Interim Design Report

Team 21(E19)

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Tall Timbers
Research Station & Land Conservancy

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TITLE AND GROUP MEMBER INFORMATION

The title of this project is the Underground Robotic Gopher Tortoise Scope.

Jane Bartley (Team Leader) - Jane Bartley is a Mechanical Engineering senior originally from Springfield, Ohio. She has a particular interest in Fluid Mechanics, Propulsion Systems, and Naval Ship Building. After graduation, she plans to work in the Naval industry developing nuclear submarines.

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Lester Nandati (Lead Mechanical Engineer) - Lester, raised in Tallahassee, FL, is graduating with a Bachelor's in Mechanical Engineering in Spring 2015. His area of interest deals with robotics and dynamic systems. After graduation, he desires to utilize his engineering experience to serve at the U.S. branch office for Jehovah's Witnesses to further international design and construction efforts.

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ACKNOWLEDGEMENT

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ABSTRACT

Tall Timbers Research Station and Land Conservancy has provided Team 21 the task of the creation of a more affordable burrow scope for the purpose of studying gopher tortoises. The final product should include an infrared camera that is able to traverse a burrow up to 15 meters in length and is connected to a screen that can not only display the image but also capture and record the footage; the entire system should be waterproof and cost less than 1000 dollars. It is still early in the timeline of producing this product, however steps have already been taken towards the completion of the system. The sponsor, Tall Timbers, has been contacted and an onsite field assessment has been completed in order to observe the environment that the final system will be operating in. The current technology Tall Timbers possesses for the scoping of gopher tortoise burrows has also been studied, the downfalls of the system observed, and improvements for the future system noted. A final presentation has been completed and the first prototype is scheduled to be complete by mid December. Testing of the prototype will begin in early January, at which time a mock burrow will be built in order to simulate the real world conditions the scope will be facing at Tall Timbers. This underground robotic scope is very critical to Tall Timbers as well as any research and land conservancy due to the fact that it will allow researchers to scope burrows with ease and take more accurate population surveys of these tortoises.

I. PROJECT OVERVIEW

This section introduces the project and provides some initial background regarding the gopher tortoise as well as some current scopes that are on the market. The need for a gopher tortoise scope is discussed and the objectives and constraints of the project are introduced.

A. Background Research

Many species find refuge in the burrow of a gopher tortoise. Due to the large effect this tortoise has on its surrounding ecosystem it is considered a keystone species [1]. This fact makes the study of the animal so imperative, especially for a research station such as Tall Timbers which specializes in fire ecology studies. Gopher tortoises however are not the only burrowing animals that require a scope in order to be studied; there are also burrowing owls, foxes, prairie dogs and many other small mammals.

Fig. 1. Sandpiper Technologies INC. Peeper 2000

To meet this need for research equipment, Sandpiper Technologies, INC. introduced the Peeper 2000, which can be seen in Figure 1. This system consists of a head mounted video display, a camera probe, a battery charger and a case. The system has the benefits of being lightweight as well as waterproof. Sandpiper Techs scopes include the Peep-A-Roo, which is 1 inch in diameter and 4 meters long, and the Peeper Video Probe, which is 2.3 inches in diameter and long enough to reach the end of tortoise burrows. These systems however have the major drawback of costing 6,000 dollars apiece, as of their most recent catalogue [2]. This is generally out of the budget of research centers such as Tall Timbers, leaving them still without a scope. In order to meet this need, Tall Timbers built their own scope for a total of about 500 dollars. It is however outdated and slightly crude in design, consisting of an infrared camera connected via long detachable wires to a portable DVD player. The wires are protected by thick rubber hosing. This hosing has proven to be heavy as well as not easily navigated through the burrow, and the DVD player is not waterproof.

The creation of a scope that is on the technological level of Sandpiper’s Peeper 2000 while also costing less than 1000 dollars would be pivotal for research centers such as Tall Timbers, and could do a great deal of good for the advancement of the study of many burrowing keystone species, not only the gopher tortoise.

B. Needs Statement

As stated, the current scope consists of a basic infrared camera that is connected to a tube and wired to a DVD player. The design is cumbersome for several reasons. In order to use the scope, the user must physically push the camera down the tortoise burrow. Thus, the camera can easily dig into the ground and get blocked by dirt. It is difficult to navigate the scope, as there is nothing to help it move forward, backwards or navigate turns. Because of this lack of maneuverability, many parts of the burrows are unreachable for observation. Often, the camera will be flipped over or rotated while attempting to go around obstacles. Consequently, the user may no longer be able to determine which side is up or down.

The scope, which involves three large components, is heavy and bulky. By the end of the day, the sponsor related that her hands would be covered in blisters from having to physically handle the heavy equipment for eight or more hours. Furthermore, after a burdensome day of work, any results the user does find will have to be handwritten, since there are no video or picture-capturing capabilities with the current model.

When the weather is inclement problems are amplified. If it is raining, the device is at risk due to the fact that it is not waterproof, and there are open wired connections. Further, water could ruin the infrared camera itself, leading to costly repairs or replacements. Also, the scope could run into obstacles and does not have enough shock resistance to handle unexpected impacts. Finally, in the common case that the lens fogs up or is covered with dirt or mud, the user must pull out the scope, clean it, and start the process over from the beginning.

Buying a manufactured scope is typically not an option for research centers such as Tall Timbers. It is a non-profit organization, and does not have the budget for a system that can cost up to $6000. Thus, research stations like these are stuck in a financial trap, and are unable to get adequate tools for underground research.

Final Needs Statement:

In all, there is a need for gopher scopes to have improved weather and impact durability, greater mobility, data-acquisition capability, and reduced weight, space and cost.

C. Goal Statement and Objectives

Due to the fact that the scoping system will be used in the field, it is essential for it to be resistant to water as well as dirt, and be able to withstand temperatures from 0 to 100°F. It should be resistant to shock as well in case it is dropped or hits any obstacles. The battery life should last for as long as it takes to complete full days of field testing and the entire system should fit into a backpack and weigh less than the current scope at Tall Timbers.

Gopher tortoises begin to burrow as soon as they hatch with some of their burrows being as small as 4 to 6 inches; because of this, the scope should be small enough to navigate inside these smaller burrows. Not disturbing the animals in the burrow is important as well, therefore the camera will be infrared and the rover will move as quietly and quickly down the burrow as possible. The camera should be able to record images, capture still photos and take temperature and humidity readings in the burrow. The entire system must also be completed within the teams budget.

The main goal is to design a mechanism that has testing sensors, better durability, and more advanced video capabilities than the current system in order to enhance the surveying process of gopher tortoises.

D. Constraints

The following is a list of the constraints of the project. The constraints are crucial to the success of the project and will allow the team to provide a fully functioning scope to the sponsor.

- The rover must not be more than 6 inches wide
- The entire system must remain under 50lbs
- The total cost must not exceed $2000
- The entire system must be water proof
- The battery has to have a life of at least 8 hours
- The camera must be infrared

Below in Table 1 is a summary of the desired subsystem features that will be explained in more detail in the following sections.

TABLE I. SUMMARY OF DESIRED SUBSYSTEM FEATURES

Subsystem	**Features**
Power	8 hours of operation
Camera	Infrared
	Tilt/Pan
	Screen
Maneuverability	Cornering
	Anti-flipping
Data Acquisition	Temperature
	Humidity
	GPS
	Depth
	Recorded video
User Interface	Control Switches and Display
Tether	Durable
	Flexible
	10-15 meters in length

II. DESIGN AND ANALYSIS

This section introduces the reader to the specific mechanical as well as electrical design concepts developed by the team. These design concepts are discussed in full detail and then a series of decision matrixes are analyzed in order to select the most appropriate designs. A functional analysis is then provided, explaining each component of the design in more detail. The last section focuses on the programming aspect of the design.

A. Design Concepts

1) Mechanical

Three chassis designs are being considered for this project: a linear track, a tri track, and a wheeled chassis. One design objective of the system is optimum subterranean maneuverability. The linear track and tri track systems excel in this area because tracks distribute the weight of the rover more evenly across the ground and put less pressure on the ground; because of this the rover will not be as likely to sink or get stuck in soft terrain. Also, the greater surface area of the treads provides more traction on the terrain. Although the linear and tri track chassis both accomplish this, the linear track performs better because of its geometry. The two track chassis also provide more stability than the wheeled system, especially on inclines. Therefore they are able to handle going over obstacles easier than the wheeled chassis is. The tri track chassis handles obstacles the best out of the three designs because of its geometry.

The rover also needs to operate quickly and quietly. In this area the wheeled design has the edge because it requires less torque than the tracked chassis to move down the burrow and is therefore quicker. The wheeled design is also rather simplistic, so the noise created by the wheels is minimal and thus does not cause as much of a disturbance to the gopher tortoise. The wheeled design has an advantage in agility as well considering it can turn more easily than either tracked chassis.

Creating a durable system is another objective that needs to be met. The linear and tri track chassis are not as durable as the wheeled chassis due to the fact that they contain multiple parts for operation which can possibly get jammed; the tread belt of the track can get misaligned from the chassis and stop the operation. On the other hand, the two tracked chassis are not able to get punctured and they do not rely on tire pressure to be operational. In this way the tracked systems are more durable than the wheeled design. Some other flaws of the two tracked chassis are that they are more expensive, and require more power to operate than the wheel design.

Along with the three designs of the chassis, three designs for the camera placement are possible: within the body of the chassis, in front of the chassis, and on top of the chassis. The camera within the body of the chassis is advantageous considering the fact that it maintains compactness of the rover resulting in easier portability. In addition, since the camera is contained within the body of the chassis it is not as likely to get damaged with this design as with the designs where the camera is placed in front of the rover or on top of the chassis. Placing the camera within the body or on top of the body decreases the amount of cost because it does not require additional parts. However, placing the camera on top of the body will cost more than placing it within the body because of the housing needed to encapsulate it. Placing the camera within the body makes it more challenging to maintain a diameter of four inches for the body, and the pan and tilt view of the camera is limited by the body of the system; placing them in front or on top of the body of the system does not limit either aforementioned factor. The design with the camera within the body and the design with the camera on top of the body will not have as great of visual quality as the design with the camera within the body. This is due to the fact that the footage from the camera in front of the body is not influenced by the vibrations of the chassis while moving through the terrain, and since the camera is in front of the chassis and connected by a rod, the camera will have an upright orientation at all times. If the system flips while the camera is within the body, the camera orientation is inverted, and if the system flips while the camera is on top of the system, the orientation will be skewed and the rover will be inoperable.

After weighing the significance of each advantage and disadvantage of all the designs for the chassis and camera placement, the linear two tracked chassis and camera placed within the body were the designs decided upon to use for prototyping.

2) Electrical

Current design requirements specify that the rover be able to film, record and display video; display data from below ground temperature and humidity sensors; and be able to be driven using a video game controller. In order to make this possible the combination of a microprocessor and a microcontroller will be needed. The microprocessor will provide the bulk of the computational power and will be the backbone of the user interface. It will interpret the inputs from the game controller and relay them to the rover. It will also receive the video feed from the camera and output it to a LCD display. On the other hand, the microcontroller can be much simpler and does not need as many interfacing options. Its main requirement will be to have a small form factor so it can fit on the rover easily. It will receive control signals from the microprocessor through the tether and use those to control the motor drivers. It will also collect data from the temperature and humidity sensors and relay that data to the microprocessor at regular intervals.

Additionally, the design team is working to keep this system as simple as possible so that an electronics hobbyist or ambitious gopher tortoise researcher could recreate the design. For this reason the design team has decided to use an open-source microprocessor and microcontroller. These devices are very affordable and easy to obtain. They also have large communities of developers who are dedicated to improving the platform. This will make it easy for the design team or users to find replacement parts or make improvements to the platform. In this paper the BeagleBone Black (BBB) and Raspberry Pi B+ (RPi) will be considered for the microprocessor and the Arduino Micro, Arduino Uno and Arduino Mega will be considered for the microcontroller.

B. Decision Matrices

Below in Tables 2 through 6, the decision matrixes for both the mechanical components of the design as well as the electrical components of the design have been displayed in order to select which design was most suitable for each separate category. How these matrixes were constructed is explained in more detail in the following section.

TABLE II. DECISION MATRIX FOR MECHANICAL DESIGN OF CHASSIS

		Design		
Category	**Weight**	Linear Treads	Triangular Treads	Wheels
Size/Weight	9	5	3	6
Stability	7	6	6	4
Power Consumption	7	4	4	7
Noise/Invasiveness	4	5	5	5
Durability	7	5	6	2
Subterranean Maneuverability	8	8	6	3
Reproducibility	4	5	4	5
Portability	5	4	4	6
Cost	7	5	4	6
Total		**309**	**267**	**281**

TABLE III. DECISION MATRIX FOR MECHANICAL DESIGN OF PAN AND TILT SYSTEM

		Design		
Category	**Weight**	Inside Chassis	Outside Chassis	Turret Camera
Size/Weight	9	10	7	4
Stability	3	10	3	6
Noise/Invasiveness	2	8	2	5
Durability	7	9	4	4
Subterranean Maneuverability	3	7	6	4
Reproducibility	4	4	7	6
Portability	3	8	4	6
Visibility	7	3	9	10
Cost	8	8	6	5
Total		**345**	**273**	**256**

TABLE IV. DECISION MATRIX FOR MECHANICAL DESIGN OF HOUSING

		Design		
Category	**Weight**	Plexiglass	Plastic	Glass
Weight	7	7	7	4
Stability	9	7	6	6
Durability	7	5	6	7
Reproducibility	4	6	7	3
Visibility	8	9	9	4
Cost	7	5	4	6
Total		**278**	**273**	**217**

TABLE V. DECISION MATRIX FOR ELECTRICAL DESIGN OF MICROPROCESSOR COMPARISON

		Design	
Category	Weight	Raspberry Pi B+	Beagle Black Bone
Power Consumption	3	5	5
Memory	5	8	8
Overall Cost	7	7	7
Expandability	5	7	6
Interface	10	10	3
Community	3	7	4
Graphics	4	10	7
Processor	8	7	10
Total		**376**	**364**

TABLE VI. DECISION MATRIX FOR ELECTRICAL DESIGN FOR MICROCONTROLLER COMPARISON

		Design		
Category	Weight	Arduino Micro	Arduino Uno	Arduino Mega
Power Consumption	3	7	5	5
Overall Cost	7	8	7	3
Size	10	10	3	1
Interface	8	4	7	8
Processor	5	4	7	8
Total		**229**	**185**	**150**

1) Criteria, Method

Chassis

The three distinct chassis options being looked at by the team are compared in Table 2. They are as follows: linear treads, triangular treads, and wheels. The first category being used to determine which chassis is optimum is size and weight. Since the design of the scope has a strict chassis size constraint of approximately four inches, this category has been given a weight factor of 9. Stability is also an important factor when dealing with the design of the chassis system. Since the rover is going to be very small and very light, it is important that it does not flip when traveling over the rocky terrain inside the burrows. The stability category, therefore received a weight factor of 7. Power consumption is another important item to consider when deciding on a rover design due to the fact that the entire system is going to be powered for an entire day without the ability to be recharged. This category, received a weight factor of 7. Noise/invasiveness was also considered. It is important that the rover system is a minimal disturbance to any animals that might be living in the burrow. This is not as important of a constraint however and since the rover is so small, there will not be very much noise being made therefore it received a weight factor of 4. The next category is durability, which is one of the rovers main design constraints. It is required by Tall Timbers that the rover be waterproof, shock proof, and dirt resistant, therefore this category received the weight factor of 7. The most important category next to size and weight is subterranean maneuverability. If the rover is not able to move down the burrow in a quick and efficient manner, then the burrow will not be able to be scoped. This category therefore, received a weight factor of 8. The next category is reproducibility. The sponsor desires a product that is reproducible, but the main goal is something that is able to scope burrows in an efficient manner. Therefore this category received a weight factor of 4. Portability is also important to consider when looking at the chassis design due to the fact that the entire scoping system has to fit compactly into a backpack. Since it is known that all of the chassis are relatively the same size and weight, this category was given a weight factor of 5. The last category that was considered was cost. As previously mentioned, Tall Timbers is a non-profit research center and therefore does not have the funds to purchase most of the scopes on the market at this time. Therefore it is desirable for the team to build this scope as cheaply as possible while also keeping the rest of the categories in mind. Cost, therefore, received a weight factor of 7.

Pan and Tilt System

There were three distinct pan and tilt system placement options which are outlined in Table 3: inside the chassis, outside the chassis, and a turret camera. The first category that would determine which system was optimal was size and weight. Since the scope has strict size constraints, it is important that the pan and tilt system are as compact as possible. This category therefore has been given a weight factor of 9. Stability is also an important factor to look at, but since the pan and tilt system will be placed onto the rover system itself the stability is not as much of a factor. Therefore, the stability factor in this case received a weight factor of 3. The next category that was considered was noise/invasiveness. Since the pan and tilt system along with its motors will be placed inside a Plexiglas box, the noise will be dampened as is therefore not as much of a factor. Therefore this category was given a weight of 2. Durability is one of the main design constraints of the entire scoping system. As previously stated, the entire system has to be waterproof, shock proof, and dirt resistant. Due to the importance of this, durability received a weight of 7. The next category was subterranean maneuverability. Since the pan and tilt system is not actually moving along the burrow, but is instead being used to observe what is taking place inside it, this category was given a weight factor of 3. Reproducibility was the next category considered and though the sponsor desires something that is reproducible, the main goal is to have a product that can scope burrows in an efficient manner. Therefore, this category received a weight factor of 4. The next category was portability. Since the pan and tilt system is mounted on the chassis body, portability is not as much of a concern and therefore received a weight factor of 3. The main function of the pan and tilt system deals with visibility, which is the next category. The pan and tilt system needs to be able to look around the burrow in order to observe not only the tortoises, but also the other creatures that share its burrow. Due to this high importance, this category received a 7. The last category was cost. As previously stated, it is desirable to build this scope as cheaply as possible while also taking the other categories into account. Therefore, cost was given a weight factor of 8.

Housing

There were three different housing materials that were outlined in Table 4: plexiglass, plastic, and glass. The first category that determined which material was superior was weight. The design team wants the system to weigh as little as possible in order to make it easier for the researcher to carry the system through the field. Therefore, the weight category received a weighting factor of 7. The next category was stability. The housing covering the rover must not shatter or crack at any time while in the field. If this happens, then all of the internal components will be exposed and the system will fail. This category received a weight factor of 9. The durability of the housing is also very important. If the housing scratches or becomes worn down the visibility of the camera could be reduced and scoping the burrows would become impossible. Therefore, the durability category received a weighting factor of 7. The next category was reproducibility. It is important that the entire scoping system be reproducible so that it if any parts fail they can be easily replaced by the user. This category received a weight factor of 4. The next category was visibility and this is extremely important due to the fact that the camera must be able to see through the housing material so that the user is able to scope the entirety of every burrow and identify the plant and animal species present. Therefore, this category received a weighting factor of 8. The last category considered was cost. The cost of the entire system must be low due to the fact that Tall Timbers is a non-profit organization. This category received a weight factor of 7.

Microcontroller

The microcontrollers were evaluated using the criteria summarized in Table 5. The least important criteria was determined to be the power consumption and processor weighted 3 and 5 respectively. Similar to the microprocessors, the power used by different microcontrollers is fairly uniform and relatively small and so does not have a large effect on the design. Unlike the microprocessors, the processor of the microcontroller is not a major deciding factor. All of the microcontrollers being considered had processors that were more than sufficient to meet their performance requirements.

The deciding factors for the microcontrollers were the overall cost, interface and size. These were weighted 7, 8 and 10 respectively. The overarching goal of this project is to make a scope cheaper than the competition. With this in mind, the team was careful to only consider inexpensive options. The interfacing capabilities of the microcontroller are important for the same reasons they were important to the microprocessor. The microcontroller will have to send and receive data from the microprocessor as well as control four motors and read inputs from two sensors. This will require a fair number of GPIO pins to achieve. Size was the most important factor because the microcontroller will be located on the rover. In order to keep the rover under four inches in diameter while still fitting treads, motors batteries and a camera, very little room has been left for the electronics. In order to meet all of the design requirements and still fit this form factor, each piece of electronic equipment used on the rover will need to be as small as possible.

Microprocessor

In order to evaluate the different microprocessor options the design team came up with the criteria summarized by the decision matrix in Table 6. The least important criteria were decided to be power consumption and community, each of which were weighted as a 3. While power consumption is an important consideration for the overall design, the difference in power usage between most microprocessors is small enough that it does not have a large impact on the design. Similarly, while having a community of consumers that use the microprocessors can aid in programming and make spare parts easier to obtain, it is not thought to be important enough to heavily influence which microprocessor we use.

The mid-tier criteria were determined to be the graphics, memory, expandability and overall cost. These were weighted at 4, 5, 5 and 7 respectively. Graphics are a necessity because the end-user must have a live feed of the camera input. It is also one of the major performance differences between the two microprocessors being considered and it is important that this difference be accounted for in the decision matrix. Memory is weighted as average importance because it is needed to record video and images along with keeping the operating system of the microprocessor onboard. Expandability refers to the number of add-on devices that have been designed specifically for the microprocessors by manufactures such as Adafruit and SparkFun. These add on devices can give the microprocessors LCD screen or temperature sensor capabilities without the team having to design custom options. However, since this is not a necessity to complete the design, it was given a lower weight. Cost was given a slightly higher weight since a major part of the design is to make the rover cost effective. The cost category does not just account for the cost of the microprocessor, but also the cost of the necessary peripherals such as microSD cards or USB cables.
The most critical criteria were determined to be the processor and interface capabilities; weighted 8 and 10 respectively. The microprocessor will be the hub for the majority of the data being input and output to our system. The processor will need to have a high enough clock speed in order to make the device function with as little lag as possible and ensure a good end-user experience. What connectivity options are available on the microprocessor will also determine how well the final design works. Available input and output ports can include but are not limited to USB, HDMI, RCA, GPIO, I2C and CAN. The more options available, the more likely a product that will be compatible and meet the criteria will be found.

2) Selection of Optimum Designs

Mechanical Design of Chassis
The first category that was analyzed was size/weight. None of the chassis designs scored very high in this category due to the fact that it is difficult to purchase them in such a small size. The triangular tread design however, would be the largest in the vertical direction due to the shape of its treads; therefore it scored the lowest out of the three. The next category was stability; both the linear as well as the triangular tread designs scored the same due to the fact that their treads allow for more surface area and therefore greater stability. The wheeled design has less surface area and therefore scored less than the other two designs in this category. Power consumption was also considered and the wheeled chassis out scored both the linear and triangular treaded chassis due to the fact that the wheeled chassis requires less torque. The next category was noise/invasiveness. All of the chassis scored the same in this category due to the fact that all are equipped with the same number of motors and therefore would all make approximately the same amount of noise. The next category was durability. Both of the treaded chassis scored high in this category due to the fact that they are compact and will have treads that are designed for all terrain. The wheeled chassis however, is not nearly as durable as the treaded chassis and scored low in this category. Subterranean maneuverability was the next category and the linear treads outscored all of the other designs. Treads are specially designed to maneuver over obstacles. Since the linear treads do not have any open spaces that rocks or dirt can become trapped in as compared to the wheeled and triangular tread design, it has the most maneuverability. The next category was reproducibility and all of the designs scores were fairly even. The triangular treaded chassis scored slightly lower than the other two designs due to the complex shape of its treads. Portability was the next category; the wheeled design scored higher than both treaded designs due to the fact that the wheeled design is easier to clean and place in a backpack. With the treads larger surface area, there is more dirt and cleaning required. The last category was cost and again the wheeled design was rated highest due to its simplicity. Treads are often more expensive due to their complex nature and therefore both the linear and triangular tread designs were ranked lower. After all of the scores were summed the linear chassis had the highest overall score of 309 and therefore was the design that was chosen for the mechanical design of the chassis.

Mechanical Design of Pan and Tilt System
The first category that was analyzed was size/weight. The pan and tilt system located inside the chassis scored the highest out of all three designs due to the fact that it is the smallest so it can fit inside the chassis body. The turret camera is slightly larger and would have to be placed on top of the chassis body, which would add unnecessary height. Stability was the next category analyzed and again the pan and tilt system inside the chassis ranked highest since being placed inside the chassis body makes it the most stable. The least stable design was the pan and tilt system placed outside the chassis. This design could potentially cause an imbalance in weight and could result in the chassis flipping over. The turret camera ranked in the middle of the two designs due to the fact that it is attached to the chassis body, but it is not inside it like the first design. The next category that was considered was noise/invasiveness and the pan and tilt system outside of the chassis body scored the lowest out of the three designs. This is due to the fact that it is sticking out from the chassis body, while the other two designs are within the chassis body. Durability was considered next and both the pan and tilt system located outside the chassis as well as the turret camera scored low due to the fact that, if dropped they would be more prone to breaking since their systems are not surrounded by the chassis wall. Then next category that was considered was subterranean maneuverability. The turret camera scored the lowest here due to the fact that it would sit very high on the chassis body and would have the potential to scrape the top of the borrow. Reproducibility was considered next and the pan and tilt system inside the chassis scored the lowest due to the fact that it will be completely made from scratch. The other two systems will have off the shelf parts and will be able to be assembled in a

more simplified manner. The next category that was considered was portability. The pan and tilt system outside of the chassis body scored the lowest in this category due to the fact that it sticks out from the chassis body. This makes it more difficult to store compactly in a backpack. Visibility was also considered and the pan and tilt system inside the body of the chassis scored the lowest due to the fact that body of the chassis will obstruct some of the visibility of the pan and tilt system. The turret camera scored the highest in this category due to the fact that it rests on the top of the chassis body and nothing is obstructing it from having a complete 360-degree view. The last category was cost. The pan and tilt system inside the chassis scored the highest in this category due to the fact that is can be made with relatively cheap parts. After all of the scores were summed the pan and tilt system inside the chassis had the highest overall score of 345 and therefore was the design that was chosen for the mechanical design of the pan and tilt system.

Mechanical Design of the Housing Material

The first category that was analyzed was weight. The heaviest of the three materials was glass due to the fact that it is about twice as dense as plexiglass and plastic. The next category that was analyzed was the stability of the materials. Plexiglass is both stronger and more shatter-resistant than plastic or glass and therefore was the most stable of the three materials. Durability was the next category and glass scored the highest due to the fact that it is more scratch resistant that plexiglass and plastic. The next category that was analyzed was the reproducibility of the materials. Since the design team is constructing this housing from scratch, it is important that the material is easy to work with. Plastic is readily available and also can be cut and molded with ease. Therefore, plastic scored the highest in this category. Though glass is also available, it is much more difficult to cut.

The visibility of the materials was considered next and both plexiglass and plastic have good resistance to glare, allowing the camera to see easily through them. Glass, on the other hand, reflects light much more readily and this can cause glares and unwanted reflections. The last category that was analyzed was cost and glass was the cheapest of the three materials. Since plexiglass and plastic are more durable and stable however, the long-term maintenance and replacement costs can be much cheaper than with glass. After all of the scores were summed, the plexiglass material had the highest overall score of 278 and therefore was chosen as the housing material.

Electrical Design for Microprocessor Selection

Using the criteria described previously, the Raspberry Pi B+ (RPi) and BeagleBone Black (BBB) were compared as options for the microprocessor. The two microprocessors were found to be identical or nearly identical in several categories. These categories included power consumption, memory, and overall cost. In all of these categories the two microprocessors received the same scores.

In terms of categories where the RPi and BBB received different scores, the BBB was determined to be much more capable than the RPi only in terms of processing power. The BBB uses an ARM8 chip with a clock speed of 1 GHz. In comparison the RPi only has a ARM7 chip with a 700 MHz clock speed.

The RPi received higher scores in the community, expandability, graphics and interface categories. The community and expandability scores go hand in hand since they are both based off of the popularity of the product. The RPi is much more popular than the BBB among tech enthusiasts and hobbyists. Because of the large community that has formed around building projects with the RPi there are many forums, websites and other resources dedicated to learning how to use it. There is also an abundance of coding examples and libraries of functions that the team can borrow from. The size of the community has also driven manufactures to create many add-on kits specifically for the RPi. These kits make it easy to expand the capabilities of the RPi using kits such as motor drivers, LCD displays and other sensors.

In the graphics category the BBB was found to be adequate despite receiving the lower of the two scores. With a PowerVR SGX30 GPU that performs at 1.6 GFLOPS the BBB is powerful enough to processes and display the video from many mid-range cameras. However, the RPi’s dual core GPU is capable of 24 GFLOPs making it 15 times more powerful than the BBB. Having a more powerful GPU would allow the design team to replace the current camera with one of higher resolution without having to change any hardware if the need arises.

In terms of interface capabilities the BBB is often considered to have an advantage over the RPi. The BBB has twice as many GPIO (general purpose input/output) pins as the BBB which allow it to send and receive signals from a large number of external sensors. The BBB also has a more extensive selection of CAN, SPI and I2C options than the RPi. However, for this project it was decided that USB would be the most utilized connection. The RPi has four USB 4.0 connections compared to the BBB’s one.

As can be seen by the above analysis, the Raspberry Pi B+ is a very capable board with a small price tag. It has the ability to connect to all of the peripherals the project will require and provide excellent processing speeds and video handling capability. For this reason it was decided that the Raspberry Pi B+ was betters suited for this project than the BeagleBone Black.

Electrical Design for Microcontroller Comparison

Using the criteria listed in the decision matrix in Table 6, the three Arduino boards were compared. There was very little difference between the boards in terms of power consumption. In the categories of interface and processor the Mega easily won with the Uno not far behind. With that said the Micro still provides sufficient processor speeds and interfacing capabilities for this project, despite being far less capable than the Mega or Uno. The Micro's strong suites are in the heavily weighted size and cost category. The Mirco is about five times smaller than both the Uno and the Mega and is the least expensive of the three. Since the Micro was by far the best option in terms of size and cost, and provides adequate processor and interface options, the design team selected it for use on the prototype.

C. Functional Analysis

3) Mechanical

There are several primary specifications that affect the overall design of the scope. The most important of these is cost. The cost for the entire project cost should be no more than $2000 and ideally around $500 for the cost of the final product. The weight and size of the final design is also important to consider, as one person must be able to carry the scope for several miles. For this reason, the full system must weigh no more than 50 pounds and fit in a backpack.

The mechanical subsystems have additional specifications that must also be considered when creating the final design. In order to fit into even the smallest of gopher tortoise burrows, the rover should be approximately four inches in diameter. It will also need to be maneuverable enough to make tight turns, and have good enough traction to be able to function in wet and muddy conditions. It will be designed so that it doesn't flip over while navigating the burrow. To handle these requirements, a body is designed that is 4 inches from one edge of the track to the other. The height of this rover is currently about 2 inches, since most burrows are oval in shape. It will have a treaded design that allows it traction to overcome the resistance from the tether, as well as resistance from obstacles within the burrow. The force that is provided to the treads is about 35 N, while the preliminary estimate for static tether friction force is only about 5.4 N. This yields enough net force for the rover to overcome obstacles. Just how competent it is at doing so will be determined in field testing.

Current tread dimensions for the rover allows a contact patch of about 52 cm^2 (versus about 8 cm^2 for wheels). This allows it to have greater traction, and avoids the possibility of a non-motorized wheel getting pinned between obstacles. The material for the treads must be durable and withstand tension and shock. Sectioned rough patches can be attached to the tread to give it additional tractive force. A challenge arises in finding the proper length belt for the track. It is possible that a desired track product has a length determined by the manufacturer. Hence, the rover wheelbase and body may have to adjust to fit the treads.

The body itself is tentatively going to be enclosed in plexiglass. This material is easy to acquire, relatively inexpensive to cut, and has unique capabilities. The front camera that will be mounted to the chassis needs to be infrared capable. Certain manufacturers produce infrared-permeable plexiglass, and can custom fabricate certain dimensions. Hence, plexiglass provides both the needed strength and durability, but also visibility. It order to mitigate glare, the orientation of the plexiglass in front of the camera will be modified [4].

In addition to the casing material, the body also needs to be weatherproof. Namely, it needs to be water and dirt resistant in order to survive in burrows that are dug into the earth. Hence, special attention must be given to the type of adhesive used to seal out any potential debris, as well as the type of sealing for each wheel axle (so that dirt and water do not seep in through the axles that protrude out of the body).

The body must be strong enough to withstand the weight of the internal components as well as shock from external forces. The high strength of the plexiglass (110MPa yield strength, 115MPa flexural strength [4]) ensures that it can withstand the impact of colliding with an object at the rover's top speed, as well as not fatigue under the load of all of the components being fastened to it.

A pan-and-tilt system is a major desire by the sponsor. Yet, even with a small camera, the need for the camera rotation, as well as the need for a mounting frame that the camera sits in, means that small space will be an issue for the pan-tilt system. To mitigate, a pan-tilt system with relatively collinear members can be placed along the length of the chassis body, a two motor system is used to navigate up/down and left/right.

Finally, the rover will be dependent on a tether. Gopher tortoise burrows can reach up to 15 m in length, and almost 5 m deep. Hence, sending a wireless rover increases the risk of losing the rover within the burrow. With a tether, even if power is lost to the rover, it can still be physically pulled out of the rover. A tether also allows for the power source (battery) to be above ground, transmitting power to the rover through the tether. Hence, the tether will have wires to control the rover, as well as having a tension guide wire (perhaps a steel cable) to relieve tension from the electronics cables. The tether is to have a tough yet flexible exterior. It is desired that a Kevlar material sheath can be used to protect the wires, while not being too rigid or large.

4) Electrical

A Logitech F310 gamepad was chosen because it has drivers that work with the RPi. Having an intuitive user input is a great way to make the learning curve very low. The two joysticks each control two sets of motors: rover left tread, right tread, camera pan and tilt motors. The USB inputs from the gamepad can be translated to keyboard inputs which will be read by linux based scripts. Maximum current draw from the gamepad is 400mA at 5V.

Raspberry Pi B+ has a 700 Mhz CPU and a very capable GPU to handle the data input/output. The four USB ports are also useful in receiving input from the RCA/USB adaptor for video feed, the gamepad for user input, power and data to the Arduino micro. The RPi has a current draw range of 600mA to 1.8A at 5V.

The lithium ion battery is 12V and has a capacity of 14AH. If the current drawn from the system is an estimated 6A, then the system can operate for 2.5 hours continuously. The battery weighs only 0.75kg so if the energy capacity is not enough for a full 8 hour day of operation then a second battery can be purchased and easily replace the drained battery when needed. The rover system is not expected to be operating longer than a continuous 3 hours out of the 8 hour work day so the battery may be sufficient. There is a power converter from 12V to 5V 3A USB port that will power the screen and RPi with a USB splitter. A DC-DC converter needs to be purchased to deliver continuous 12V output to the camera and motor drivers.

Arduino Micro is small in size and has ample performance in the CPU to read the USB input from the RPi and output PWM signals through the GPIO pins. The GPIOs will also be used for a 4 pin temperature and humidity sensor input. The maximum current draw of the Arduino micro is 50mA at 5V.

Motor drivers use a L298 chip to read the PWM signal from the Arduino to change the power outputted to the motors. Each motor driver has signal input and output for two motors. Each motor driver has an input of 12V and the current draw changes based on the load of the motor.

EasyCap DC60 RCA to USB adaptor converters the RCA video feed from the camera, and converts it to USB signal. This adaptor was chosen because there are drivers and other projects that use this device on the Rpi. There is a 0.4 second delay because of the analog to digital data conversion. The maximum power draw of the adaptor is 250mA at 5V.

The size of the 7-inch screen has been proven by mass produced products as a great size for mobile monitors. The screen is the same resolution of 800x480 pixels as the camera feed. This does not allow for distorted image quality. Having a USB for power will make for easy integration into the system by adding a USB hub to the 5V 3A adaptor source from the battery. The maximum current draw is 500mA at 5V.

TABLE VII. ELECTRICAL COMPONENT CRITERIA

Component	Category	Actual	Target
Logitech F310	Data interface	USB	USB
	Number of buttons	12	>5
	Number of joysticks	2	>2
Raspberry Pi B+	CPU clock	700 MHz	>500 MHz
	Power usage	3 – 9 W	<5 W
	Number of USB	4	>3
	Large community	Yes	Yes
	GPIOs	40	>0
Battery	Voltage	12 V	=12 V
	Material	Lithium-ion	Lithium-ion
	Capacity	14 AH	>16 AH
	Weight	0.75 kg	<1.0 kg
Arduino Micro	GPIOs		>12
	Size		
	Power usage	250 mW	<5 W
SeeedStudio L298	Voltage input	+5 to 46 V	=12 V
	Max power output	25 W	>10 W
	Number of motors	2	=2
EasyCap DC60	RCA input	Yes	Yes
	USB output	Yes	Yes
Adafruit HDMI 4 Pi	Screen size	7 in	>5 in
	Power usage	2.5 W	<5 W
	Touchscreen	No	No

C. Programming

Fig. 2. Placement of controls on Logitech controller

A majority of the I/O and data processing will be handled by the Raspberry Pi B+ (RPi) located in the User Interface. For this reason, a majority of the code written will also be for the Raspberry Pi. The most critical code will be that which reads in user input from the gamepad joysticks and then makes the rover motors, and pan and tilt motors spin accordingly. When a user moves one of the joysticks on the user interface, the gamepad sends two integer values to the Raspberry Pi; a horizontal coordinate ranging from -32,767 to 32,768 and a vertical coordinate also ranging from -32,767 to 32,768. In order to turn these horizontal and vertical coordinates into useful directions for the motors, they are converted into polar coordinates and the charts in Figure 3 and Figure 4 are used.

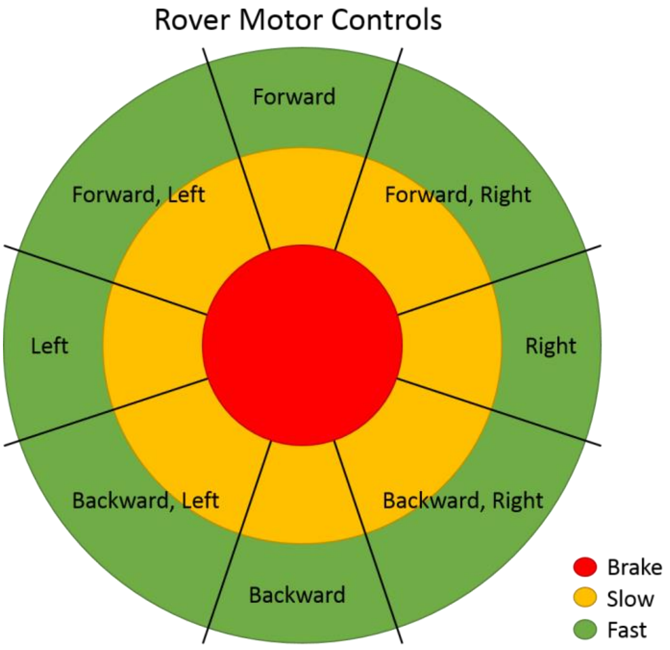


Fig. 3. Chart visualizing how joystick input will control the motor

For the Rover motors, the chart in Figure 3 is used. In Figure 3, the domain of possible joystick inputs is represented as a circle. Radially, the circle is divided into 8 sections, corresponding to the direction that the rover will move for a given angle of the joystick. The domain of possible inputs is further broken up into three concentric circles. If the magnitude of the joysticks position falls into the red circle, then the rover will brake. The yellow circle corresponds to slow movement, and the green circle fast movement. Overall, the domain of possible user inputs is dived into 24 sections.

Once the Raspberry Pi reads in which of the 24 possible cases has been selected by the user, a five bit code is sent to the Arduino. Using this and the information in Table 7, the Arduino is able to send the proper signals to the motor drivers to move the rover as the user instructed. In order to limit the amount of data being sent between the RPi and Arduino, the Arduino will continue to drive the motors in this way until a change in the user input is detected by the RPi.

TABLE VIII. ALL POSSIBLE USER JOYSTICK INPUTS AND THEIR CORRESPONDING ROVER MOTOR OUTPUTS

Case	**Rover Action**	**Joy Stick Input**		**Motor Response**		**Command Sent to Arduino**
		Magnitude	**Angle**	**Left Motor**	**Right Motor**	
0	Brake	0 to 20	0 to 360	Idle	Idle	00000
1	Slow, Right	21 to 16,378	0 to 10	1/2 Speed CW	1/2 Speed CCW	00001
2	Slow Forward, Right	21 to 16,378	11 to 79	1/2 Speed CW	1/4 Speed CW	00010
3	Slow Forward	21 to 16,378	80 to 100	1/2 Speed CW	1/2 Speed CW	00011
4	Slow Forward, Left	21 to 16,378	101 to 169	1/4 Speed CW	1/2 Speed CW	00100
5	Slow Left	21 to 16,378	170 to 190	1/2 Speed CCW	1/2 Speed CW	00101
6	Slow Backward, Left	21 to 16,378	191 to 259	1/4 Speed CCW	1/2 Speed CCW	00110
7	Slow Backward	21 to 16,378	260 to 290	1/2 Speed CCW	1/2 Speed CCW	00111
8	Slow Backward, Right	21 to 16,378	291 to 349	1/2 Speed CCW	1/4 Speed CCW	01000
9	Slow Right	21 to 16,378	350 to 360	1/2 Speed CW	1/2 Speed CCW	01001
10	Fast Right	16,379 to 32,768	0 to 10	Full Speed CW	Full Speed CCW	01010
11	Fast Forward, Right	16,379 to 32,768	11 to 79	Full Speed CW	1/2 Speed CW	01011
12	Fast Forward	16,379 to 32,768	80 to 100	Full Speed CW	Full Speed CW	01100
13	Fast Forward, Left	16,379 to 32,768	101 to 169	1/2 Speed CW	Full Speed CW	01101
14	Fast Left	16,379 to 32,768	170 to 190	Full Speed CCW	Full Speed CW	01110
15	Fast Backward, Left	16,379 to 32,768	191 to 259	1/2 Speed CCW	Full Speed CCW	01111
16	Fast Backward	16,379 to 32,768	260 to 290	Full Speed CCW	Full Speed CCW	10000
17	Fast Backward, Right	16,379 to 32,768	291 to 349	Full Speed CCW	1/2 Speed CCW	10001
18	Fast Right	16,379 to 32,768	350 to 360	Full Speed CW	Full Speed CCW	10010

The pan and tilt functions are dealt with in a similar way to the rover motors. The main difference is that the domain of user inputs is divided into 8 sections as in Figure 4 and three bit command is sent to the Arduino as defined in Table 7.

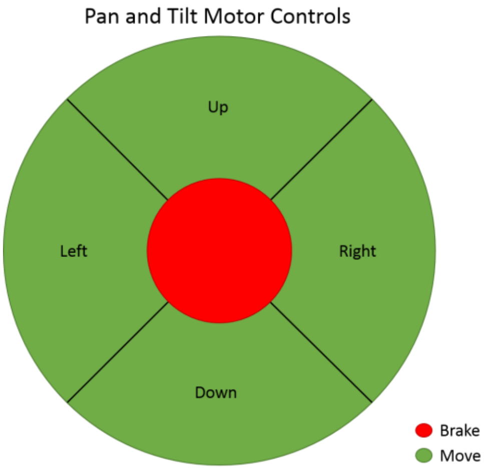


Fig. 4. A chart visualizing how joystick input will control the pan and tilt of the camera

TABLE IX. USER JOYSTICK INPUTS AND THEIR CORRESPONDING PAN AND TILT MOTOR OUTPUTS

Case	**Action**	**Joystick Input**		**Motor Response**		**Command Sent to Arduino**
		Magnitude	**Angle**	**Pan**	**Tilt**	
0	None	0 to 16,378	0 to 360	Idle	Idle	000
1	Tilt Right	16,379 to 32,768	0 to 45	Idle	Full Speed CW	001
2	Pan Up	16,379 to 32,768	46 to 135	Full Speed CW	Idle	010
3	Tilt Left	16,379 to 32,768	136 to 225	Idle	Full Speed CCW	011
4	Pan Down	16,379 to 32,768	226 to 315	Full Speed CCW	Idle	100
5	Tilt Right	16,379 to 32,768	316 to 360	Idle	Full Speed CW	101

Since there is only one USB connecting the RPi to the Arduino, it is important the two devices coordinate with one another so that all messages are sent and received properly. In order to achieve this, the default states of the devices will be the RPi transmitting data and the Arduino receiving data. This will only change when the RPi requests that the Arduino send it data. This request will only be sent once every ten seconds. When it is sent, the Arduino will poll the temperature and humidity sensors and then send the collected data back to the RPi to be displayed on the User Interface. The Arduino will then go back to listening for motor control data from the RPi.

III. DETAILED DESIGN FOR MANUFACTURING

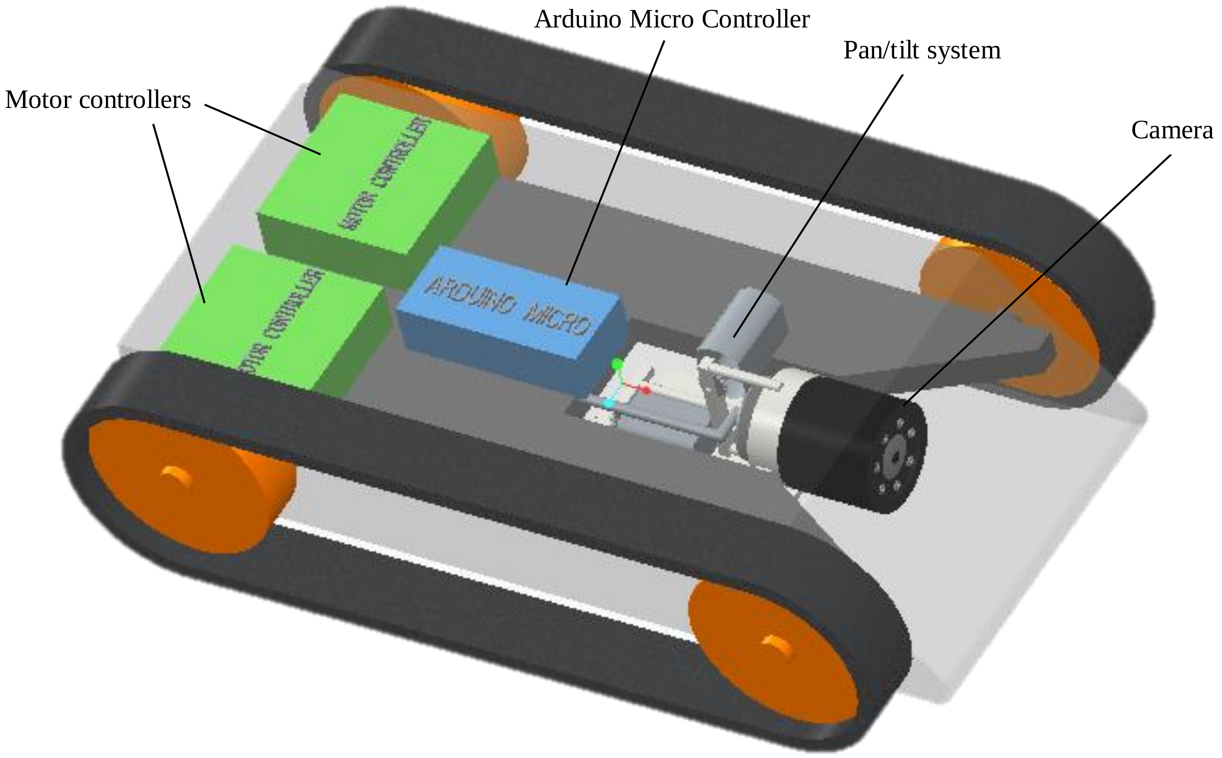


Fig. 5. Current robotic gopher tortoise scope design fully assembled

The scope has undergone multiple design changes, yet the basic layout for the rover remains the same. The chassis is a planar straight-tread chassis that is about 4 inches in width, 7 inches in length, and 2 inches in height. The body resembles the form of an oblong rectangular prism, and is geometrically analogous to a tortoise. This implies that the scope will be able to maneuver comfortably in areas that the tortoises themselves venture. As can be seen in Figure 5, the proposed final design includes mechanical and electrical components. This CAD model was produced in order to demonstrate the ability for the rover to contain all of the required components within its dimensions.

This final design includes a majority of the needed components. The rover currently consists of a dual-motor gear box (on the bottom side of the main body baseplate), motor controllers that manage the rover motors, the Arduino Micro, a compact pan-tilt camera unit with a 7-infrared light camera mounted, a plexiglass exterior casing, and twin treaded tracks.

Not included in this model are the location and orientation of the wiring needed to power and control the scope. Also, temperature and humidity sensors are not yet finalized, and consequently are not included in the current design. Yet, from the tentative layout shown in Figure 5, there seems to be enough room within the casing to fit the appropriate amount of wiring into the body, along with the sensors. A second aspect not included is the tether. It has been decided that the tether will fasten to the back of the plexiglass casing, yet the method for weatherproofing the connection from the tether to the rover is not yet determined. Also, the diameter and position of the cable on the back of the body is not finalized. Yet, the open nature of the scope's body suggests a moderate freedom in choosing the tether connection location. Also noteworthy is the fact that the wheels are sunken in towards the body, versus being flush with the outside of the tread. This allows for the installation of a plate or cover on the sides of the treads to protect the tread and wheels from obstacles getting caught. These side covers will be able to come off, so the user can wash out the treads with water after a day of testing, and not worry about water seeping into the rover.

The approximate placement of the plexiglass housing is made such that the front panel is a flat piece that is tilted. This is done to reduce glare that the camera picks up when the plexiglass is perpendicularly facing the camera. As Figure 6 shows, there is still enough room for the pan tilt system to work, allowing for almost 90° of up/down camera tilting.

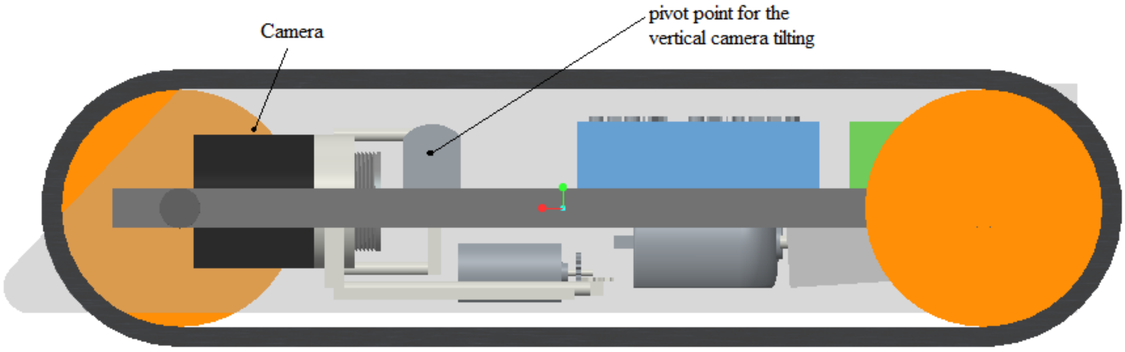


Fig. 6. Side view which illustrates the ability for the camera to be tiltied up and down.

Thus, the camera can pan and tilt within the body without running into glare or hitting the casing itself. Thus, this design is able to maneuver with ease, allow for infrared visibility, and protect its internal components.

The pan-tilt device itself consists of a motor that is mounted to the main baseplate. As the motor shaft spins, it tilts the camera as well as the attached left-right pan mechanism. The second pan-tilt motor is connected to longer tie rods in parallel. As the motor spins one rod goes forward, the other goes backwards. These rods slide along a slotted wall, and are connected on both ends by ball joints. Causing the horizontal angle of the rover to change. A close up of the pan tilt system can be seen in Figure 7.

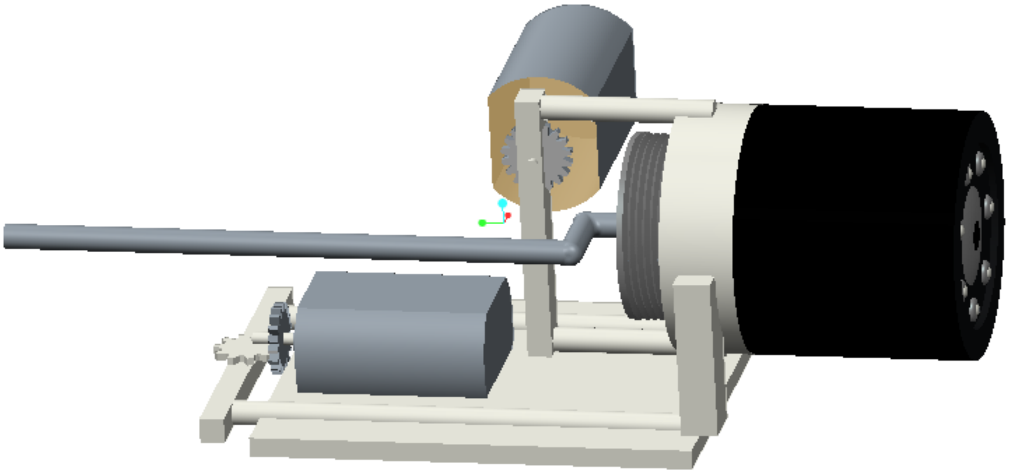


Fig. 7. Compact dual parallel-tierod pan-tilt system with infrared camera.

IV. RISK AND RELIABILITY ASSESSMENT

As with all projects there are certain risks and challenges that will need to be overcome during the course of this year. One of the major requirements for the rover is for it to be waterproof. The rover body will be encased in plexiglass, but there will be a point where the wires from the tether will have to run into the casing. The interior of the case must also be accessible, so not all the joints will be permanently sealed. These two areas of the rover will be extra susceptible to water leakage. The tether and the connections at the rover and the user interface will have to be waterproofed. With the tether it is important that the wires themselves are not stressed when the rover is being pulled out. To mitigate this risk a steel guide wire may be placed in the tether sheath along with the wires. This guide wire will take the brunt of the force when the rover is being pulled out of the burrow. It is also quite likely that the system will at some point be dropped or hit an obstacle during use in the field, so high durability is essential.

V. PROCUREMENT

So far there have been a variety of parts purchased in order to obtain a rough prototype and provide some simple testing. The first component purchased was the chassis. This was a simple kit that consisted of a rubber tracked tread, dual gearbox, two motors, and a baseplate. Two 6V DC motors were purchased to power the pan tilt system (yet to be constructed) and an additional two were purchased in case a backup was needed. In order to drive the motors a Seeed Studio L298 dual H-bridge motor driver was purchased. Another main component purchased was an infrared camera with LED's. In order to read the feed from the camera to the monitor a USB 2.0 video capture adapter with editing software was purchased. To store the video feed and pictures from the camera a 32GB micro flash card was purchased. The Raspberry Pi B+ Broadcom and Arduino Micro without headers were purchased in order to start programming. In order for the two to communicate with each other a Rosewill black USB RCAB-11016 connector was purchased. A lot of the programming will deal with the game pad controller, also purchased, in order to maneuver the rover along with other capabilities. To manage and distribute the voltage from the power supply a USB buddy portable power pole (12V) to USB (5V) converter and device charger was purchased.

Within the next couple of weeks the team plans on purchasing a more durable tread, a battery for the power supply, and materials to construct a pan tilt system. This way a more finalized prototype can be obtained to execute more intensive testing.

VI. COMMUNICATIONS

The design team must communicate not only within the team but also to the teams sponsor Kim Sash at the Tall Timbers Research and Land Conservancy as well as the teams mechanical and electrical advisors Dr. Jonathan Clark, Dr. Bruce Harvey, and Dr. Michael Frank. Communication with the project sponsor is primarily done through email wherein the group updates the sponsor on its progress every two weeks and makes sure that the sponsor is pleased with the work and does not have any suggestions or changes that she wants implemented into the design. The group also meets with the sponsor face to face after every presentation to elaborate on the progress of the design. Constant communication with the sponsor is imperative so that she receives a final product that is satisfactory.

The team meets with the Mechanical Engineering sponsor, Dr. Clark approximately every two weeks to pose mechanical questions regarding the design. The team also presents their presentations to Dr. Clark before the due date so that he can provide suggestions and changes can be made to the presentation.

The team meets with the Electrical Engineering advisor Dr. Frank every two weeks in order to pose electrical questions and to provide an update on the design as a whole. The other electrical advisor, Dr. Harvey, is consulted when the design team has questions regarding electrical components of the design.

The team meets with the senior design class instructors, Dr. Gupta and Dr. Helzer every two weeks for Staff Meetings where the group updates the instructors on their progress. The instructors also give constructive criticism on the teams design process and review the team's performance on past reports as well as presentations.

VII. ENVIROMENTAL AND SAFETY ISSUES

Safety concerns include using a sealed and certified battery because of the toxic chemicals within the battery. A closed, leak-proof battery is used in order to protect the environment and humans that would be exposed to the battery.

The wires and electronics used must be properly coated by non-conducting material in order to eliminate short-circuiting and shock to the end-user. By having a weatherproof casing around the system, the water also cannot penetrate the materials to short circuit the electronics or conduct electricity out of the system where the user might come in contact with.

Environmental issues include disturbance to the animals in the burrow and the condition of the burrow itself. The camera uses an infrared camera with infrared LEDs as a light source in order not to disturb the tortoises with visible light inside the normally dark burrow. Having electric motors and moving parts produces noise that can disturb the burrowed animals, but having a weatherproof case will greatly muffle the noise produced by internal components of the rover. The rover itself is light and does not dig-up the ground it drives on so that the original burrow made by the tortoise is not changed in any way after the survey is complete.

VIII. PROJECT MANAGEMENT (GANTT CHART, RESOURCES,BUDGET)

Scheduling has proven to be a rather challenging aspect to ensuring the project stays on schedule. Hence, throughout the fall semester, the team has allocated 2 regular weekly work sessions in order to determine needed parts, assess project functionality, prepare presentation and communication of project work, and build and test initial models. At this point the team has assembled a working prototype and designed the first full prototype. The Gantt chart, accessible in the appendix, presents the current layout for the remainder of the project. At this rate, the project will be completed by mid-March 2015 with a working final product.
Utilizing machinery and work space at the FAMU-FSU College of Engineering proves effective in saving time and cost for rover fabrication. For the initial prototype, the laboratory equipment provided by advisor Dr. Clark included the voltage power source to test the rover mobility, scrap material for incline tests, and lightweight temporary material, such as cardboard, for the chassis body.

Further investigation into scrap materials in Dr. Clark's lab, as well as other shops and laboratories in the College of Engineering may yield availability of usable plexiglass for the final body casing. Materials and resources can also be obtained through external facilities. For instance, local waste and recycling facilities may have large stocks of raw material that can be used for the final design. Ultimately such efforts can reduce cost and waiting time.

Yet, most of the resources demand a measure of reliability and consistency. Obtaining second-hand material can likely result in mismatching parts, inconsistent thicknesses and tolerances, and worn or broken materials. Hence, to minimize the risk of faulty parts, the group will continue to primarily rely on vendors and manufacturers' marketed products for acquiring resources.
Time, product quality, and financial management are three key components of the design that will continue to remain pertinent. Figure 8 displays the current rate of spending based on a $2000 project budget. To date, the project has spent about $300 – about 15% of the total budget. This figure includes the initial prototype chassis kit, motors for the pan-tilt design, motors for the rover mobility, and spare parts. In addition to parts for a mock-model, the majority of the spent money was directed permanent components. These parts include the infrared camera for the final product, Arduino Micro, Raspberry Pi B+, and the under-interface controller. Hence, part of the amount currently spent reflects long term project investments.

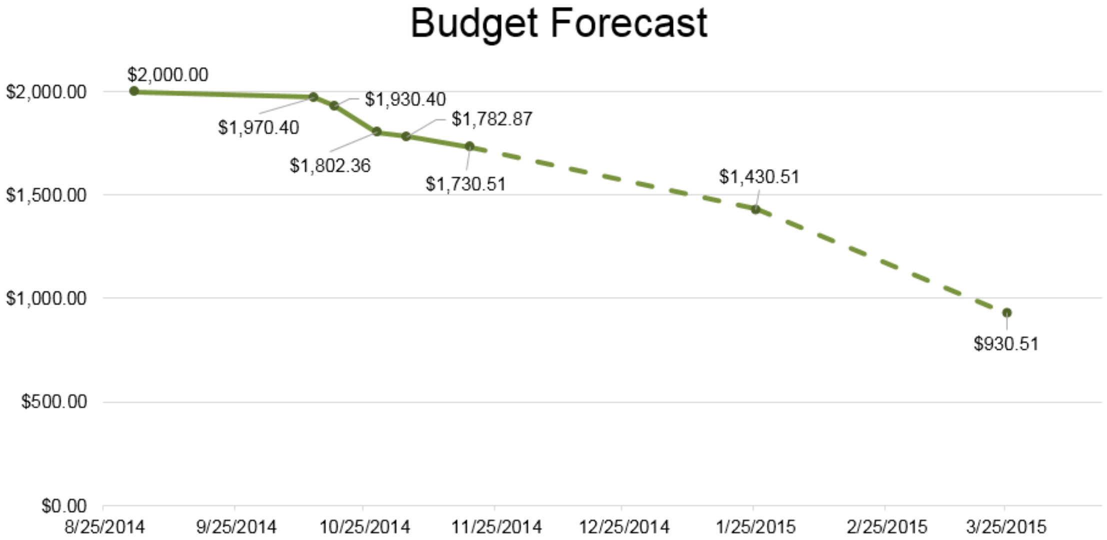


Fig. 8. Total budget burn chart for the entire project scope.

Items that have not yet been purchased include the plexiglass material (and any machining costs), durable tread materials, the wiring and casing for the tether, and the battery power source. In addition, new gear sets will need to be acquired for the modified pan-tilt system. With these costs accounted for, the projected remaining budget will be a surplus of $930.51. This surplus allows for the possibility of spare parts in case of product failure, as well as accessories and additional components the sponsor may later desire. The cost of the final product of course will be much lower than the total amount spent since the amount that was spent includes temporary parts, prototype fabrication, and testing.

IX. CONCLUSION

It is evident that the underground robotic gopher tortoise scope is a device that has a significant role in both biological and ecological research, but also has major obstacles that are preventing it from being used more prominently. The problems that researchers often face include a lack of durability, no video or picture capturing capability, no mobility, and poor ergonomics. High-end rovers may mitigate many of these problems, but are inaccessible for many non-profit research institutes such as Tall Timbers due to their typically large price tags.

Thus, Team 21 is assigned with devising a means to scope these underground burrows. Over the course of this semester they have done extensive research into design options, chosen a final design, and built a prototype that is capable of running. The Raspberry

Pi and Arduino have begun to be programmed, and are actually processing commands from the controller. Preliminary testing has found that the rover can climb a 45° incline.

Regarding future work, the team will fabricate a permanent chassis and assemble the case. The pan and tilt system for the camera will be built, and the gamepad controller will be completely programmed. Further testing will also be done, such as building a mock burrow to mimic the environment in the field.

REFERENCES

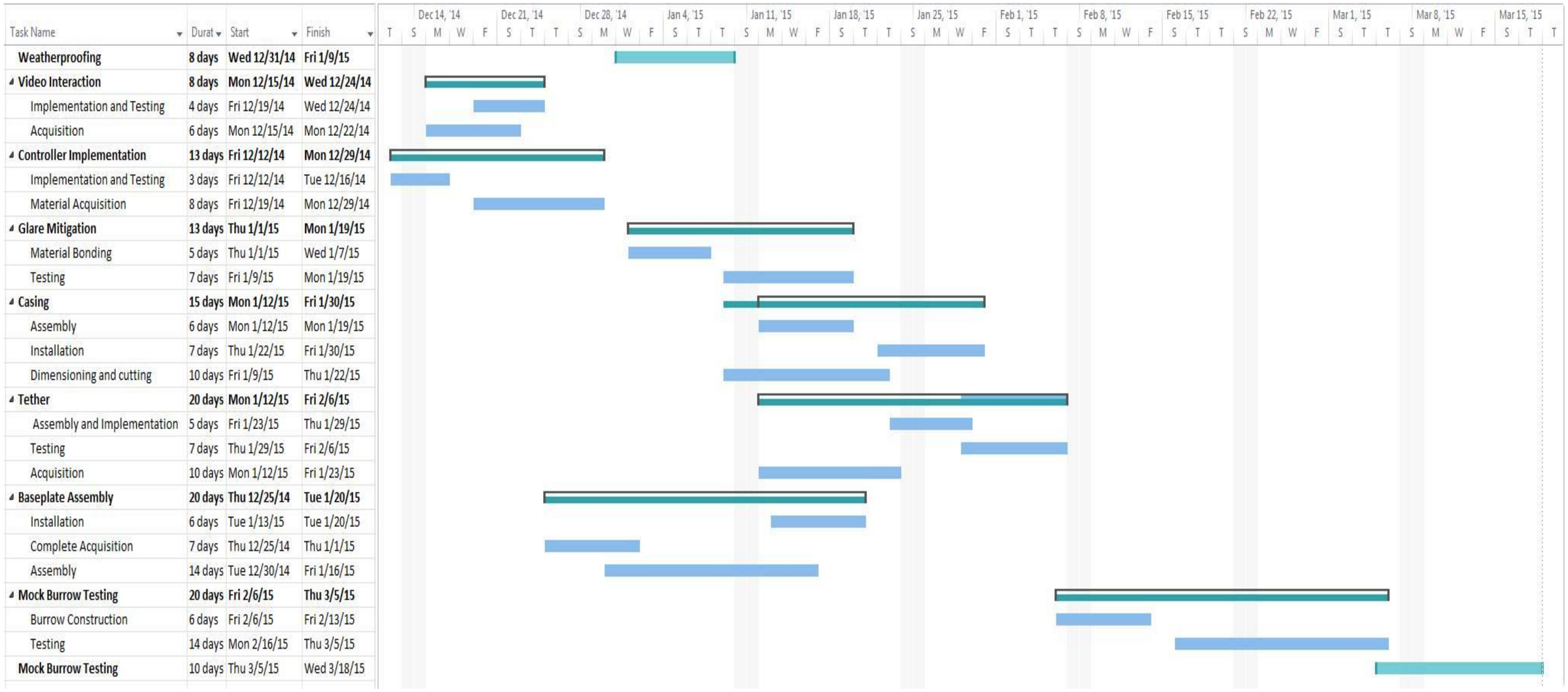
[1] Service, U.s. Fish & Wildlife. "Section 4 of the Endangered Species Act." Candidate Species (n.d.): n. pag. Http://www.fws.gov/. U. S. Fish and Wildlife Service Endangered Species Program, 2011. Web. 25 Sept. 2014. <http://www.fws.gov/endangered/esa-library/pdf/candidate_species.pdf>.

[2] Sandpiper Technologies, Inc. "2006-7 Catalog." Metal Finishing 104.6 (2006): 67. Sandpipertech.com. Sandpiper Technologies, Inc, 2006. Web. 25 Sept. 2014. <http://sandpipertech.com/Sandpiper_Tech_Web_2006_Catalog.pdf>.

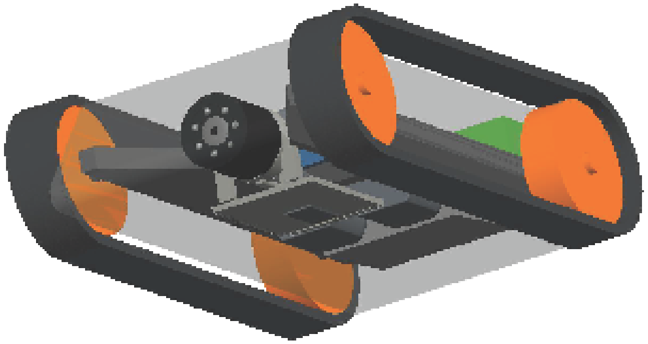
[3] "Properties of PLEXIGLAS," Plexiglas. Evonik Industries. 2010. Web 17 Nov. 2014. <http://www.plexiglas.de/product/plexiglas/en/pages/privacy-policy.aspx>

APPENDIX

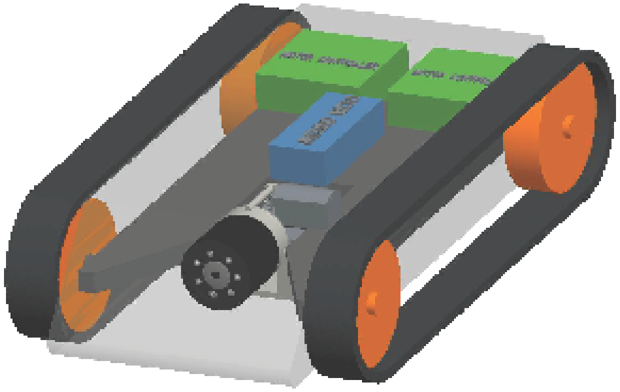
A-1 Gantt Chart



Task Name	Durat	Start	Finish
Weatherproofing	**8 days**	**Wed 12/31/14**	**Fri 1/9/15**
Video Interaction	**8 days**	**Mon 12/15/14**	**Wed 12/24/14**
Implementation and Testing	4 days	Fri 12/19/14	Wed 12/24/14
Acquisition	6 days	Mon 12/15/14	Mon 12/22/14
Controller Implementation	**13 days**	**Fri 12/12/14**	**Mon 12/29/14**
Implementation and Testing	3 days	Fri 12/12/14	Tue 12/16/14
Material Acquisition	8 days	Fri 12/19/14	Mon 12/29/14
Glare Mitigation	**13 days**	**Thu 1/1/15**	**Mon 1/19/15**
Material Bonding	5 days	Thu 1/1/15	Wed 1/7/15
Testing	7 days	Fri 1/9/15	Mon 1/19/15
Casing	**15 days**	**Mon 1/12/15**	**Fri 1/30/15**
Assembly	6 days	Mon 1/12/15	Mon 1/19/15
Installation	7 days	Thu 1/22/15	Fri 1/30/15
Dimensioning and cutting	10 days	Fri 1/9/15	Thu 1/22/15
Tether	**20 days**	**Mon 1/12/15**	**Fri 2/6/15**
Assembly and Implementation	5 days	Fri 1/23/15	Thu 1/29/15
Testing	7 days	Thu 1/29/15	Fri 2/6/15
Acquisition	10 days	Mon 1/12/15	Fri 1/23/15
Baseplate Assembly	**20 days**	**Thu 12/25/14**	**Tue 1/20/15**
Installation	6 days	Tue 1/13/15	Tue 1/20/15
Complete Acquisition	7 days	Thu 12/25/14	Thu 1/1/15
Assembly	14 days	Tue 12/30/14	Fri 1/16/15
Mock Burrow Testing	**20 days**	**Fri 2/6/15**	**Thu 3/5/15**
Burrow Construction	6 days	Fri 2/6/15	Fri 2/13/15
Testing	14 days	Mon 2/16/15	Thu 3/5/15
Mock Burrow Testing	10 days	Thu 3/5/15	Wed 3/18/15

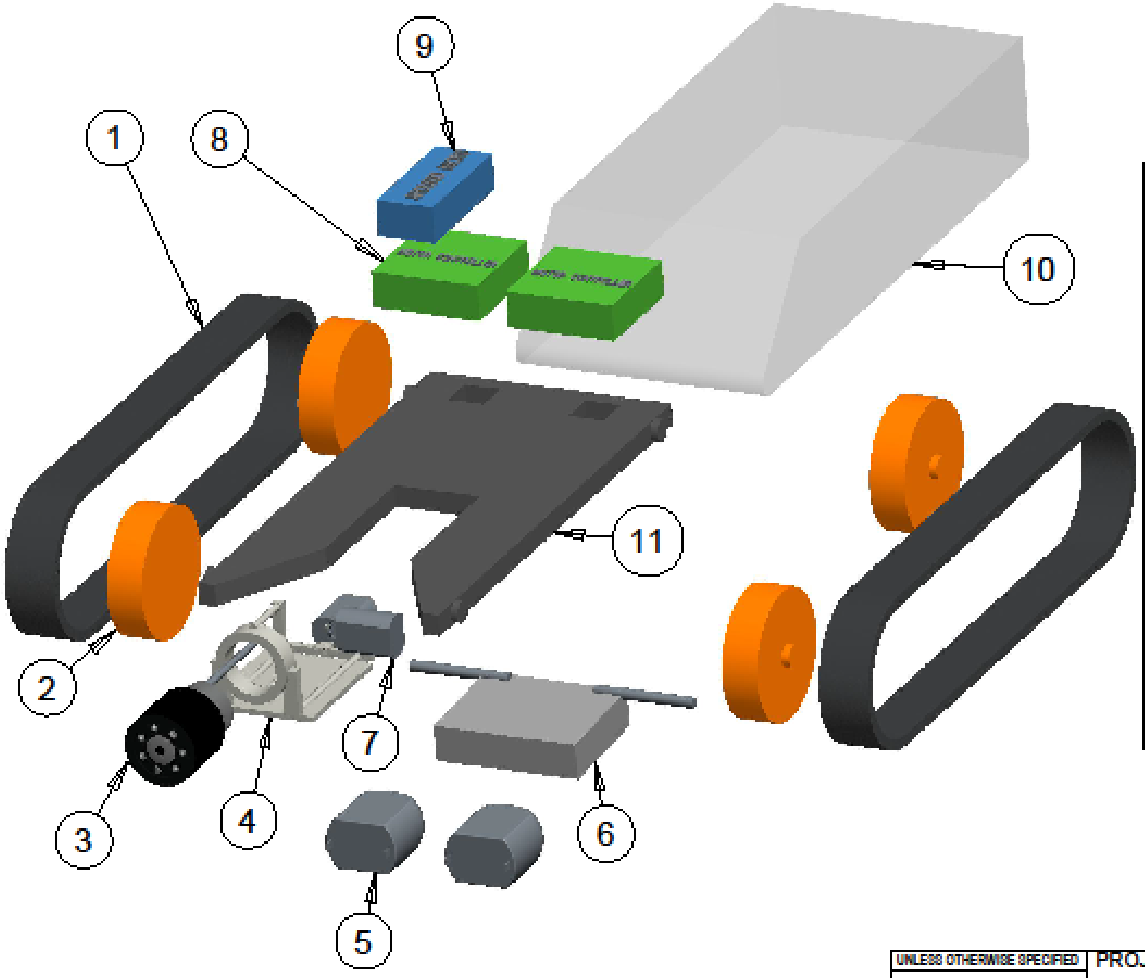


LOWER VIEW



UPPER VIEW

UNLESS OTHERWISE SPECIFIED	PROJECT MACH I PROTOTYPE	PART NAME ASSEMBLY	
DIMENSIONS IN INCHES TOLERANCE ± 0.005	DRAWN BY TEAM 21	PART NUMBER 1	REV 1
	SCALE 1.000	DATE 8 DECEMBER, 2014	SHEET 1 OF 1



BILL OF MATERIALS

NUM	QTY	PART NAME
1	2	TREAD TRACK
2	4	WHEEL
3	1	IR CAMERA
4	1	PAN-TILT
5	2	ROVER MOTOR
6	1	GEARBOX
7	2	PAN-TILT MOTOR
8	2	MOTOR CONTROLLER
9	1	ARDUINO MICRO
10	1	CASING
11	1	BASEPLATE

UNLESS OTHERWISE SPECIFIED	PROJECT MACH I PROTOTYPE	PART NAME EXPLODED ASSEMBLY	
DIMENSIONS IN INCHES TOLERANCE ± 0.005	DRAWN BY TEAM 21	PART NUMBER 2	REV 1
	SCALE 1.000	DATE 8 DECEMBER, 2014	SHEET 1 OF 1

A-3 Calculations for design analysis

```
%Motor Torque Calculations for Rover
clc
clear all


mass_max = .05; %kg
distance_max = .02; %m

M = mass_max*9.81*distance_max;


Y = ['Maximum Moment Caused by Camera and Mounting: ', num2str(M)];
disp(Y)

for i=1:1:2
H = input('Enter Motor Power in W ');
d = input('Enter wheel diameter in mm ');
w = input('Enter rotational speed in rpm ');
Wt = 60000*H/(pi*w*10);
T = (d/2)*Wt;
disp(' ')
X = ['Torque ' num2str(i),' = ', num2str(T)];
disp(X)
disp(' ')
disp(' ')
end
```

```
Maximum Moment Caused by Camera and Mounting: 0.00981

Enter Motor Power in W 5.94

Enter wheel diameter in mm 10

Enter rotational speed in rpm 12530

Torque 1 = 4.527

Enter Motor Power in W 8
```

```
Enter wheel diameter in mm 10

Enter rotational speed in rpm 300

Torque 2 = 254.6479
```

Rover Mobility Calculations

$$A_{surface} \quad width_{wheel} * length_{surface\ contact}$$

$$Wheel\ contact\ patch \quad 1.3\ in^2$$

$$Tread\ contact\ patch \quad 8.0\ in^2$$

$$\therefore 6.2\ times\ more\ area\ over\ which\ torque\ acts$$

$$weight_{additional\ tread} < 0.05\ lbs$$

$$m_{tether} \quad 0.91\ kg$$

$$T_{motor} \quad 0.014\ Nm$$

$$F_{pinion} \quad \frac{T_{to\ tread}}{r_{wheel}} \quad \frac{0.014 Nm}{0.004\ m} \quad 35\ N$$

$$F_{forward} \quad 35\ N$$

(Assuming constant torque for each gear in gearbox)

$$F_{friction} \quad F_n * \mu_{static} \quad 0.91 kg * 9.81 * 0.6 \quad 5.4 N$$