels themselves, it was undesirable to have a high density expensive material increasing the loading on the actuators, thus the software yielded the following materials for possible use:

- a) Polyurethane (tpPUR)
- b) Natural Rubber (NR)
- c) Polyisoprene Rubber (IIR)

The criteria in particular during selection was for any material which was low in cost, low in density and yet able to deform sufficiently to offer grip in the same manner of how a wheel operates. Thus, the parameters: Elongation $\geq 500\%$ and sorted by cost as well as density. A further sorting was done by using the graph tool for moldability in alphabetical order.

2.8 Bill of Materials

Table 3 show the bill of materials. Figure 12 to 22 shows an image of the part from the table.

Part	Specification/Description	Quantity
Motor control board	Rover 5 Motor Driver Board - 4 x "H" Bridges - 4 x FET "H" Bridges -4 Channel motor control -6V to 12V operating Voltage -4A stall current	1
Robot Chassis	Rover 5 Robot Platform - 4 Independent DC motors - 4 independent hall-effect encoders - 10kg/cm stall torque per motor	1
Wireless Transmitter/Receiver	XBee 2mW - Series 2 (ZigBee Mesh) - 400ft (120m) range -2mW output -250kbps Max data rate	2
	XBee Shield	1
	XBee Explorer Dongle	1
Caster	Tilt caster - 2.96" x 2.96" x 2.21" Wide Housing - Wheel 2.75" Dia. x 7/8" Wide Polyurethane w/Ball Bearings 100 lb. Capacity	1
Arduino Mega	Arduino Mega - Atmega1280 Microcontroller - 7 to 12V operating voltage - 54 Digital I/O Pins	1

	- 16 MHz Clock Speed	
Lifting Wheel	<p>Wheel with Gear Motor</p> <ul style="list-style-type: none"> - 3 to 12V operating Voltage - 800g.cm maximum torque at 3V - 170RPM at 3V - Gear reduction ratio 1:48 - 250 mA Max 	2
Robot Cab	<p>Waterproof Plastic Enclosure</p> <ul style="list-style-type: none"> - 230mmx150mmx85mm 	1
Battery	Venom 20C 3s 6400mAh 11.1 LiPO Battery with Universal Plug System	1
Servo Motor	<p>Futaba S3305 Standard Metal Gear Servo</p> <ul style="list-style-type: none"> - 4.8 to 6V operating voltage - 8.9kg.cm Stall torque - Dual ball bearing 	2
Tilt Sensor	<p>Adafruit 9-DOF IMU Breakout - L3GD20H + LSM303</p> <ul style="list-style-type: none"> - L3GD20H 3-axis gyroscope: ± 250, ± 500, or ± 2000 degree-per-second scale - LSM303 3-axis compass: ± 1.3 to ± 8.1 gauss magnetic field scale - LSM303 3-axis accelerometer: $\pm 2g/\pm 4g/\pm 8g/\pm 16g$ selectable scale 	1

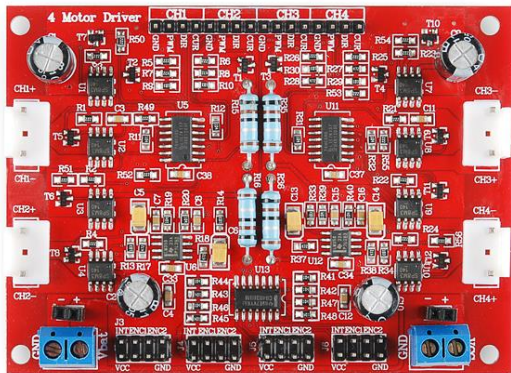


Figure 13. Motor Control Board

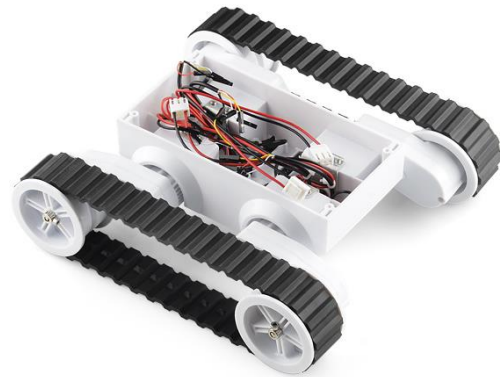


Figure 14. Robot Chassis



Figure 15. XBee Radio

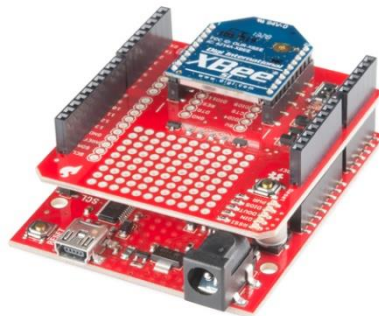


Figure 16. XBee Shield



Figure 17. Tilt Castor



Figure 18. Arduino Mega



Figure 19. Rear lifting wheel



Figure 20. Robot Cab



Figure 22. Servo Motor

Figure 21. Battery

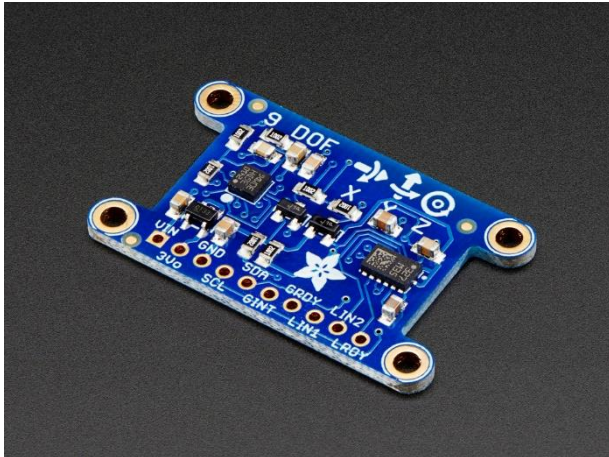


Figure 23. 9DOF Sensor.

2.9 Process Plan

The following is the sequential procedure used in the building of the Robot:

1. The first approach was to assemble the Robot Chassis with all the electronic components.
2. The programme for the Arduino Mega and the programme to control the Robot from the computer was then written and tested on the Chassis.
3. The Robot Chassis was then tested to determine the maximum slope and maximum stair thread height that it can climb before canting over.
4. The above data was recorded. The team then build a test stair case with the following thread heights: 3", 4", 6" and 8".
5. The parts for the lifting arm were made and the entire Robot was assembled.
6. The team then experimented on the varying the length of the rear lifting arm to determine the maximum height that the current design of the robot can climb. The data was then used to determine the final length of the arm and the torque for the arm servos.

7. The Robot code was then optimized to control the Robot climbing action based on the above parameters.
8. The final design was then tested and the pid control was tuned for smooth operation.

The following is a layout of the process for the parts the team decided to make:

Table 3. Servo Bracket build plan

Step	Tools Needed	Materials Needed	Description
1	Hacksaw, measuring tape	1 1/2 x 1 1/2 x 12" Angle Aluminum	Measure and cut material to design specifications.
2	Scriber, steel rule, hacksaw	Part from step one	Mark off the length for bending and 45 degree cut section. Use hacksaw to cut and remove a 45 degree section from both sides of the material where bending should take place.
3	Bending machine	Part from step two	Bend both ends at 90 degrees.
4	Scriber, steel rule, hacksaw	Part from step three	Mark off both servo cutout sections. Use hacksaw to cut and remove waste material.
5	Hand Drill, 1/16 drill bit.	Part from step four	Drill servo mounting holes and bracket mounting holes
6	Hand file	Part from step five	Remove all blurs and shape edges. Check final dimensions. File to fit.
7	Hand drill	Servos, Castors	Assemble servos and castors to bracket according to design.

Table 4. Build plan for Lifting Arm

Step	Tools Needed	Materials Needed	Description
1	Hacksaw, measuring tape	1/2 PVC pipe,	Measure and cut two pieces of pipe to length.
2		Two 1/2 elbows, one tee joint, two 3d printed Servo arm, RC dc motor, Parts from step one	Assemble all the parts according to design specifications

2.9.1 Build progress

Table 6 below show the Robot at different stages of the build process.

Table 5. Build Pictures

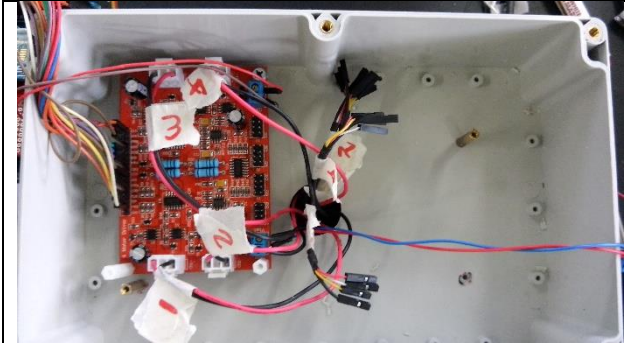


Figure 24. Installing the motor control board

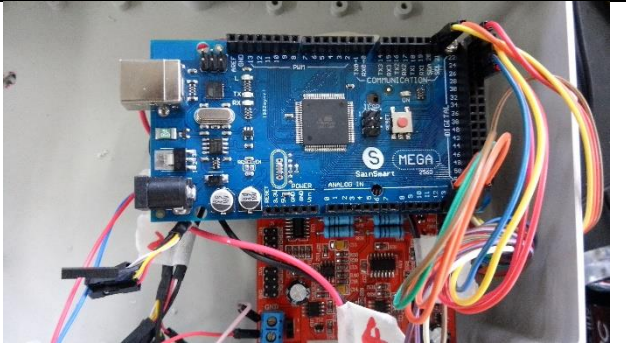


Figure 25. Installing the Arduino Mega

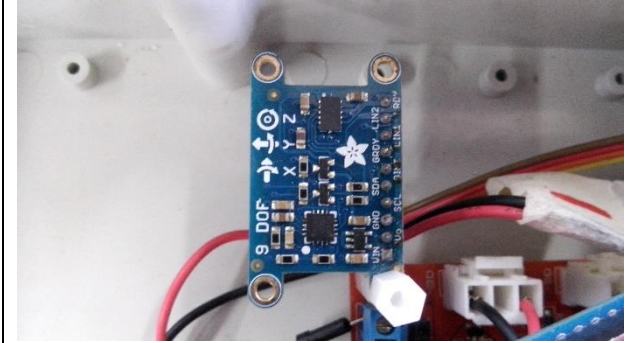


Figure 26. Installing the 9DOF sensor

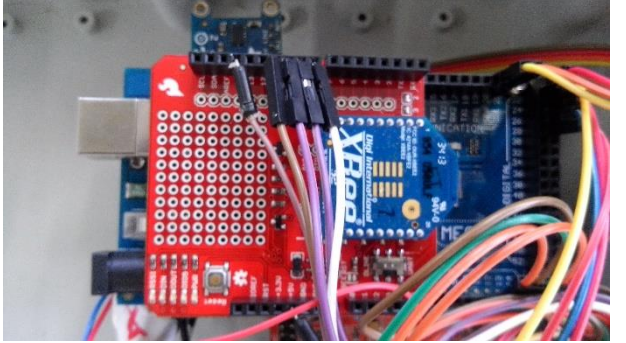


Figure 27. Installing the XBee Radio

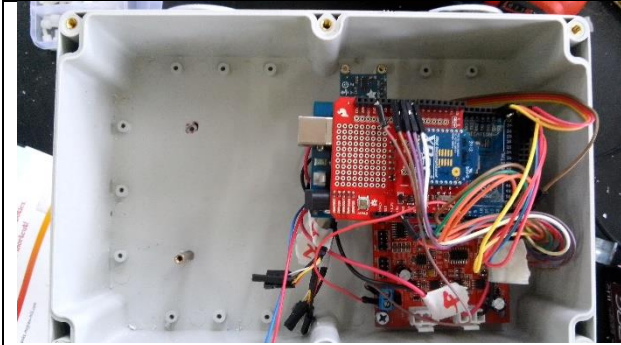


Figure 28. Complete electronic assembly

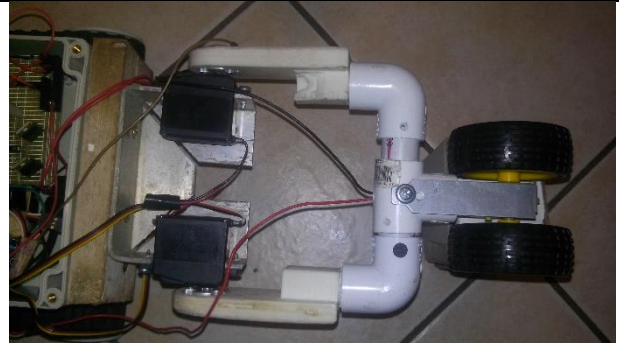


Figure 29. Complete Arm assembly top view

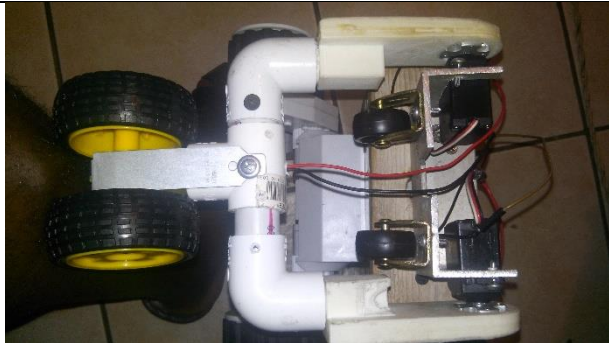


Figure 30. Complete Arm assembly rear view



Figure 31. Front balancing wheel



Figure 32. Worktable view 1

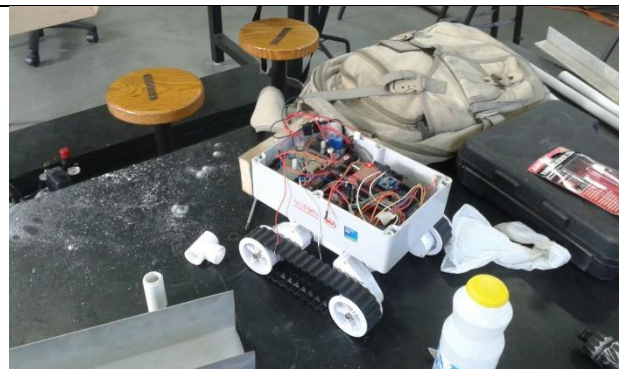


Figure 33. Worktable view 2

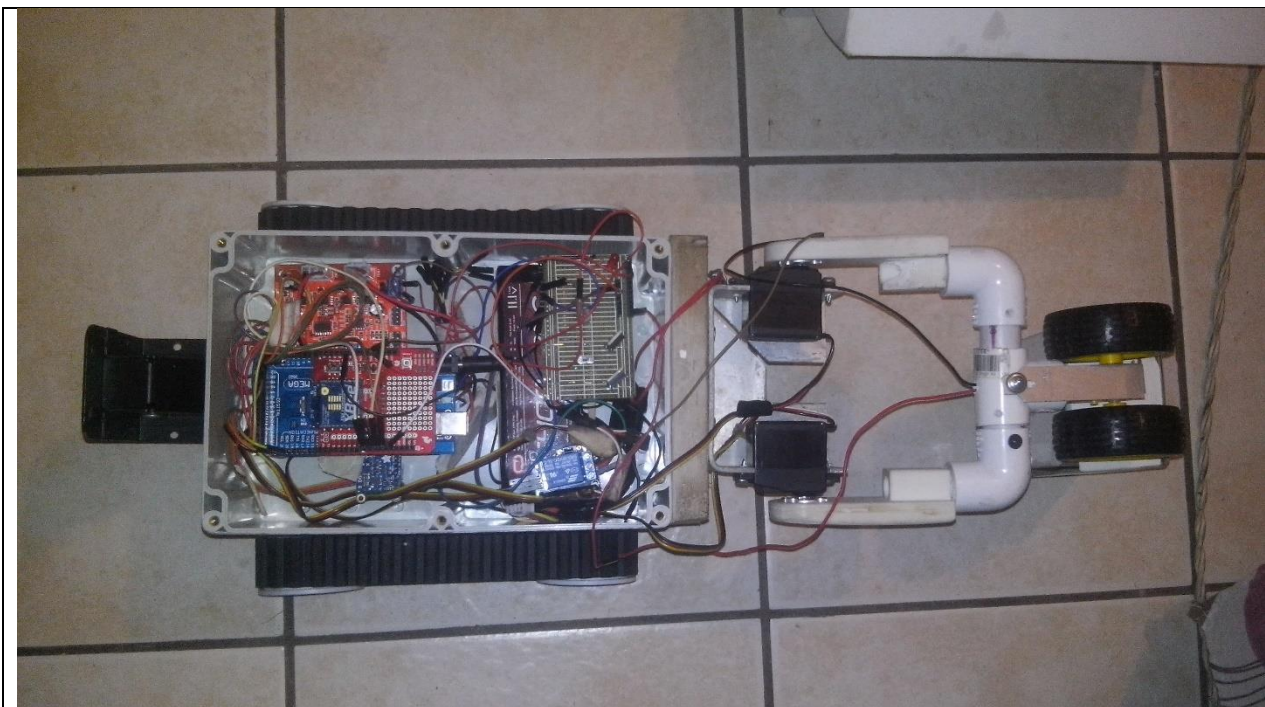


Figure 34. Final Robot Assembly Top view



Figure 35. Final Robot Assembly Side view



Figure 36. Final Robot Assembly perspective view

3 Discussion

3.1 Tests

Three major test were conducted while building the Robot. Other minor tests were also conducted while tuning the system but in the interest of space this report will only deal with the major ones.

- 1) **Major Test One** - The goal of this first test was to determine the maximum height and slope that the Robot chassis can climb. The measurement obtained from this test indicated that the Robot chassis can climb a maximum height of 30cm with a slope angle of approximately 24 degrees. Part two of this test involve testing the Software controls and the Robot handling ability. Table 6 shows images of this test. The test successfully accomplished it objectives.

Table 6. First Major test of System Capabilities



Figure 37. Chassis Climbing 30cm height



Figure 38. Chassis Climbing 70cm height



Figure 39. Chassis failing the final stage of the climb



Figure 40. Testing the Software controls

2) **Major Test Two** - The goal of this test was to determine experimentally the optimum length the lifter arm should be to carry out the lifting functions. This allows the team to compare the theoretic values with actual performance values. The first arm had a center to center distance of 6.5". This arm performed well but there was a high rate of servo failure. The calculated lifting torque required is 17.6 kg-cm. A single 24 kg-cm servo was used however this servo keep failing. Three was changed in total before it was replaced with 8.9 kg-cm torque servo and this servo performed well after several test runs. Table 7 show images of this test. Part two of this test involved testing a 9.5" length Lifting Arm. This arm failed to produce desirable results.

Table 7. Second Major Test - Varying the Length of the Lifting Arm

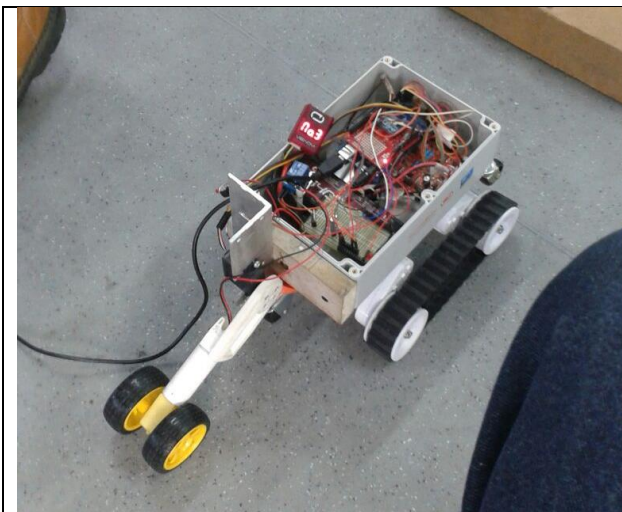


Figure 41. 6.5" Lifting Arm - single support

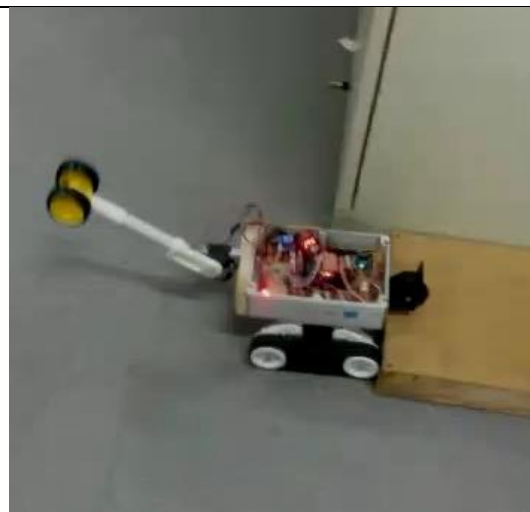


Figure 42. 9.5" Lifting Arm - single support (stage 1)



Figure 43. 9.5" Lifting Arm - single support (Stage 3)



Figure 44. 9.5" Lifting Arm - single support (Stage 4)

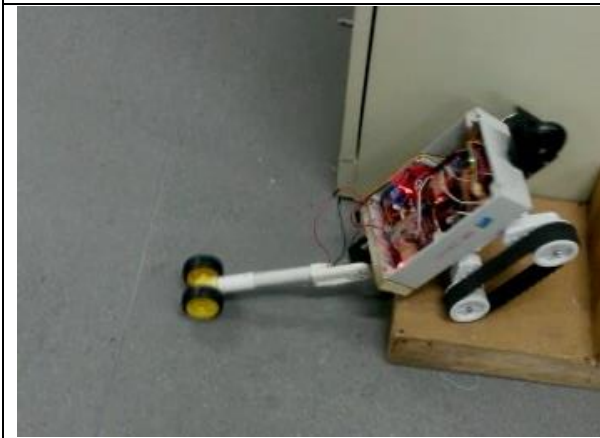


Figure 45. 9.5" Lifting Arm - single support (Stage 4 part 2)

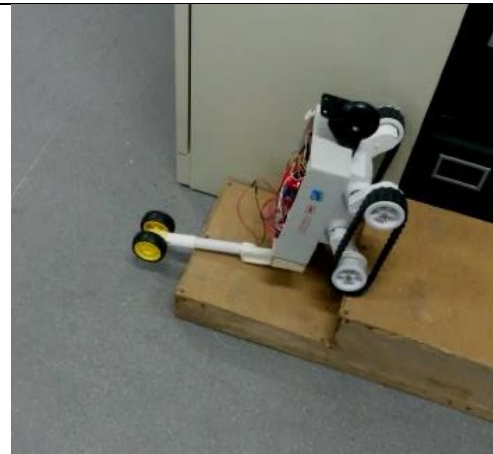


Figure 46. Lifting Arm - single support (Stage 4 part 3)

3) Third Major Test - The objective of this test was to determine if changing the Arm pivot support from one to two would have any notable effect on the overall performance of the Robot and decrease the failure rate of the servos. Two 8.9 kg-cm servos and an Arm length of 6.5" was also used in the setup. The result of the test showed that after several test runs both servos failed. One to solve this problem one servo was left un-powered and only one 8.9 kg-cm servo remained powering the arm. This single servo produced successful results. Table 8 shows images of the Robot going through all the stages as per design.

Table 8. Third Major Test - Change in design of Lifting Arm



Figure 47. 6.5" Lifting Arm - double support (Stage 1)

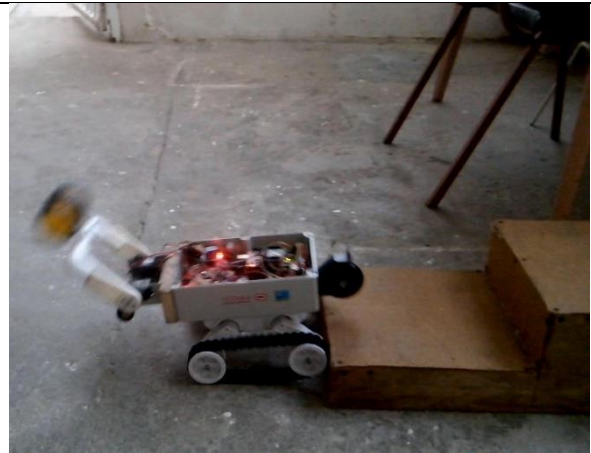


Figure 48. 6.5" Lifting Arm - double support (Stage 2)



Figure 49. 6.5" Lifting Arm - double support (Stage 3)

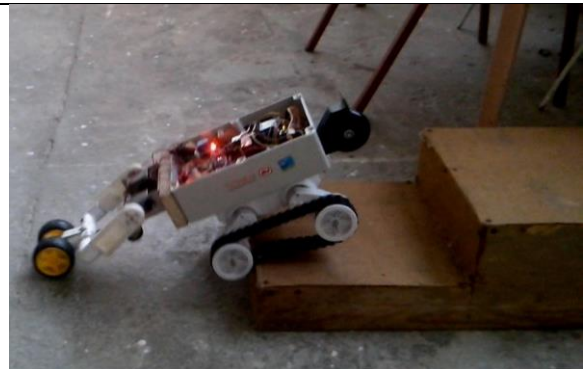


Figure 50. 6.5" Lifting Arm - double support (Stage 4 part 1)



Figure 51. 6.5" Lifting Arm - double support (Stage 4 part 2)



Figure 52. 6.5" Lifting Arm - double support (Stage 5)

3.2 Challenges and Solutions

The major challenges faced during the design, building and testing of the Robot was the functioning of the lifting Arm and the high failure rate of the servos used. While the theoretical calculated torque values seem correct the system appears to have higher value of shear stress on the gears of the servos, which was beyond their design limit, causing failure. The problem was solved by using metal gear servos instead of plastic gears and by reducing the lifting torque provided by approximately one half the theoretical calculated value.

4 Conclusion

This project set out to implement a prototype robot model capable of climbing steps as proof of concept to traversing uneven terrain and the team successfully designed, build and tested a unique Robotic model. The results of the test conducted on the prototype shows that the concept used in accomplishing the object works but need further refining and stress analysis to address the high failure rate of the servos used in the lifting arm. Nevertheless, the was well conceived and executed.

5 References

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6 Appendices

6.1 Appendix I -Build Log

Date	Activity
2/3/2015	Temporary connect Robot Chassis
3/3/2015	Began Initial programming
5/3/2015	Started First Analysis of the capabilities of the Current System.
6/5/2015	Assemble Robot Chassis and Cab and Electronics. Test initial control system
16/5/2015	Build first Robot Arm, Add program code to control Arm, Test arm functionality
23 -24/5/2015	Make changes to Robot Arm.
26/5/2015	Make final test of Robot System

6.2 Appendix II - Project Parts Costs

Part	Description	Quantity	Cost	Total (USD)	Total (TTD)
1	Rover 5 Motor Driver Board - 4 x "H" Bridges	1	24.95	24.95	
2	Rover 5 Robot Platform	1	59.95	59.95	
3	XBee Radio	2	25.95	51.9	
4	XBee Shield	1	14.95	14.95	
5	XBee Explorer Dongle	1	24.95	24.95	
6	Tilt Caster (front)	1	6.54	6.54	
7	Arduino mega	1	25.99	25.99	
8	Rear Wheels	2	5.49	10.98	
9	Battery (11.1 V 6400mAh)	1	64.97	64.97	
10	Electrical Box	1	12.23	12.23	
11	9dof Sensor	1	19.95	19.95	
12	Balance Battery Charger	1	45.99	45.99	
13	Hook up wire kit	1	20	20	
14	Nylon Hex Spacers - kit	1	12.89	12.89	
13	Motor Driver Module	1	5.65	5.65	
14	Solderable PC Breadboard	1	5.9	5.9	
15	200mm male to female cable kit	1	5	5	
16	Low Voltage Monitor	1	9.99	9.99	
17	Charger Adapter	1	7.55	7.55	
18	Servo Motor	2	34.99	69.98	
19	TIP 121 Transistor	2	8.1	16.2	

20	5V Relay Module for Arduino	1	3.57	3.57	
	Sub Total			520.08	
	Shipping, Handling and Customs Cost			156.024	
	Total			676.104	\$4,306.78