Senior Project Final Report:
Robotic Landmine Vehicle

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Abstract

The team of Dave Watson, Vicky Hoag, Tom Syvertsen, Clark Davenport, and advisor, Professor Carl Erikson, built a remote-controlled, robotic vehicle that can safely and effectively navigate through a minefield. This vehicle is adaptable for various uses, depending on the needs of the demining operation using the vehicle.

Acknowledgements

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1 Introduction

1.1 Description

The robotic landmine vehicle project entailed four stages of tasks before a satisfactory finished product was achieved. These stages were research, design, construction, and testing. The research and design stages were completed through the first semester of work on the project. Research of minefields and the needs of deminers was the first area researched, as this research aided in the decisions made about specific details of the vehicle design. Some of these details were the vehicle size, shape, and weight; type of materials used to build the vehicle; type of tires; type and size of batteries; type of motors and motor controller; type of remote-control system; and video camera unit mounted on the front of the vehicle.

The design of the vehicle came from the research done of the many different components of the vehicle. We decided exactly what parts and types of equipment we wanted to use on the vehicle, and then design a graphical model to represent what the finished vehicle would look like. Along with this graphical model, we also developed a list of specifications for the vehicle. These specifications list the precise capabilities needed in this type of vehicle. The specifications were also based on the research done of both the minefields and the parts being used on the vehicle.

The next step was the construction of the vehicle. This involved finishing the finding and ordering of needed parts, and then putting them together by following the vehicle design and specification. We ran into difficulties during the construction phase due to problems associated with welding aluminum. Otherwise, construction progressed smoothly. Once the vehicle was constructed we tested it. Test results were compared to the following objectives:

1. To build a robotic vehicle that will benefit the mine removal process by being adaptable for various uses in the minefield, such as mine detection, mine removal, or brush clearing.
2. To construct this vehicle with the capability to withstand an average mine blast so that only minor repairs are necessary.
3. To have battery power in the vehicle that can last for a running time of 45 minutes.
4. To limit the needed time to replace the batteries to 10 minutes.
5. To design the vehicle with the capability to climb a 10% incline.

6. To utilize remote control and video camera systems that can function at a distance of 100 meters.
7. To limit the total weight of the vehicle to under 200 pounds.

1.2 Literature Review

The problem of landmines is widespread and causes thousands of casualties each year. As United States Ambassador to the United Nations Donald K. Steinberg said in November 2000, “we owe the next generation of world citizens nothing less than the right to walk the earth without fear" (UN 2000). A great deal of work still remains in ridding the world of landmines. In fact, the “Landmine Monitor Report 2001” states that there were 15,000 to 20,000 new casualties from landmines and Unexploded Ordnance (UXO) in the year 2000 (ICBL). These casualties occurred in 73 different countries. In total, ninety countries are affected by landmines and UXO (landmine monitor). There is a definite need for technologies that will make demining safer, faster or more cost effective than current methods. “To develop realistic techniques and procedures that will truly enhance the process of mine clearance, two primary factors must be considered: mines and the environment” (King). The mines themselves can be difficult to detect, however the environment is the primary concern for this project.

As for the environment, “the stereotypical image of a flat, grassy minefield is just as harmful as that of the ‘non-metallic’ blast mine. Yet the ‘football pitch’ image is constantly reinforced by the trials, demonstrations, and publicity shots that invariably take place in near perfect conditions. Even ignoring the special circumstances of Kuwait’s oil lakes, the Middle East’s drifting sand dunes, Afghanistan’s mountains, or the Falklands peat bogs, minefields are rarely simple. Minefields are not harvested or grazed, and many lie in the sort of hot, wet environment that promotes the rapid growth of foliage. Most of the world’s minefields have been in place for years and many have become totally overgrown. Not only does this create a physical access problem, but also the inability to spot fragmentation mines and tripwires makes overgrown minefields particularly dangerous. In some areas of Cambodia, over 70% of operational time is spent on the clearance of undergrowth – at the expense of mine clearance. To complicate the situation, the minefields of the real world are often uneven on the macro and micro scales: rocks of all sizes create problems for the deminer, and even small stones can make probing almost impossible. Further, terrain with steep slopes and large outcrops of rock, common in Afghanistan and the Falklands, simply make the use of most vehicle-borne systems impractical.

Not surprisingly, mines are often found in and around battlefields, where the ground has been contaminated with the scrap of war. At best, there will be large quantities of metal present: one shell can produce thousands of steel fragments, and each splinter will be large enough to dwarf the signature from a minimum-metal mine. At worst, they may be cratered, strewn with barbed wire and guidance wires from missiles, and littered with UXO. (King).

With the characteristics of landmines and the environment in mind, it is possibly to begin to address the technology needs of humanitarian deminers. “A technology needed by deminers is one which would measurably improve either safety, quality or cost-effectiveness without compromising the others if it were available in the form of equipment or other means. This includes technologies which are known, and possibly available for purchase now, and those which need further research and or development” (Trevelyan). Deminers have expressed the need for mechanization. “Deminers need mine-resistant vegetation cutting machinery, and other multi-purpose machinery which can be adapted for demining and other construction tasks as required. They prefer versatile machines to special purpose machines. Much of this machinery is currently available from commercial suppliers, with some (mostly minor) modifications. Further, magnets can reduce later work by manual deminers by collecting surface metal fragmentation. Significant cost reductions and production rate improvements are achievable with more mechanization" (Trevelyan).

Currently, robots are not in widespread use in demining operations. However, several interesting demining robot designs have been built and field tested. One of the most promising designs is Tempest, developed by the Humanitarian Demining Technology Development Programme. Another interesting demining robot is the Pemex-BE, which is small enough to fit in a backpack when disassembled. Also, a small, lightweight, 4 wheeled robot under development is the Fetch II by iRobot Corporation. In addition to Fetch II, iRobot Corporation has developed a tracked robot known as Packbot, which could be adapted for use in minefields. The final group of robots suitable for demining use is explosive ordnance disposal robots such as the Engineering Services Incorporated MR-1E and MR-5, which are commonly used by bomb squads in developed countries.

"Tempest is tailored specifically to meet the needs of post conflict mine-clearance in less developed countries. It is designed to clear vegetation and trip-wires as a precursor to accelerated manual clearance. It has a relatively low purchase cost, is easy to operate and transport, and cheap to run. Sustainability is a priority in its design, and wherever possible components have been chosen which can be found or manufactured in the mine affected region. Tempest is suitable for maintenance and repair by indigenous users" (Gehring).

The first Tempest has completed testing in the UK, including blast testing of components by the Royal Engineers, with very positive results. "The Tempest remote controlled vehicle can support a variety of interchangeable clearance heads. Presently, a horizontal axis chain flail is in use and other attachments such as vertical axis trimming heads and rakes are envisioned. Tempest has a 2200 Kg working weight, is 1.4m wide, 1.4m tall and 3.5m long (2m vehicle & 1.5m arm). It is capable of clearing $200m^2$ of 500mm tall, thick green grass per hour. Tempest can also cut a 100 mm tree in 3-4 minutes. Presently, Tempest has a 1.2m cutting width. Importantly, Tempest can survive an AP blast without interruption to operation. Minimal damage can be repaired in a few minutes with a welding kit. In the event of an AT blast, the wheel station is blown clear, while components are protected inside the vee-hull. Also, Tempest is protected against fragmentation in all directions" (Gehring). No information about the turning radius, or type and difficult of terrain Tempest can operate in are specified.

The Pemex-BE is a lightweight, two-wheeled robot for searching AP mines. It weighs less than 16 Kg and can be dismantled to fit in a backpack. It is battery powered and can run for over 30 minutes. Also, it has a top speed of 6 km/hr. Pemex-BE can operate by hardwired remote control, or autonomously.

When operating autonomously, Pemex-BE avoids large obstacles (50 cm barrels) and can operate in terrain with holes and ruts that are less than 10 cm deep. In autonomous mode, a metal detector flashes a light when a buried metallic object is found. While moving forward, the Pemex-BE scans a 1.2m wide lane. However, obstacles or incorrect navigation can leave behind unscanned areas.

Pemex-BE has the ability to climb steep slopes (approaching 20 – 30 degrees) that are made of hard soil, concrete or small stones. Its climbing ability is enhanced by the addition of climbing "cleats." The Pemex-BE can also be fitted with foam floats that allow it to operate on water. The effectiveness of its sensors in water is not known. The Pemex-BE uses two Maxon

70 Watt high-efficiency motors with 50:1 torque reducers. An additional 2.5:1 torque reduction is provided by the gears and bicycle chain driving the wheels." Onboard control electronics give the Pemex-BE the ability to operate autonomously. The control electronics consist of two 68331 microprocessors, communicating via a serial line. Eight piezo Polaroid distance sensors and eight PSD distance sensors are used to detect obstacles. The Pemex-BE metal detector is used to detect buried metal at a distance of 5cm. The purpose of the current metal detector is, "to test and demonstrate the basic problem that the robot is intended to solve" (Mächler).

The Fetch II by iRobot Corporation is "a new approach to the counter mine problem." It is envisioned that "a team of low cost Fetch II robotic mine hunters will provide rapid and complete coverage of a mine field." In the second phase of Fetch II's development, "this swarm of robots will be capable of cooperatively clearing a field of landmines under the supervision of a single operator. The Fetch II robots feature advanced computational and mechanical components, yet are designed for low cost duplication. The Fetch II robots perform most of their tasks autonomously. Each Fetch II contains behavior based intelligence which enables it to navigate through real world terrain autonomously, using a relative coordinate system and task specific sensors mounted on a robust four wheeled mobility platform. The ultimate field capable system will enable an explosive ordnance disposal technician to clear a large area of unexploded munitions without personal risk" (Fetch II).

The Packbot by iRobot Corporation is designed as "a robust robot to aid in reconnaissance operations in urban terrain." Currently, the prototype Packbot is being developed with funding from DARPA. "Packbot is designed for durability and versatility, featuring robust systems and onboard data processing capabilities that will enable rapid response to a dynamic, urban environment. Its portable size and ability to endure adverse conditions will make it ideal for venturing into areas that are hazardous or inaccessible to humans." Further, "Packbot's patented mechanisms are designed to give it complete freedom of movement in indoor or outdoor environments. Its self-righting mobility platform is equipped with tracked "flippers" that allow the robot to climb hills and stairs. Packbot is housed in an aluminum shell, which offers exceptional durability; the prototype is designed to survive a 3m drop onto concrete, and has survived multiple launches from a second story window. The next phase of the DARPA contract will develop payloads, sensors, and behaviors to extend the systems autonomy. Packbot's responses to environmental stimuli will be enabled by sensors: cameras, microphones, sonar, infrared sensors, inclinometers, laser sensors, and micro-impulse radar, each specifically tailored to the unique system architecture. Sensors customized to specific missions may also be integrated into the system" (Packbot).

Engineering Services Incorporated (ESI) has developed two advanced and versatile robots, the MR-5 and MR-1E, for use by emergency personnel and ordnance disposal teams. These two robots are remote controlled and feature 6 wheeled chassis with a highly maneuverable robotic arm. This robotic arm can be fitted with various modules such as "extension links, grippers, cameras, and disrupter mounts" (MR-1E).

The MR-5 is .68 x 1.27 x .8 m (w x l x h) and weighs 250 kg. The MR-5 can reach speeds of .8 m/s. The all wheel drive system gives the MR-5 impressive mobility. It can climb 35^0 slopes, execute a 360^0 turn in a 1.5m wide space and handle curbs, ditches and other obstacles (MR-5).

The MR-1E has dimensions of .7 x 1.14 x 1.25 m (w x l x h) and weighs 252 kg. The MR-1E can reach speeds of 1.0 m/s, climb 40^0 slopes, execute a 360^0 turn in a 1.5m space and also handle curbs, ditches and other obstacles (MR-1E).

Clearly, robotic vehicles have the ability to aid in demining activities. However, deminers have been reluctant to use heavy, expensive, complex robots that require large amounts of money to maintain and operate. The development of Fetch II and Packbot is a good model to follow, where a small, lightweight "mobility platform" is developed first and "modules" are designed and added later to address specific needs. One aspect of robot design that was only incorporated into the Tempest system is blast protection from AP mines. Limiting damage to expensive robotic systems should be a priority of robot designers. Also, mobility is an extremely important factor in real world robot usefulness.

1.3 Solution

We followed the development models of Fetch II and Packbot by concentrating on the design of a small, lightweight "mobility platform" which can carry "modules" into the minefield. Our "mobility platform" consists of a four-wheel drive, battery powered, remote controlled robot with a wireless camera system and a front bay with attachment points for "modules." Four-wheel drive was chosen in order for the vehicle to meet the objective of climbing a 10% incline.

Nickel-metal hydride batteries were used to provide the necessary 45 minutes of runtime stated in the objectives. The frame of the vehicle, as well as the metal covering the vehicle, is aluminum. Aluminum was used because it is lightweight compared to steel and allowed us to keep the vehicle weight low. A four channel FM radio control system was used to allow the vehicle to be controlled from a distance greater than 100 yards, as stated in the objectives. Finally, a X10 wireless camera system was adapted for our use, with the intention that it could provide images of the terrain immediately in front of the robot to the operator at ranges of at least 100 yards.

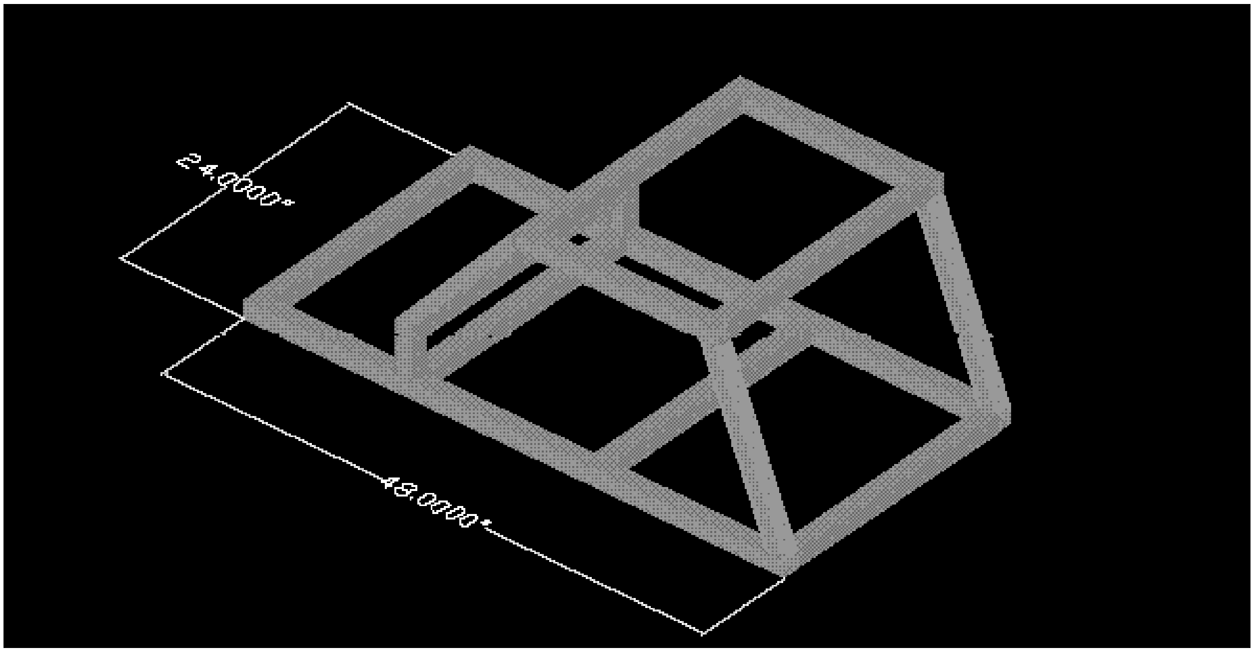
2 Design Process

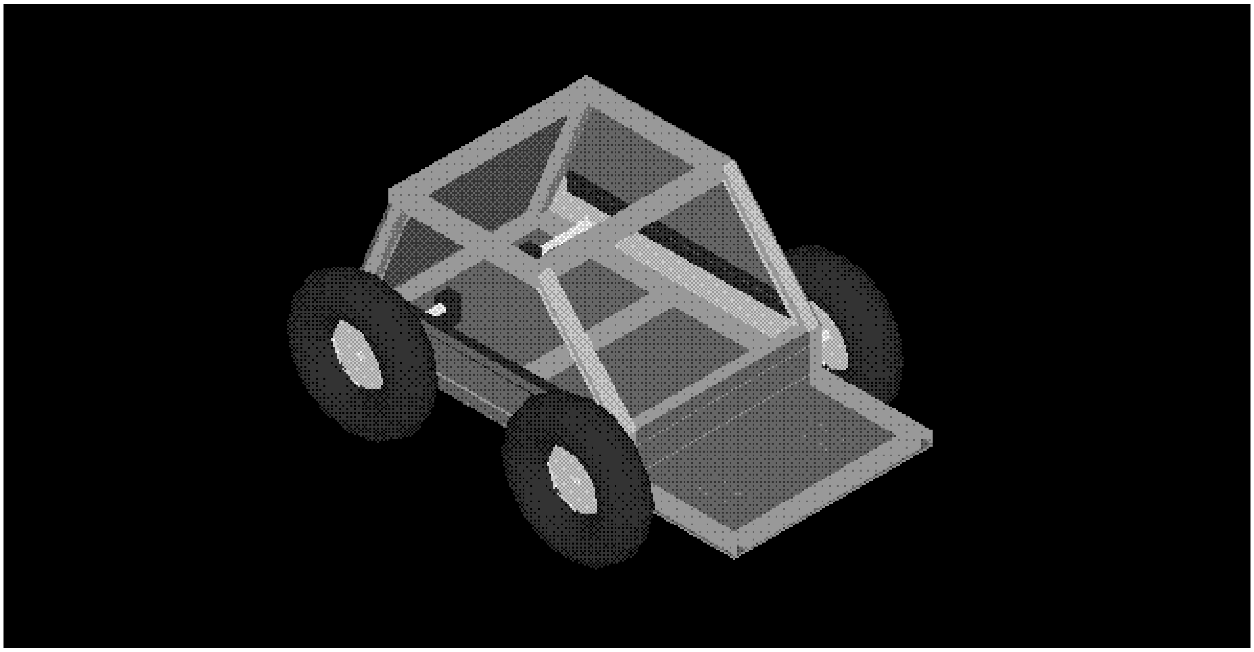
As our research, investigation, and modeling of parts and ideas progressed in the fall, we were able to more clearly understand what our vehicle design would look like. The initial ideas that we each created for our project (see Figures 1 and 2 in the Appendix) were changed and refined as we worked, and these concepts all converged to form our final vehicle design. This design is based primarily on our objectives and vehicle specifications. The following is a list of the components and dimensions of our design, as well as some visual representations of various aspects and stages of our vehicle's design.

Vehicle Frame, Wheels, and Dimensions

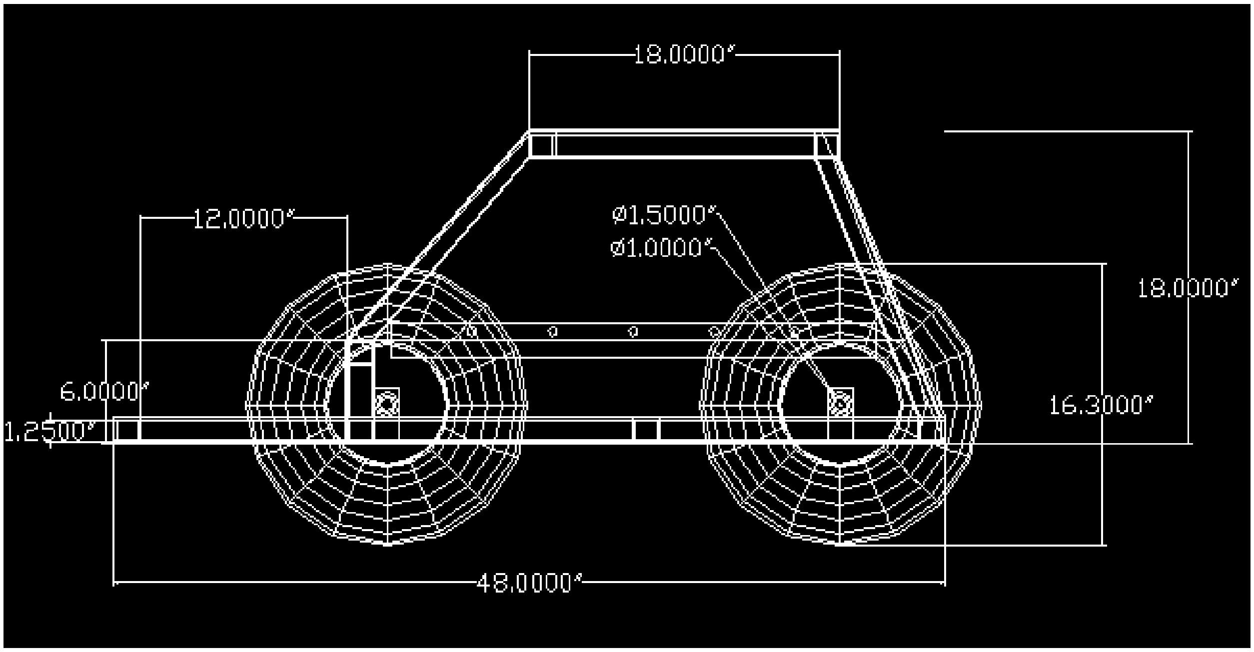
-The vehicle's body is constructed of aluminum plates and square tubing. It has a thick plate (.25 inches) on the base of the vehicle's body to hold the motor and batteries, etc.; thinner plates (.125 inch) on the vehicle's sides for protection from the elements; and 1.5 inch by 1.5 inch by .125 inch aluminum tubing around the body for support. The aluminum plates on the sides, top, and back of the vehicle are bolted on to allow for easy removal to access internal parts. We chose aluminum because of its light weight and the access we had to free aluminum plates through the Rock of Ages Corporation.

The following pictures show the aluminum tubing that provide the foundation for the vehicle's frame and the frame with the side plates, bottom plates, and wheels





-The vehicle weighs 259 pounds (118 kilograms) and its dimensions are approximately 4 feet long (1.23 meters), 3 feet wide (.92 meters), and 2 feet high (.62 meters). The rubber tires are 16.3 inches in diameter and 4.3 inches wide. These dimensions allow space for all the inner vehicle components and meet the vehicle specification. The vehicle has a one cubic foot space in the front for various attachments deminers could use, such as mine-detection devices, brush-clearing tools, or mine-removal equipment. The following picture shows these dimensions.



Vehicle Motors, Controls, and Drive System

-Our vehicle is four-wheel drive, driven by two motors, powered by a 24 Volt nickel-metal hydride battery pack, and steered by skid steering. The two wheels on each side are independent of the wheels on the other side, allowing the vehicle to have a turning radius equal to half of its length.

-The wheels are driven by #35 chain and sprockets from the motor shafts to the wheel axles. The motors are already significantly geared down and did require any major gear reduction for use.

-The vehicle is controlled by a FM remote control/receiver system, functional at 100 meters.

-The vehicles' two motors are controlled by a dual motor, variable speed controller, model Vantech RDFR 23.

-The vehicle has a video camera mounted on the front, although it did not meet our operating range objective . The camera's purpose is to watch the terrain immediately in front of the vehicle for obstacles in the way or for whatever else the deminers need to watch for.

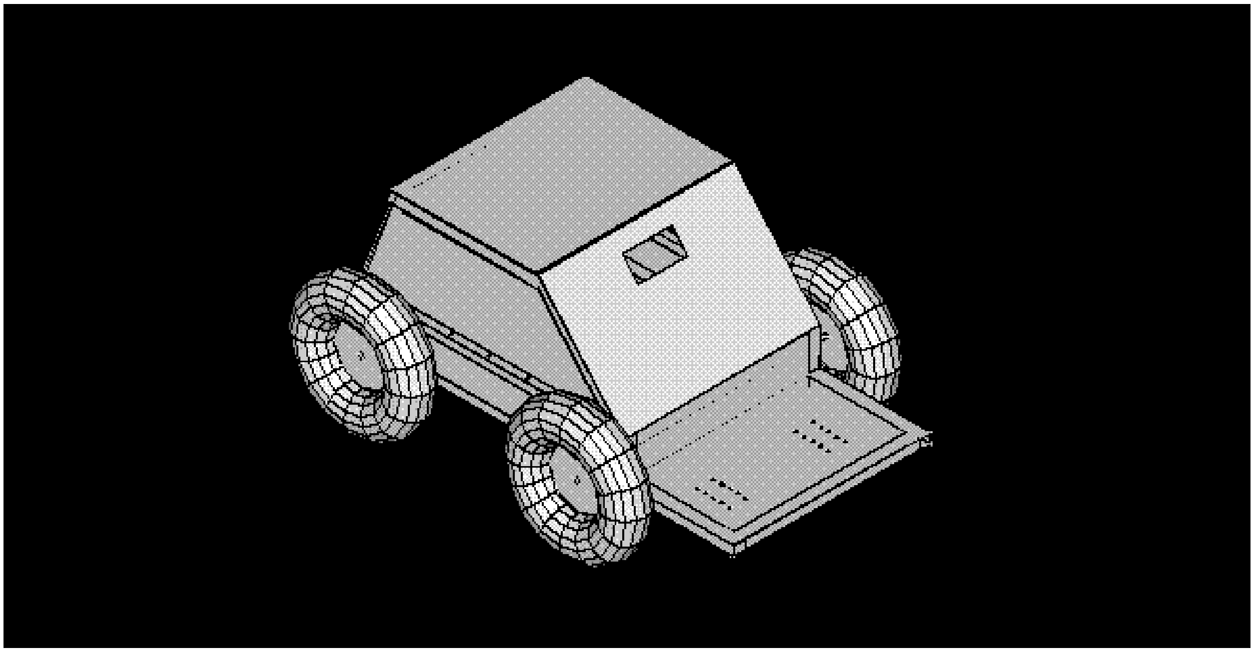
Design Extras

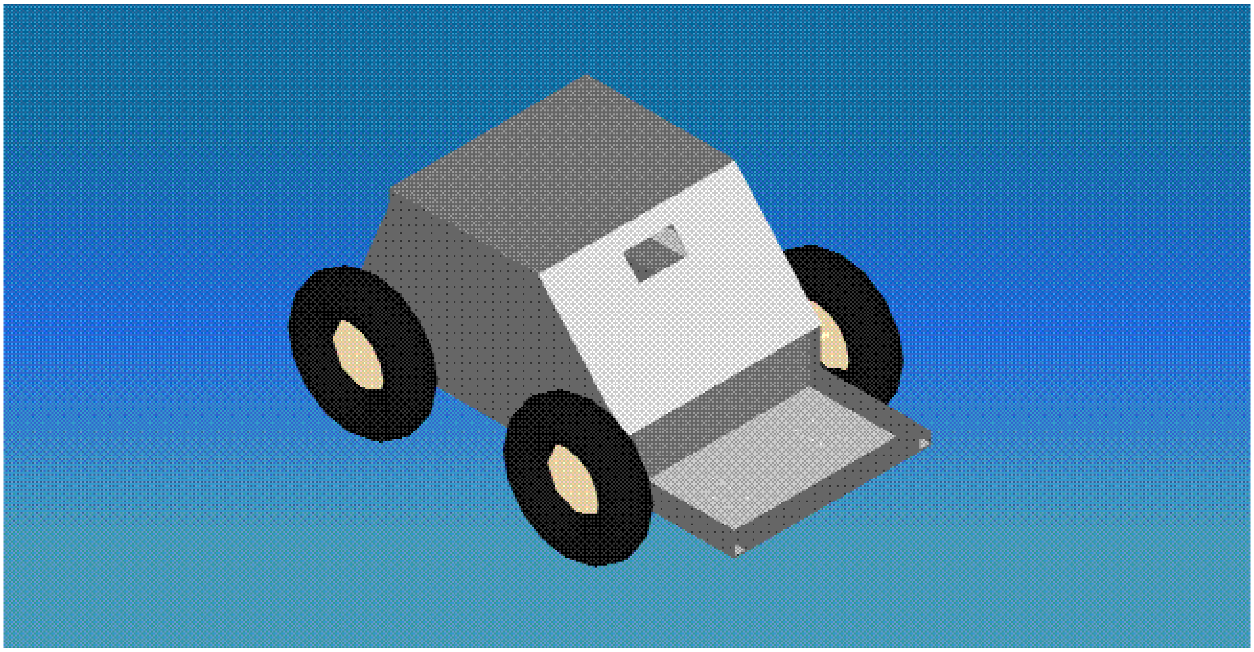
-There are several extras that we have built onto our vehicle. We used a lexan sheet to protect the camera, since lexan is a clear but blast-resistant material. The place where this lexan shield has been implemented is shown in the drawings below, near the top of the angled front of the vehicle.

Design Analysis and Experimental Work

The DC wheelchair motors with attached gear reducers were tested to determine their current draw with and without a load. The analysis of the motor's current draw allowed us to pick the motor controller that best meets the electrical needs of our robot, while staying within our budget (Figure 3 in the Appendix). Also, several Lego vehicle designs were constructed (Figure 4 in the Appendix). The Lego vehicles gave us an appreciation of the need for powerful motors, combined with low friction gear reduction. In addition to the Lego models, a larger model of the robot was constructed to allow team members to critique and evaluate the design before construction began (Figure 5 in the Appendix). The larger wooden model of the robot allowed us to test the placement of components in the robot and to finalize the size of the robot. Additionally, subsystems of the robot such as the wireless video system were analyzed. In initial tests, the wireless system was shown to work at a distance of at least 235 feet. Also, the remote control transmitter was tested to ensure that it operates reliably at the 100-yard distance given in our specifications.

The design has been described and visually depicted in parts in the preceding section, and the following drawings show approximately what the final product design looks like (also see Figure 6 in the Appendix).





3 Implementation

3.1 Construction

The construction of the frame of our robot started out with 1 inch aluminum tubing. The aluminum tubing was cut to the appropriate sizes and then welded together using the MIG welder (Figure 7 in the Appendix). Using the MIG welder for aluminum is uncommon and took some practice to get correct. After some trial runs figuring out what speed and voltage was needed and some practice, it was not that difficult to weld the aluminum with the MIG welder. However, it was a long process, much longer than we had anticipated.

One of the reasons why welding the aluminum took longer than we had allotted was because we were unaware that the aluminum had to be prepared before it could be welded. The preparation consisted of grinding away the oxidized layer of aluminum from the areas that were going to be welded. After this was done, the welding could be started. We started by welding the bottom of the frame together. We had some deformation when we did this because we failed to keep the pieces clamped as we were welding them. This was easily corrected by adding some force when we clamped it all together.

After completion of the frame of the vehicle, the rest of the shell of the vehicle could be constructed and put into place (Figure 8 in the Appendix). The shell is comprised of one-eighth and one quarter inch thick sheets of aluminum. All specifications for thickness and exact dimensions had been laid out in AutoCAD in the design phase so our next task was merely to carefully mark the sheets for cutting to appropriate sizes. These markings were compared directly with the frame to ensure an exact fit in the case of slight warping of the frame in the welding process. The marked sheets were then cut on the vertical band saw into pieces which would serve to cover the frame of the vehicle on all sides.

This aluminum was free for us to use but presented challenges because it contained numerous drill holes. Our original plan was fill the holes with aluminum weld but this proved to be a very time-intensive process. Between grinding all surfaces, filling the hole with weld, and finishing the surface, the process took nearly thirty minutes and was not an operation that could be repeated several dozen times within scheduling constraints. The team then decided on aluminum fill which would provide a solid and fairly strong patch for the plates and seal all the sheets to keep blowing sand out from inside the vehicle.

After a brief failed bout with welding the four by two foot plate to the bottom of the frame, the team opted to rivet the piece to the frame. The welding was becoming too time-consuming, leaving messy weld joints, and not accomplishing anything more than a riveted fastener connection could not. The original design had called for welding of several sheets, not just the bottom plate, to the frame of the vehicle, but upon seeing the success of the riveted piece, the sides specified to be welded on were changed to mechanical fastener. The bottom side pieces were next riveted on as was the flat front plate and the slanted front plate.

The next task was to place the removable plates by drilling holes through the plates and the frame to provide means of bolt fastening. Thin strips of sealing foam were placed on the frame where plates would be fastened by bolt. This allows for some compression when tightening the bolt, and forms a good seal between the plates and the frame, preventing sand or other unwanted materials from entering the inside of the vehicle where they may damage the machinery. At this point the sides and the top of the vehicle could quickly and easily be removed for repair or inspection. The back sheet, especially, is designed for easy removal. Four drill holes were made in the frame for the back sheet and bolts were placed in these holes, with the head of the bolts on the inside of the vehicle. Thin machine nuts were then tightened on the outside of the frame to keep the bolts attached to the frame even without the sheet in place. The sheet could then be mounted through these holes and tightened down by hand with wing nuts for quick and easy removal.

Bearing holes were next drilled through the lower (fixed) sides of the vehicle in the appropriately measured and marked locations with a two-inch diameter drill saw. The bearings used for these openings, which were salvaged from the previous year's "flail project," have an outer diameter of 2.05 inches, so manual filing followed to allow the bearings to sit inside these openings. The bearing brackets were then set in place and tightened. These four bearings provide the opening for our axles to enter the vehicle where they are then held in place by pillow block bearings.

Inside the vehicle is where we had to attach a mounting plate for our components. This height dictated the height of our bearings and thus the clearance of the vehicle itself. We mounted the pillow block bearings on the plate directly in-line with our outer bearings and then tested the placement by placing an axle through the bearings. The one-inch diameter solid steel axles were salvaged from the flail project and had been cut to lengths of thirteen inches to allow the proper length inside and outside of the vehicle. The exact placement of the pillow block bearings was difficult for a couple of reasons. First, the must be in correct placement or the axle could place a moment on the bearings and create added friction. Secondly, we got an opportunity to learn from our mistakes. The order of operations is important and unfortunately we found that the riveted front slant piece was in the way for drilling the correct placement of the pillow block bearing brackets. This meant that we had to drill through the bottom plate to the exact placement within the vehicle. Drilling though two plates separated by one and a half inches poses placement problems, which was not what we needed when it came to lining bearings up as precisely as possible. After several misdrills, the bearings could be lined up and tightened down securely to keep them in line and the friction incurred down.

We next bored our sprockets to the proper inner diameter to fit the motor shafts since sprockets of exact diameter required were not available for order. However, after boring the sprockets, we needed custom keys to fit the keyed area of the motor shaft as well as the keyed sprocket. This was accomplished by modifying the existing key from the motor shaft as it already fit the shaft. We needed to decrease the height of the key, as well as decrease the width of the key on the top half where it would slide into the sprocket's key area. This was done for both keys on the milling machine, set length-size next to each other, end to end. Several passes were made to the exact dimensions required to fit both key areas and then were hand filed down to remove burrs and decrease sharp edges. We then put the sprockets onto the axles with the modified key and tightened them down with the setscrews to resist axial movement and torsional movement (with aid from the keys).

The motors were mounted next, which was difficult due to the geometry of the motors themselves. We chose to use the mounting system from their previous application, modified to our needs. The motors have brackets that can be tightened down onto some hollow steel tubing, which we recovered from the wheelchair project. We cut this tubing to minimum dimensions and welded it upright onto a small piece of steel plate. The motors could then be mounted to the plate by tightening down the set screwed from the mounting bracket. Due to the geometry of the tubing and mounting bracket, the motors could resist movement in all directions. In order to mount these steel mounting plates onto our aluminum internal mounting sheet, we chose to use mechanical fasteners, specifically nuts and bolts. This design had some advantages such as the motors could easily be removed from this application, and the motor height could be adjusted if needed (for desired chain length in the drive system connected to the sprockets) by adding material under the steel mounting plates and tightening down the bolts. The design was not advantageous in regard to the strength of the mounting. We found that the motor produced enough torque to want to move it from its location inside the vehicle. In fact, it was a strong enough force to break part of the tubing mounting weld on one side, allowing the motor to move on its mount. This mount was replaced with a solid steel cylinder welded to the base and tightened to the motor, but still seemed less permanent of a mounting solution than we would have liked.

We decided to save money and use shafts from a previous project but had to cut them to the correct length and had to key the shafts for the sprocket placement. The shafts were cut on the horizontal band saw, and the keying was again done on the milling machine to the proper depth and width (0.25 inches) as specified for standard keys. We next connected the axles to the wheel hubs by producing a bushing design to fit the two components together (Figure 9 in the Appendix). Our axles had a one inch diameter, while out hubs had an inner diameter of approximately two inches. These pieces were joined by designing bushings, which were cut similar to large steel washers. The bushings were cut from a section of circular steel tubing of two inch outer diameter, and one inch inner diameter. Eight sections of one quarter inch thickness were cut on the horizontal band saw to provide two of these "washers" per wheel. They were then ground to the exact specified outer diameter needed to fit in the hubs, and tapped into place by a mallet. They were then secured into their place in the hub by using a press to force them into the hub to the point where they rested against a lip inside. Bushings were placed on each side of the hub and then the inner diameter of the bushings were filed by hand to allow enough of a tolerance to force the axles through. Once the axles were tightly in place, the bushings were welded to the hub as well as the axles for added strength. The hub and axle components were then placed through the flange mount bearings on the sides of the vehicle, as well as through one inch inner diameter sprockets and then finally into the pillow block bearing. At this point the sprockets could be visually lined up with the sprockets on the motor shaft, and all sprockets and bearings could be tightened down onto the shafts (Figure 10 in the Appendix).

Chains were then put into place as tightly as possibly by using combinations of chain lengths and half-link connecting pieces (Figure 11 in the Appendix). While the chains could not be secured at any shorter of a length, there still seemed to be some slack in the chains when the machine was run. This could lead to problems with noise as well as the chain skipping links on the sprocket or jumping off the sprocket entirely. A possibly future design could include an extra sprocket mounted to a spring that the chain could run past between the motor shaft and the tire shaft. This would keep a constant tension in the chain and would permit smoother running.

At this point the electrical systems could be added. The electrical systems of the robot were assembled in two sections. First, the motors, batteries, motor controller and remote control system were wired together to form the locomotive system (See Figure 12 in the Appendix). Wiring was done according to the manufacturer's recommendations. Additionally, fuses were added to protect the motor controller from drawing too much current. The second section of electrical system construction was the auxiliary electrical systems. An auxiliary power supply was created to supply the front bay with 12V and up to 5A. One important design feature for the auxiliary power supply was that it would draw the power evenly from the entire 24 volt battery pack. As an extra feature, the power supply also provides 5V at 3A to the front bay, so future groups can also use TTL. The power supply was also used to supply the wireless video camera with power.

3.2 Operation

The robot's operation was tested against our overall design objectives. First, the operational objectives such as minimum ground clearance, overall weight, the time required to change batteries and the maximum overall width of the robot were tested. Our objective of a 4 inch minimum ground clearance was based on the need for the robot to be able to operate in an off-road environment. Our testing showed that the robot has a 4.5 inch minimum ground clearance (Figure 13 in the Appendix). We specified in the objectives an overall weight for the robot of less than 200 pounds. This weight was decided upon because of the operational need for the robot to be light enough for two men to pick it up out of the back of a truck. Our testing revealed that the robot has an overall weight of 259 pounds. While the robot is heavier than our objective, it is still light enough for two men to pick it up out of the back of a truck. We specified in the objectives that the batteries should be able to be replaced in less than 10 minutes. This operational objective is important because it assures that the robot can be easily maintained in the field. Our testing shows that the batteries can be replaced in less than 5 minutes. Also, our objectives state that the overall width of the vehicle should be no more than 39 inches (approximately 1 meter). This objective is important because minefields are divided into 1 meter lanes for demining and we want our robot to fit into the typical 1 meter wide lane. Our testing showed that the robot is 36.5 inches wide, which meets our width objective (Figure 14 in the Appendix).

The robot was also tested against operational objectives such as hill climbing, minimum run time on 1 charge of batteries, minimum maintainable speed, weight carrying ability and the range of the wireless video and remote control systems. The objectives state that the robot should be able to climb a 10^0 incline. This objective is intended to assure that the robot can operate in off-road conditions. Our testing revealed that the robot is capable of climbing a 10^0 hill. Also, the objectives specify that the robot should be capable of running for at least 45 minutes on one charge of batteries. This objective allows the robot to stay in the field for almost twice as long as human deminers. During testing the robot ran for an hour on one charge of batteries. Further, our operational objectives specify that the robot should be able to maintain a speed of 1 ft/second. This objective was decided upon to minimize the time needed to drive the robot to an active area of the minefield to do its work. Our testing shows that the robot can maintain a speed of 5 ft/second. We specified in the objectives that the robot should be able to carry a 20 pound load, to simulate the weight of future modules. Our testing, including the hill climbing and speed tests, were conducted with 22 pounds in the front bay. We specified in our objectives that the wireless video system and the remote control system should have a range of at least 100 yards. This range allows for the robot to be operated from a safe distance. The results for these objectives are mixed. First, the wireless video system did not meet our expectations. Under the best conditions, it had a range of 25 yards. In contrast, the remote control system exceeded our objectives with a range of 382 feet.

If possible, a video of our testing titled, “Robot Video” will be placed on the internet along with this report.

4 Schedule

In making a schedule of events to take place during a project such as this, it is very difficult to know how much time to allot for certain tasks to be completed. In the course of the second half of our project we were often not on schedule. For the most part, our parts came in on time and that was not the cause of being behind schedule. We did not assign enough time to tasks that needed more time than we realized. One example of this is the exterior body manufacture. This was to be completed February 20, 2002. We did not actually complete this until March 6, 2002. As mentioned previously, we were not aware that the welding process would take as long as it did. As a result of this, we were behind schedual for everything.

On the whole, we were behind schedule the whole second half of our project. We were not however, so behind that we were scrambling to try to get things finished. Our Gantt chart and original schedule was unrealistic and this is the main reason why we were not on schedule for the most part. Everything was finished in a timely manner and we completed our project on time. We gained some knowledge on the length of time needed to complete projects and now have a better understanding on how to appropriately complete a Gantt chart. Our Gantt chart can be seen in the Appendix.

5 Budget

As we have indicated in our earlier report we have exceeded the alotted $300 for our project. We were fortunate enough to have additional funding from the Landmine Action Project. We have been able to obtain some parts from previous projects and from donations from other sources. For instance the motors for our project were obtained from the wheel chair project from last year and we have also obtained batteries from Dr. Pratt and the Genesis team. This has greatly reduced our cost. Below you will find a list of the main parts for our project with a price next to them. This will give a basic idea of what the total cost of our project will be.

Tires	$14 ea. (x4)
Wheel Rim	$12 ea. (x4)
Wheel Hub	$28 ea. (x4)
Motor Controller (Vantech RDFR 33)	$360
Gears / Bearings	$210
Aluminum Square Tubing	$110
Lexan	*$28*
Video Camera with Transmitter/receiver	*$80*
Remotely controlled Transmitter/Receiver	*$95*
Batteries	*$10,000*
Motors	*$250 ea.*
Metal	*$150*
Television	*$75*
TOTAL :	$896
TOTAL :	$11546 (With donated items)

Those items in italics are donated items therefore they will only be used in figuring out the total cost of making our robot. It does sound like it would cost a lot of money to make one of these robots but the main cost of our robot was the batteries. With some different batteries the cost could be significantly reduced. It is also possible that it may actually cost less money to make one of these robots in an assembly line type of arrangement. We feel that the $11546 that it takes to make one of these robots will be worth the lives that it may save in removing a land mine.

6 CONCLUSIONS

To measure the level of success of our project, we had to examine our specified objectives to determine whether they were met by our final product. We found that most of our major objectives were indeed satisfied, as shown in the following sentences, by our remote operated vehicle. Our desired product would be adaptable for various uses in the minefield, and our vehicle has this capability. Our desired remote control range was 100 yards, which we easily exceeded. We specified 10 minutes to change batteries, and this can be done in 5 minutes. Our desired run time on one charge of batteries was an hour, which our vehicle can do. We specified that our vehicle must be able to climb a 10 degree incline, which it can do. Our desired ground clearance was 4 inches, and our actual clearance is 4.5 inches. Our budget for the project was $900, and we spent $896. Nearly all all of our objectives were met.

Two of our objectives were not completely satisfied by our vehicle. Our desired vehicle weight was 200 pounds, which we exceeded by 59 pounds. However, this objective was based on being able to lift the vehicle with two people, which can still easily be done, despite the extra weight. The other unsatisfied objective is that our video system did not function at 100 yards, which is what we desired. The reason for this is due to the combination of the facts that the camera we used was designed ideally for still use, and the camera's receiver was shielded by the vehicle's side panels. A different model of camera, and a modified receiver type could allow a camera to be used adequately on our vehicle.

Overall, our remote operated vehicle was definitely a success. Only two of our minor objectives were not satisfied, and these do not affect the vehicle's capability to function properly. There were also several other minor problems such as motor stability and current draw into the motor controller, and these are discussed more fully in the recommendations for future work. These problems were also fairly minor, and while it was disappointing to see any problems occur, these were fairly insignificant to the overall success and workability of our vehicle.

We learned a great deal about working on a major engineering project through this experience. Other than learning much about the specific design and manufacturing elements that this particular project required, there are several overriding concepts that we have taken from this project:

1. Allow more time than you think you need for each step of the process. Things take longer than expected, and this impacted us particularly in the construction phase of our project. Machining, welding, drilling holes, and making circuit boards are just several areas where our project construction was more time-consuming than anticipated.
2. Organize and plan a specific construction process. When there are many different construction aspects that all need to be done, it is important to think carefully and plan what needs to be done first, second , etc. This helps to avoid problems where one process is completed before another one that needed to be done first.
3. Test early, so that changes can be made and problems can be solved. Once again, things do not get finished as quickly as expected, so testing early gives time to correct problems that had not necessarily been anticipated.

These principles can be applied to many different kinds of projects and construction processes, and this project has shown us how important planning and organization are when taking on any type of major project. A realistic timetable for completion, a proper order of processes, and planning on various types of failures occuring are things that are easy to overlook, but doing so could cause a project to fail or never get completed. As engineers, we have been trained to design, analyze, and build, and this project has shown us that these three principles must be combined with two other crucial ones: planning and organization.

7 Recommendations for Future Work

There are many things that can be done to improve upon our robot. We feel that The major areas that should be worked on are as follows. We would like to see modules for the front bay area made and installed. We designed our robot to be able to accommodate such modules so we feel that this is one of the most important things for future work. Next, we would suggest more permanent motor mounts. The motor mounts that we have are sufficient for the short-term application but to be used for long-term applications, more permanent motor mounts are definitely necessary.

The video system that we have is designed more for indoor applications and so when we used it outside there was a lot of interference with the signal, especially when the vehicle was moving. We would suggest a different video system and maybe even exploring the use of a ground-penetrating radar, which would enable our robot to be able to see landmines that are buried in the ground. We wanted our robots to be able to climb a 10-degree incline. It was able to do this, but it unfortunately blew a few fuses on slopes greater than 10 degrees. The same happened when we tried to turn our robot. It was able to turn but the turning radius was rather large and when we tried to turn it faster, more fuses were blown. We would suggest working on this problem by maybe gearing down the motors or installing a motor controller that can handle more current.

Lastly, we would suggest doing some actual blast testing. We wouldn’t suggest doing it with our actual robot but doing it with some aluminum sheets and tubing and also with some tires. This way, we could see how much damage a blast would cause to our robot. After this, we would suggest doing the same tests with some Linex coating on the aluminum and tires. Linex is a blast protective coating and it would be good to see the difference in damage caused by a blast on material with Linex and material without Linex. From this we could see if it is beneficial to get the Linex coating on our robot.

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Appendix

Specifications

Structural

- -1 ft^2 of area in the front bay for modules
- -Internal systems protected from a 100 g of TNT blast, while damage limited to easily repairable, non-critical systems
- -Hook in the back serves as an attachment point for towed devices
- -Structure is resistant to flipping over due to a mine blast
- -A frame built of steel

Electrical Systems

- -Power supply to front bay 12V @ 4 A
- -Motors are electrically powered
- -Batteries can be replaced in less than 10 minutes
- -Robot operates for at least 1 hour on each charge of batteries

Locomotion

- -Capable of operating in the desert environment found in Chad
- -4 wheels
- -4 wheel drive
- -Maintain a speed of at least 1 ft/sec
- -Uses 2 permanent magnet DC wheelchair motors.
- -Tires are easily replaceable
- -Tank style steering (skid-steer)

Applications

- -Total weight less than 200 lbs.
- -Capable of clearing a 4” obstacle
- -Able to climb or traverse a 10^0 grade
- -Able to carry at least a 20 pound load

Control

- -Wireless video system broadcasts 100 yards minimum with a clear line of sight
- -Steering and speed are regulated by remote control from a minimum distance of 100 yards

Cost

- -Cost to build in real life (parts): $2500.00

Figure 1 - An Initial Design Idea

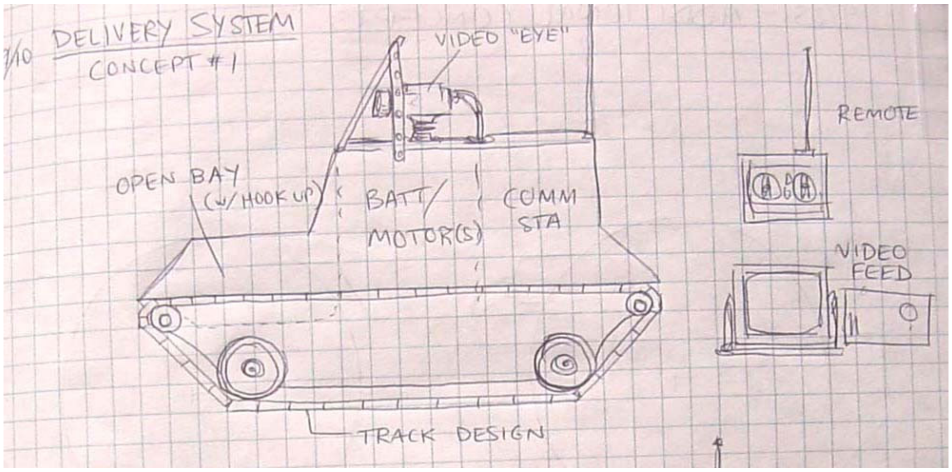

Figure 2 – An Initial Design Idea

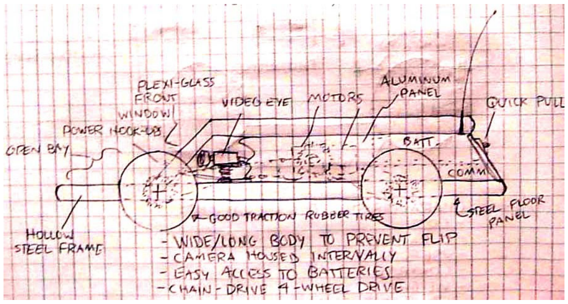

Figure 3 – Testing Motors for Current Draw

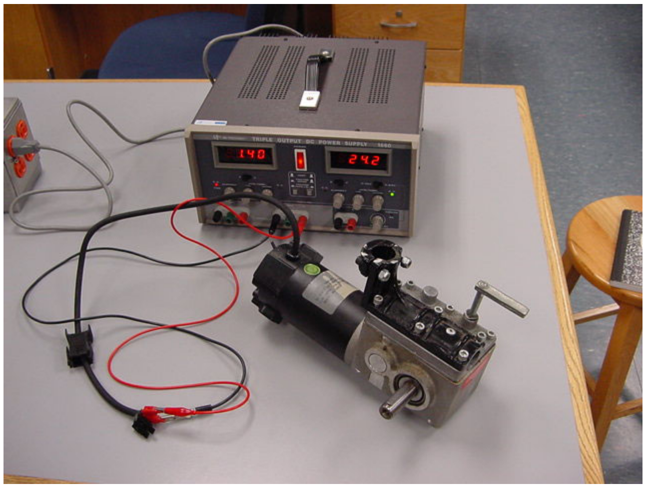

Figure 4 – A Lego Model

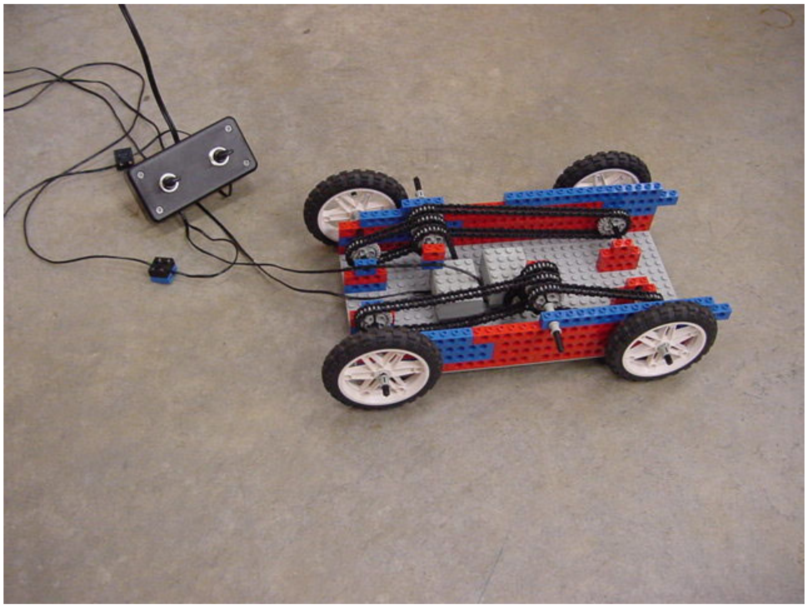

Figure 5 – Large Wooden Scale Model of the Robot

Figure 6 – The Final Design

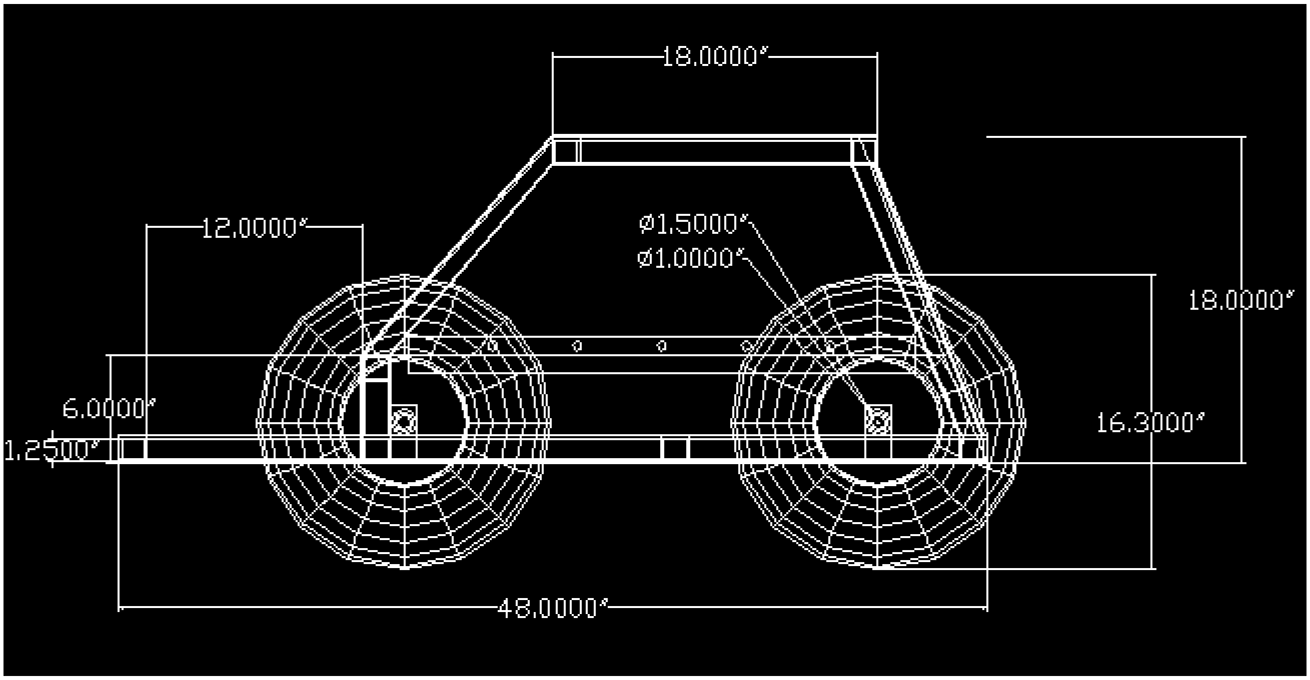

Figure 7 – Welding the Aluminum Frame

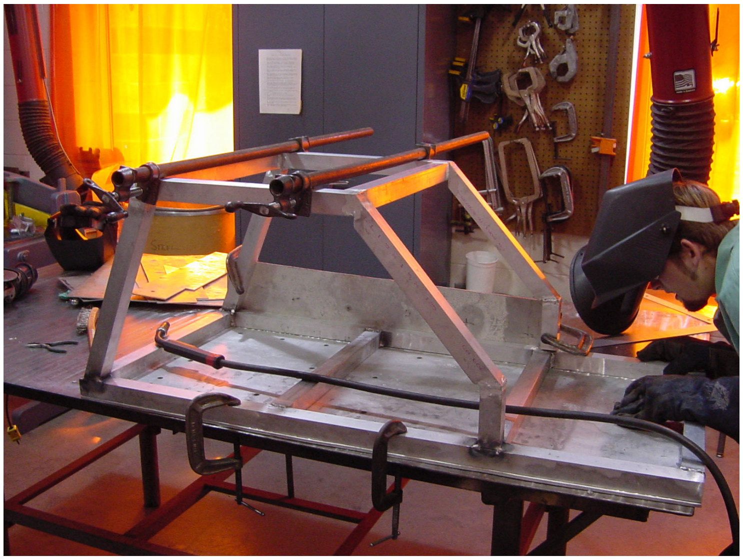

Figure 8 – Attaching the Shell

Figure 9 – Attaching the Bushings

Figure 10 – Mechanical Components Assembled

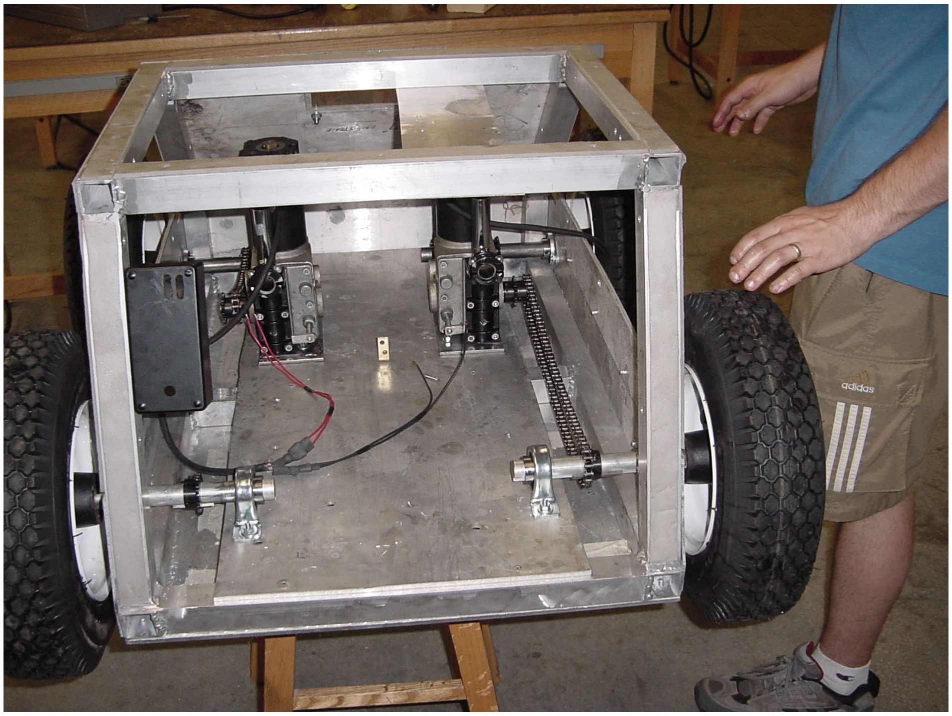

Figure 11 – Attaching the Chains

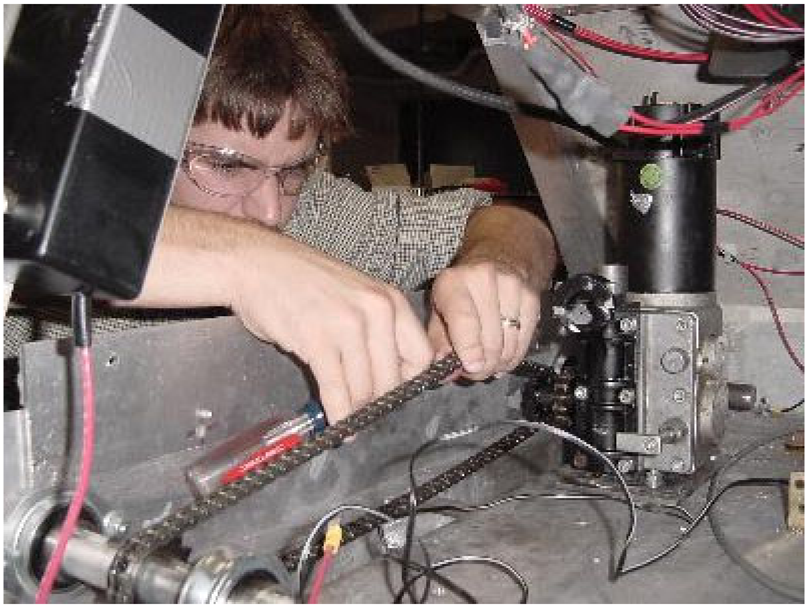

Figure 12 – Electrical System

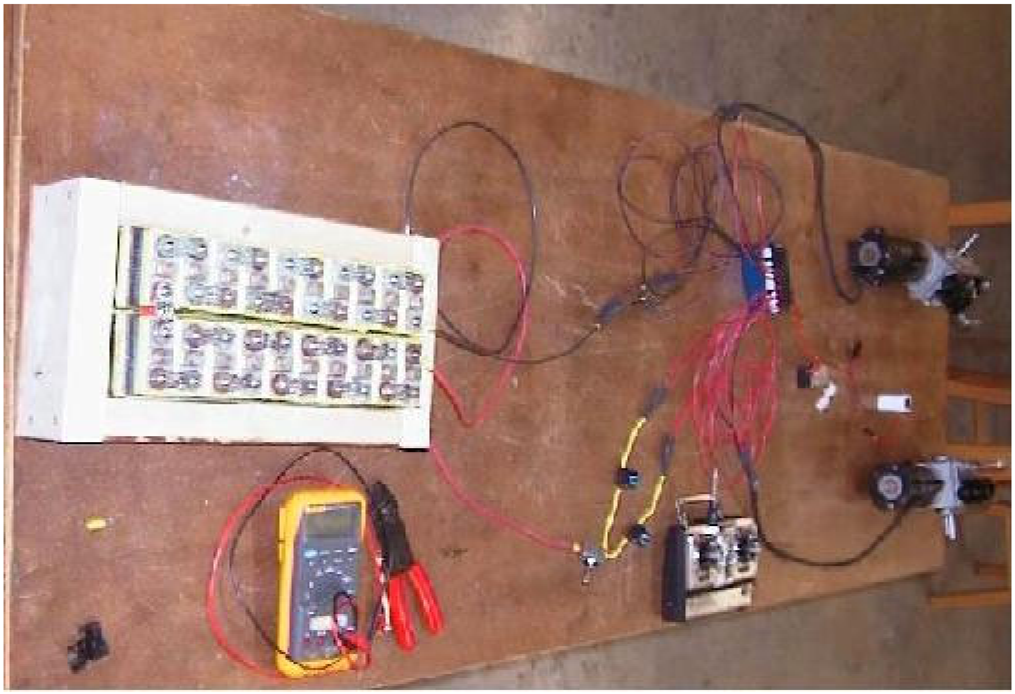

Figure 13 – Ground Clearance Measurement

Figure 14 – Robot Width Measurement

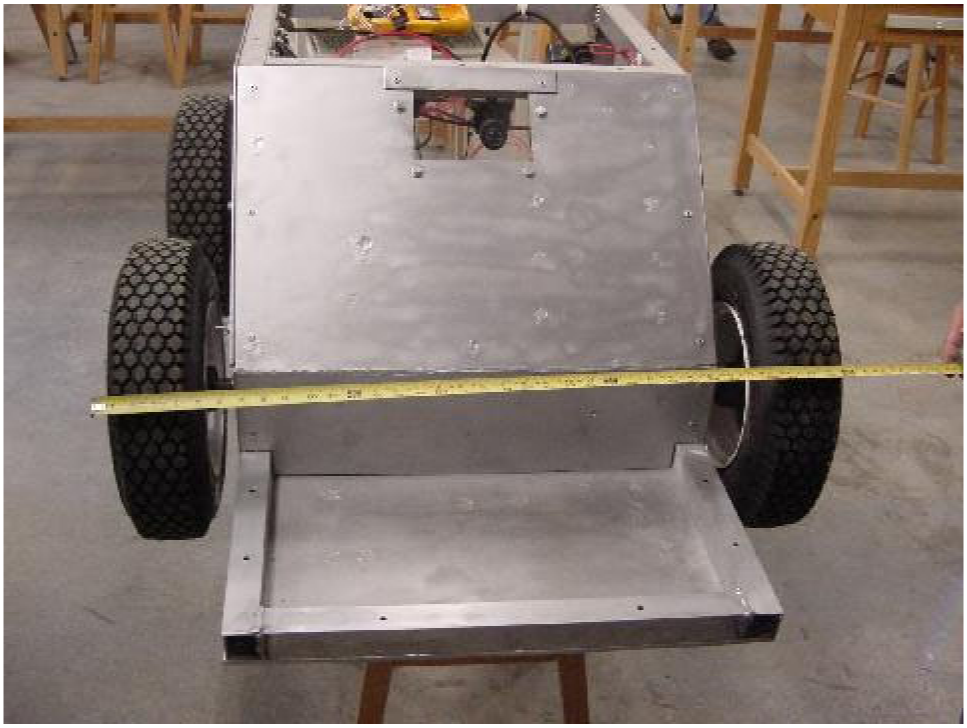

Figure 15 – Completed Robot Pictures