DESIGN OF A RESCUE ROBOT FOR SEARCH AND MAPPING OPERATION

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by
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In this thesis study, I had a chance to be one of the researchers to find out a solution, which could give hope to the human beings after disasters. During this study I deal with the robotic design, which I have been fascinated while following the robotic science and designs news all around the world. I would like to thank Dr. Emin Faruk Keçeci to give me a chance to work with him and for supervising my project. From the beginning to the end of this study his motivation gives me the highest energy to complete this thesis.

In addition, I want to thank to my family for their belief and to my friends for their support.

Finally my special thanks go to my spouse for his understanding and support and to my son for always being by my side.

ABSTRACT

DESIGN OF A RESCUE ROBOT FOR SEARCH AND MAPPING OPERATION

The aim of this thesis is to design a mobile robot for rescue operations after an earthquake. The robot is designed to locate injured victims and life triangle in debris, to create a map of the disaster area and to collect the necessary information needed by digging and support robots in order to the database center. This robot enables us to rescue the victim in the shortest time with minimum injury. This will let us risking the lives of the rescue teams much less as well as rescuing much more victim alive.

Robot is designed with the longitudinal body design. Shock absorber system gives the damper effect against falls as well as adding advanced equilibrium properties while passing through a rough land. Driving mechanism is a tracked steering system. Front and back arm system is developed to provide high mobility while overtaking the obstacles.

Secondly hovercraft type robot, which works with the cushion pressure principle, is designed as a rescue robot. It is thought that if the adequate height is supplied, the robot could manage to overcome obstacles.

As a third design, ball robot, which could easily move uphill and has a capability to overrun obstacles, is studied. Jumping mechanism will be working by magnetic pistons.

In addition robot is equipped with the sensors so that it has capable of the navigation. In order to achieve feasible sensor systems, all electronic components are evaluated and the most effective sensors are chosen.

ÖZ

ARAMA ve HARİTALAMA OPERASYONLARI İÇİN KURTARMA ROBOTU TASARIMI

Bu projenin amacı deprem sonrası arama kurtarma faaliyetlerinde kullanılmak üzere mobil robot dizaynının mekanik tasarımının yapılmasıdır. Robot enkaz içinde ilerleyerek sensörler sayesinde yaralıları ve yaşam boşluklarını tespit edecek, enkaz bölgesinin haritasını çıkaracak, kazı destek robotlarına yaralının konumunu ve durumunu rapor edecektir. Robot enkaz altında kalan insanların en kısa zamanda zarar görmeden çıkarılmasını sağlayacaktır. Böylece deprem gibi doğal afetler sonucunda yaşamını yitiren insan sayısı azalacak, kurtarma çalışmalarında olabilecek sakat kalma olayları aza indirilecektir. Enkaza müdahale eden arama kurtarma takımlarının hayatlarını daha az riske attığı gibi enkaz altından daha fazla kazazedenin canlı olarak çıkarılması mümkün olacaktır.

Arama robotu olarak kriterlere göre belirlenen üç tasarım seçilmiş, ayrı ayrı incelenerek arama robotu olarak ne kadar performanslı olabileceği analiz edilmiştir.

İlk olarak, paletli robot tasarımı çalışılmıştır. Diğer paletli robotlardan farklı olarak hareket kabiliyetinin arttırılması için esnek gövde tasarlanmıştır. Düşme ve darbelere karşı şok emici yaylar kullanılarak dayanımı ve aşabileceği engellerin yüksekliği arttırılmıştır. Ön ve arka kol tasarıma eklenerek merdiven çıkabilmesi ve inebilmesi sağlanmıştır.

İkinci olarak hovercraft robot tasarımı üzerine çalışılarak arama kurtarma robotu olarak hava basıncı prensibiyle çalışan sistemlerin uygunluğu araştırılmıştır. Belli bir yüksekliğe çıkması durumunda engelleri kolayca aşabileceği düşünülmüştür.

Üçüncü tasarım olarak, hareket sistemi elektromanyetik pistonlarla sağlanacak top robot tasarımı üzerine çalışma yapılmıştır. Yüzeyi tamamıyla kaplı olacağı için dış ortamın şartlarından etkilenmeyecek, mekanik sistem zarar görmeyecektir.

Arama kurtarma robotları, haritalandırma ve enkaz içindeki bilgileri kurtarma takımlarına iletecek sensörler ve elektronik elemanlarla donatılmıştır. En uygun elektronik parça seçimi için, kapsamlı bir değerlendirme yapılarak parçalar seçilmiştir.

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CHAPTER 1

INTRODUCTION

The main reasons of the increasing number of people dying in disasters are the lack of on time first aid, impossibilities to interfere with the situation immediately or not to be able to determine the position of the disaster victim. Unfortunately, the opportunity of the disaster victim to survive is measured by minutes.

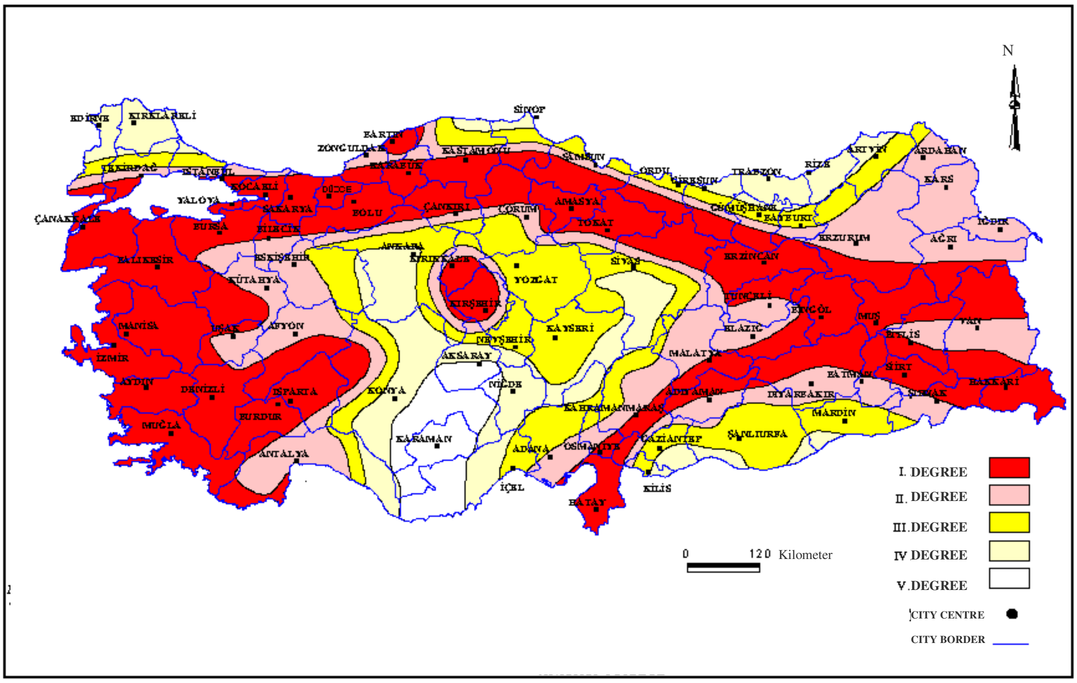


Figure 1.1. Earthquake region map (Source: General Directorate of Disaster Affairs Earthquake Research Department, Ankara Turkey, 1996)

Earthquakes are the most probable disasters for Turkey (Figure 1.1). Turkey lies on one of the most active fault line called North Anatolia Fault Line. Moreover, Turkey is the 3rd country on the basis of the seismic activity in the world. Each day 10 earthquakes of severity 2.0 Richter are recorded. North Anatolia Fault Line caused 7 great earthquakes since 1939. According to specialists, there would be a quite destructive earthquake of severity 7.0 Richter in Istanbul in 20–25 years.

Golcuk Earthquake, August 17th 1999, shows the reality without any doubts. More than 52.000 buildings were damaged because of the Izmit and Duzce earthquakes in 1999. About 70 percent of those structures were slightly damaged, 25 percent were heavily affected and the rest 5 percent were completely collapsed. On the other hand, 45 percent of the damaged buildings could not accommodate any more. (Erdik, Mustafa.2000. Report on 1999 Kocaeli and Duzce Earthquakes.)

Great amount of the non-qualified buildings and impossibilities in research and rescue activities increased the number of people suffered from the disasters. In the past years, research and rescue operations were used to be performed by human and animal power leading to dramatic consequences. Contemporary approaches in such activities suggest the use of complex machines and special rescue equipments.

However, even such complicated devices might not locate the victim; hence rescue actions slow down leading to dramatic consequences. The main reasons are problems in detecting the location of the victim under the wreckage, slow motion capacity of the construction equipments, the limits of the rescue equipment and the need of educated team.

1.1. Current Rescue Searches

Currently, a usual search and rescue team is consisted of about ten people. Each team includes dogs, a paramedic, an engineer, and various specialists to find and take out a victim by using specific equipments. Current equipments include cameras and various listening devices. Usually video cameras are used as search cameras that are mounted on some device like a rod which can be inserted into gaps and holes to search any evidence of victims. If an empty space is suspected to exist on the other side, often a hole is drilled into the obstructing walls. Highly sensitive microphones that can listen for a person who may be moving or attempting to react to rescuers calls and listening devices are also used. This total searching activities can take lots of hours to search one building. If a person is found, all rescue operations can take even longer.

The first and primary tasks in rescue operations are to evaluate the situation, to locate the coordination of victims, and to found a first contact with them. To do this is both very difficult and very risky for the human rescuers. The collapsed structures are not resistant, holes and gaps could be too narrow for human passage, orientation is difficult in debris, fire and smoke can hold back sight.

Because of the dangerous environments where rescue team move to do their duty, they may carry on injuries from the secondary disaster. Then rescue machines or robots which save human lives in the hazardous environment of disaster, must be developed and provided at fire-brigade stations, police stations, railway stations and city offices etc.

1.2. Need for Rescue Robots

Mobile robots that are highly useful can provide as very valuable tools to assist the humans rescue workers in these tasks. Hence, the robots independently supply functional information to rescuers. On the other hand, always there has to be a human to evaluate the correctness and the implications of the given data.

A small highly mobile robot can search more easily holes, life triangles in a rubble pile that the equipment and dogs cannot sense. The highest main concern for rescue team in a rescue operation is the safety of everyone, especially for the team members. Collapsed buildings are often unbalanced and dynamic. The second seismic movement that can be followed by aftershocks can start the further collapse. A robot can easily search under an unstable structure and the team members can collect data from the robot at a safer distance.

It is interesting to note that rescue operations during typical disasters more often recover dead bodies than live ones. While live rescues are the primary goal, the rapid recovery of dead bodies is also valuable to the surviving relatives and is often important in some cultures (Yim et al, 2000). A robot can do the rapid recovery of dead victims as well without risk to the rescuers.

In this study rescue robot is designed for earthquake operations. This thesis is especially focused on the mechanical design of the mobile robot for rescue robot applications to help people after disasters.

Because the emergency responders take a risk for their own lives to rescue the victims under debris, robots can be used to save lives.

1.3. Limitations of Robots

During the design of mobile robots, there should be some limitations such as the mission time, wireless operating distance, and rough terrain capability and fall durability. Since the robot needs to go through into the wreckage, extra limitations to mobile robot are required; the rescue robot should be small and light enough not to disturb unstable objects in the debris.

The major difficulty of rescue robot design is to have a mobile base, which can go over on a rough terrain.

At the World Trade Center, existing mobile robots were used for surveillance, but most of these robots were designed for military applications, not specifically for rescue operations in an earthquake zone (Kenn et al, 2003).

In earlier studies the problems encountered with the mobile robots in a rescue field are explained, but the design process of the robot is not mentioned.

1.4. Earlier Designs

Especially rescue robot types are seen in the RoboCup Rescue competitions. Approximately half have been wheeled vehicles and half have been tracked. A variety of sensors have been used, such as sonar, video cameras, range finders, bumpers, and microphones. Sizes range from 100mm square up to 500mm square. Most of these robots are teleoperated over wireless links, which is to say that they have very little autonomy. By definition, the conditions in a disaster situation cannot be accurately predicted or controlled (Kenn et al, 2003).

In the design of rescue robots several models and applications has been tested. To raise the performance and effectiveness of these robots, the researchers have been inspired by the nature.

When the rescues robots are categorized, the locomotion of the robots are mostly either as tracked vehicles (Kenn et al, 2003) or snake type robots (Tadokoro et al, 1997). It is also suggested that if they can change their shapes, this will assist them to climb and maneuver in confined spaces (Matsuno et al, 2000). The reason a wheeled robot cannot be used easily in rescue operations is that; the robot will have less ability to overcome the obstacles because of the fact that a wheel cannot go over an obstacle bigger than its radius.

The mechanical design advantage of a snake type robot is that it can be small in width and height, which enables the robot to penetrate into the rubble easier compared to a tracked vehicle (Burke et al, 2004). However; the snake type robots are more difficult to control and their load to body weight ratio is smaller than a tracked type robot.

1.4.1. Snake-Like Robots

Mechanical snakes are complex to design because there are many degrees of freedom (DOF) involved, and also for the complexity on motion planning. Nevertheless, the authors also have been developing many new types of snake-like robots with unique characteristics. However, despite the good performance achieved by our mobile robots, a major concern still remains: the energy source. Search-and-rescue robots should operate continuously for hours, if not days, and one cannot tolerate a robot returning to the surface just for recharging or change of batteries. And to be realistic, one cannot expect that the robot will ever succeed to return (Hirose et al, 2004).

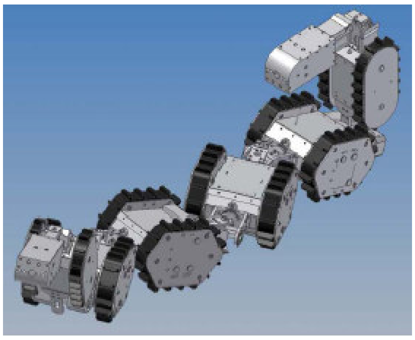


Figure 1.2. Snake-like Robots (Source: Hirose et al, 2004).

Urban Search and Rescue, industrial inspections in hazardous environments, and military intelligence have one need in common: small-sized mobile robots that can travel across the rubble of a collapsed building, squeeze through small crawlspaces, and slither into the shelter of insurgents to gather intelligence. One species of mobile robots that promises to deliver such hypermobility is the so-called serpentine or snake robot (Borenstein et al, 2005).

A "snake robot" or (snake-like robot) is a multi-segment mechanism that derives propulsion from undulations (a wave-like motion of the joints only), that is, it uses no wheels, legs, or tracks for propulsion (Borenstein et al, 2005).

Snake robots have advanced movement capabilities. They can use their body as legs when moving or as arms when traversing. Because of their long and thin structure, they can enter narrow places and they can move inside small cracks.

Snakes should have complex design because they need many degrees of freedom. Other disadvantages of these type robots are energy source, speed and lack of space for electronic components, sensors and circuits.

Capacity of the battery should be high so that tethers could be driven. But this will be caused to decrease the total weight of the robot.

Figure 1.3. OmniTread serpentine robot (Source: Borenstein et al, 2005)

Serpentine robots typically comprise of three or more rigid segments that are connected by 2- or 3-degree-of-freedom (DOF) joints. The segments typically have powered wheels, tracks, or legs to propel the vehicle forward, while the joints may be powered or empowered.

A "serpentine robot" is a multi-segment mechanism that derives propulsion from wheels, legs, or tracks. Joints connecting the segments may be either powered or empowered.

OmniTread design (Figure 1.3) comprises four segments, and each segment has two longitudinal tracks on each of its four sides, for a total of eight tracks per segment. The 2-DOF joints between segments are actuated by pneumatic cylinders (Borenstein et al, 2005).

A hermetic 3D active cord mechanism that can move both on the ground and in the water could be seen in Figure 1.9. Its creation was based on the study of motion of a corkscrew shaped microorganism called "Spirochete". Amphibious robots may be extremely useful in searching- rescue operations around the bay area (Hirose and Fukushima, 2004).

1.4.2. Tracked Robots

The tracked robots generally have better off-road capability than the wheeled robots, bugs or foot type robots. In order to improve the performance to irregular terrain, many tracked vehicles have been designed.

In a general mechanical engineering point-of-view, the less mechanical parts and degrees of freedoms a robot has less are the possibilities of mechanical failures. In order to optimize the snake-like robot mechanical design, a crawler-type articulated body mobile was improved (Hirose and Fukushima, 2004).

Although it was intentionally conceived with a limited number of degrees of freedoms, it still presents good mobility characteristics peculiar to snake-robots. This robot (Figure 1.10) is composed of front, center and rear bodies, which are connected by special 2 dimensional joint mechanisms that change the front and rear bodies' postures symmetrically around the center body's pitch and yaw axes. Moreover, all the 6 crawler segments are actuated by a single electric motor, thus totaling only 3 DOF for the entire robot. This robot includes a CCD camera and a microphone in the foremost part, and is suitable for finding victims buried under the rubble of a disaster scene (Hirose and Fukushima, 2004).

Figure 1.4. Having crawler arm in the front side. Easy climbing over obstacle (Source: Hirose and Fukushima, 2004)

1.4.3. Wheeled Robots

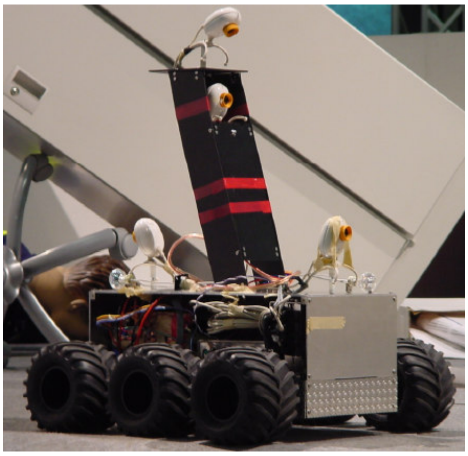


Figure 1.5. Wheeled robot (Source: Kenn et al, 2003)

The robots have to have a significant amount of robustness, suited locomotion capabilities that go beyond what is needed in normal office environments, and nevertheless sufficient flexibility to allow for an exploration of the unsolved scientific questions linked to this field.

Based on the experiences with prototype robots that participated in the RoboCup Rescue competition 2002 in Fukuoka, Japan, one of the new types of robots is developed (Figure 1.5). The robot is based on complete in-house designs, ranging from the mechanics over sensors and actuators to the software level. This allows optimizing the designs for the particular tasks of rescue operations (Kenn et al, 2003).

The robots are based on the CubeSystem (Figure 1.5) (Ultrasound Sonar, Active Infrared, USB−cameras, Motorcontrol, Motioncontrol, Odometry), a rich set of hardware and software modules for rapid prototyping of robotic devices. The robots are semi-autonomous, i.e., they allow teleoperation while providing quite some independent functionality (Birk and Kenn, 2002).

This robot represents the first and up to now unique system, which produces a human readable map that can be directly given to the rescue, team to quickly locates victims (Carpin et al, 2005).

CHAPTER 2

PROBLEM DEFINITION

In case of an earthquake, search robots will be sent at first and will be responsible for the determination of the victims. The main objective of these robots is to go further through the wreckage, to map the disaster region as well as to find the victims and life cavities. Search robots are composed of small bots. Their main tasks are to find out the people in need of help by means of its sensors and inform the digging robots about the position of the victim. Reported information from the search robots is filtered and the important data gathered in data processing center.

Search robots have sensors for mapping and searching. Mapping would be performed by means of ultrasonic wave and infrared laser based sensors. On the other hand, cameras and microphones are generally used for searching activities. These robots are equipped with small cameras which would record under poor light have anti-vibrating systems.

Microphones would sense frequencies varying from normal voice level to heartbeat. Moreover, sensors would determine the temperature and odor of the human being around the search region. There will be advanced sound sensors on the robot; hence required sound frequencies would be focused and located on the basis of direction and displacement. For example; Heart beats with some period depending on the age and activity. For an old person this period is 60 times per minute whereas it can reach up to 140 beat per minute for a young person. If the research robot sensors could separate the frequencies of heartbeat sound mentioned above from the others, it would locate the victim. In addition to this, ammonium sensor would find out any victim around the search area by means of measuring the ammonium residues, which leads to a human nearby. Thanks to the highly qualified thermal cameras, any search robot detached things of 30-40^{o}C body temperature. Specialized odor sensors help us to decide whether there is any explosive gas accumulation around. Such things that might be considered as unimportant details of daily life would save a persons life by decreasing the search time.

2.1. Difficulties to Overcome

There are difficult subjects for designing the rescue robot. One of most important problem is the field and other one is the limitations on the robot. Others are:

Geometric difficulties, Shape of the Robot, Parts and Materials, Interaction of Parts, Manufacturing Difficulties.

2.2. The Field

The land surface is the major problem in collapsed buildings. Because robot should have the ability of moving under all land conditions. Surface characteristics would switch from gravel terrain to sand terrain just in one step. In such a condition, there should be no disability in its steering system in order to prevent any problem.

Moving under every condition itself is not enough. Geometrical difficulties should also be considered carefully throughout the design procedure. Because each element (sensors, circuits) added to increase the functionality will also increase the weight of the robot that will lower the moving capability.

2.3. Geometric Difficulties

Design criteria of the rescue robot mechanism should be chosen considering all the possible difficulties that the robot should face under the wreckage during the search and rescue activities. Some difficulties are listed below;

1. Falling into the Ditch: The robot needs to fall determined height and during this fall it should not get damaged mechanically.
2. Climbing up the Ditch: The robot needs to have the ability to climb over determined height straight wall.
3. Passing under the Passage: In order to limit the total height, the robot should travel under the passage.
4. Inclined Surface: The robot should climb determined slope, which requires extra engine power.
5. Peak: The ground clearance of the robot becomes important at this stage for the robot not to get stuck at the peak point.

6. Declined Surface: During the travel on the declined surface the robot should have breaking ability not to fall.

2.4. Shape of the Robot

First question to be answered is the shape of the robot. We would be inspired of the animals hence it would be in shape of a beetle, snake or a scorpion. On the other hand, it would be designed as specially supplied truck or land cruiser with pallet.

Throughout the final decision strength of the body and the level of the motor torque are taken into account. Both should be high enough so as to meet the power requirement in descent and ascents. However, high torque and strength will affect directly the weight which is a crucial point from the safety point of view fort he robot that moves under the wreckage. Movement of a heavy robot that causes the gaps in the wreckage collapse would cause fatal consequences for the victim.

It should be small in order to pass through small cavities. Hence it should be in dimensions of a beetle, snake or even worm. However, it is so clear that building such a small robot is quite difficult considering the time it should stay under the wreckage and the various sensors placed on the robot.

Another specification which would increase the robots dimension in huge amounts is the special arm systems with additional control devices that give the robot ascent and descent ability.

Flexibility of the main body is an important property. By means of sensors such robots can lower its dimensions and pass through cavities that could not enter
Although this seems logical at first sight, flexible structure can be built outside the main control unit so this would enclose again a large place.

Maneuver capability should be high enough to enable the robot move in all directions so that it would go through in case of any barriers in front.

Another point is the ability of turning to its original position after it turns reverse direction. Without such a specification even perfectly designed robot from all point of views would be disabled by turning reverse and this is unacceptable.

Rescue robot shapes should be determined attending to all these specifications. However, a robot providing all these will be too heavy, too high or too wide. Because of that, some properties should be optimized whereas some are highlighted. Optimization brings us to determine the limitation of the designed robot.

2.5. Limitations of the Robot

In the collapsed buildings small holes, mounds, narrow passages, wide gaps, tall steps should be occurred. Because of this the limitations of the robot is very important. If there are no physical limitations on the robot, the natural intention will be making the robot bigger to overcome any obstacle. However, in general, robots for rescue operations should be small to penetrate the rubble better and should be light in order not to apply too much pressure on trapped people, or unstable parts of the building.

When the shape of the robot is studied, it is useful to have access to the obstacles, because the obstacles are envisioned as bigger and the robot’s dimensions are imagined as smaller, which makes the problem look more difficult than it is.

2.6. Parts and Materials

Next step after selecting the desired specifications is the material selection. Metal is appropriate for main construction especially because of its high resistance against falls and strokes. However, it should be taken into account that metal use will increase the unit weight.

Process area is not only a hard working place in mechanical manner, but also hard for electronic components choice. It will be problematic to control a robot and to obtain the target signals in a closed area. The range of Bluetooth, RC or wireless systems in the closed area should be taken into account. In the lack of light or dark places there should be a precise selection of camera systems for vision control.

There must be enough power supply in the rescue process. Energy choice should be determined with respect to the electrical properties of electronic components. For that reason energy consumption is as important as the electronic devices precision. There is a difference of 0.5–1 kg between two power supplies for 1 hour and for 3 hours.

Additionally the process temperatures of the devices on the search and rescue robots must be inspected. The devices should be chosen such that the operating temperatures must be suitable for hard winter days to hot summer days. A very well designed robot does not mean anything if its sensor or camera does not work in hard weather conditions.

2.7. Interaction of Parts

Each function should be evaluated later for interactions with the other functions. Mechanisms to achieve these functions should be found and evaluated. After testing, successful mechanisms are implemented on the robot where the failed mechanisms are studied more carefully and if necessary replaced with other mechanisms.

2.8. Manufacturing Difficulties

All items that will be used in the construction of the robot should be cheap and easily manufactured. Because the robot will be corrupted under the debris and lots of them could be used after disasters. So the manufacturing expense should be cheap because of this fact. On the other hand, because of the conditions of debris (dust, conditions of the weather etc) some parts of the robot could be broken down. As a result spare parts of the robot could be manufactured and found easily.

CHAPTER 3

THEORETICAL DESIGN

3.1. Rescue Robot Design

The reason for using robots during search and rescue works is to hazard one's life minimum while rescue maximum number of injured human being under the debris.

Because of this, the robots are going to be designed that it will need minimum human intervention.

At the first step some designs will be decided to have essential functions to complete the task. From all sketch drawings the most appropriate ones will be chosen and will be made scheme drawings. Making comparisons between these designs, final design will be determined and will be made a final scheme drawing.

Within the context of the project, 15 designs are considered to be realized (Table 3.1).

Table 3.1.15 rescue robot designs

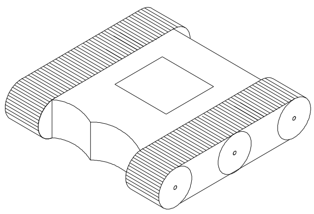
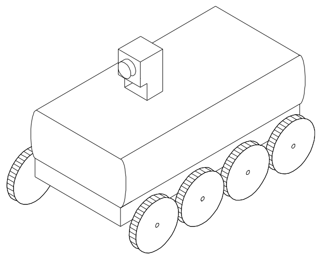
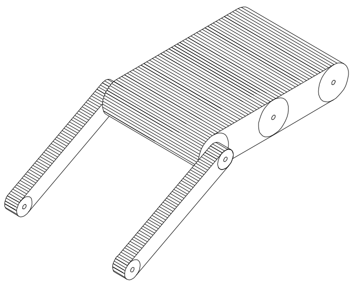
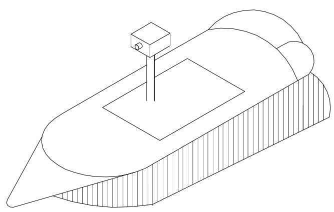
 1. 6 Wheeled Truck With Pallets	 2. 8 Wheeled Truck
 3. 6 Wheeled Truck With Lever System	 4. Front Design Resembling Plane Tip, Air Inflated Pickup Truck With 6 180 Degrees Rotating-Wheel

Table 3.1.(cont.)

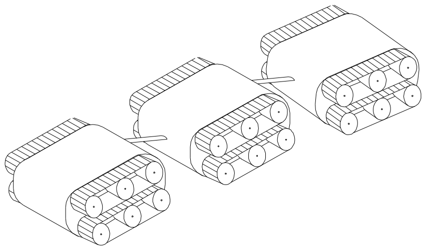
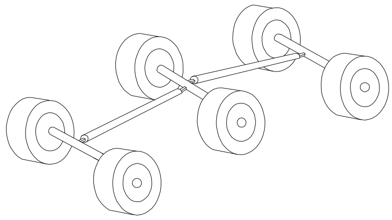
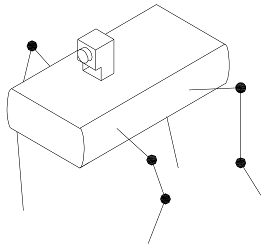
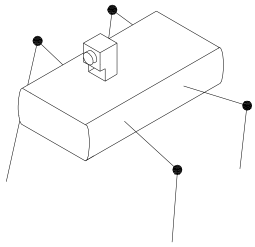
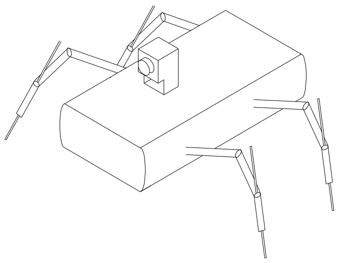
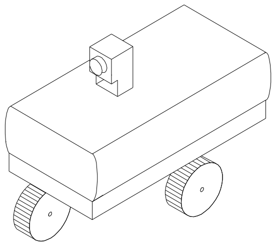
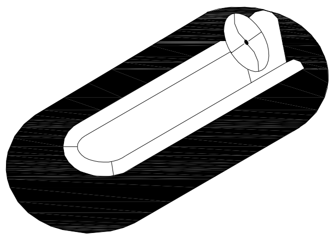
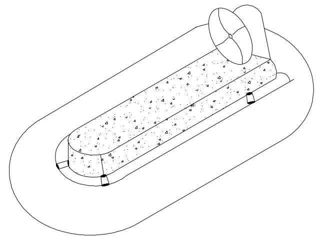
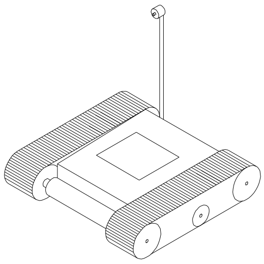
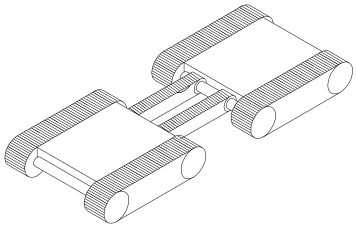
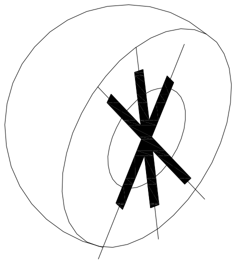
 5. 3 Segmented Snake With Two Pallet In Each Segment	 6. 6 Wheeled 3 Spined Snake
 7. Bug With 6 Feet, Each Foot With 3 Joints	 8. Bug With 6 Feet, Each Foot With 2 Joints
 9. Bug With 6 Feet, Each Extendable Foot With 3 Joints	 10. Car With 4 Spinned Joints
 11. Hovercraft With Fixed Control Panel	 12. Hovercraft With Moving Control Panel

Table 3.1.(cont.)

 13. Mono Tank	 14. Chain Tank
 15. Ball Robot	

1. 6 Wheeled Truck With Pallets

Electronic components, sensors, batteries are inside the main body in the middle of the robot. At the front there is a camera and microphone. Body will be made of hard plastic. The robot could clutch the road with pallet system. Disadvantage of this robot will be to overcome geometric difficulties such as steps, gaps and holes.

2. 8 Wheeled Truck

All the electronic components will be located in the middle of the design. Movement system of the robot will be obtained with 8 wheels. Disadvantage of this robot will be to overcome geometric difficulties.

3. 6 Wheeled Truck With Lever System

Body will be consisting of two parts. To increase movement capability of the robot lever system is added into the body. With the lever system it is aimed that climbing up or climbing down could be done easily. At the front there will be electronic systems, sensors, camera and batteries. Remote controlled.

4. Front Design Resembling Plane Tip, Air Inflated Pickup Truck With 6, 180 Degrees Rotating-Wheel

A flexible system which wrap around the chassis as an air cushion will be designed. According to the data which come from the sensors, the robot could change its shape to enter into narrow gaps by discharging air inside the cushion. At the same time this specification will decrease the shock of the impact because of flexibility of the air cushion. Air cushion system also will obtain the balance of the robot.

Front design will be resembled plane tip. It's thought that this will give advantage to enter gaps or holes. System will obtain the air from atmosphere so there is no need to use separately air tube.

5. 3 Segmented Snake With Two Pallet In Each Segment

Body will consist of three segments. Each segment has two pallets that make able to move from any side of body. Electronic systems, sensors, batteries will be distributed through the segments. At the head there will be a camera and end effectors of the sensors. Snake will be remote and program controlled.

6. 6 Wheeled 3 Spined Snake

Body will consist of three spines. Each spine has two wheels. This robot has a unique and advantageous characteristic of using spines. In order to evaluate the mobility performance and to develop control algorithms for this type of robot electronic system will build.

7. Bug With 6 Feet, Each Foot With 3 Joints

Main body carries electronic systems, batteries, and motors. Legs has three joints, one joint makes two rotations other one rotation and foots are able to rotate also. Because of 3 legs must stay on the surface for balance, must move each leg in a sequence, which makes this robot slow and hard to steer. Remote controlled.

8. Bug With 6 Feet, Each Foot With 2 Joints

Legs has two joints, one joint makes two rotations other one rotation and foots are able to rotate also. Remote controlled.

9. Bug With 6 Feet, Each Extendable Foot With 3 Joints

Main body carries electronic systems, batteries, and motors. Legs has three joints, one joint makes two rotations other one rotation and foots are able to rotate also. Extendable feet get the robot high maneuver capability. While climbing up or down the stairs or high distance, extendable feet play in part very important. The dimensions of the robot especially its height will be small in the normal conditions. Remote controlled.

10. Car With 4 Spinned Joints

Car has four spinned joints to have capability of moving four directions. At the front there will be electronic systems, sensors, camera and batteries. Remote controlled.

11. Hovercraft With Fixed Control Panel

Main body carries electronic systems, batteries, and motors. Fan that is located at the back of hover pushes the body for moving forward. Remote controlled. Cushion pressure is very important for this design.

12. Hovercraft With Moving Control Panel

Main body carries electronic systems, batteries, and motors. Fan that is located at the back of hover pushes the body for moving forward. Remote controlled. Cushion pressure is very important for this design. In case of falling down in a reverse, moving control panel will change its direction. This could be possible by the location of its gravity center.

13. Mono Tank

At the front there will be electronic systems, sensors, camera and batteries. Remote controlled. The driving system will be consisting of the wheels and belt system.

14. Chain Tank

At the front there will be electronic systems, sensors, camera and batteries. Remote controlled. The driving system will be consisting of the wheels and belt system.

This robot is designed to have driving motors of the left side tracks to be towards the front side, and for the right side to be in the back in order to have the weight of the motors to be distributed equally. Electronic equipment is placed in the middle of the system.

15. Ball

This robot has four electromagnetic pistons that used for changing the center of mass of the robot. The changing of the center of mass occurs a motion to the robot but this kind of motion is needed more energy source.

3.2. Evaluation and Selection of Robot

The first stage of this step is to find design parameters from which the robots will be evaluated. There can be up to 18 different parameters, where any robot should be evaluated according to all of these parameters.

An evaluation system is developed for designating the final design. Criterions of evaluation system are defined by paying attention the conditions of the debris.

18 design parameters for a rescue robot are found and they are listed as:

1. Weight: the weight of the robot itself is desired to be less.
2. Velocity: speed of the robot should be high.
3. Dimensions: dimensions of the robot body are desired to be small.
4. Height: height of the robot from the ground should be as big as possible.
5. Volume capacity: if there is more space inside the robot, it can be used for carrying different sensors.
6. Weight capacity: if the weight carrying capacity is larger, the robot can transport more necessary equipment inside the earthquake zone.
7. Overcoming geometrical difficulties: on a difficult terrain, defined in the problem description section, the robot is desired to be able to go over as many obstacles as possible.

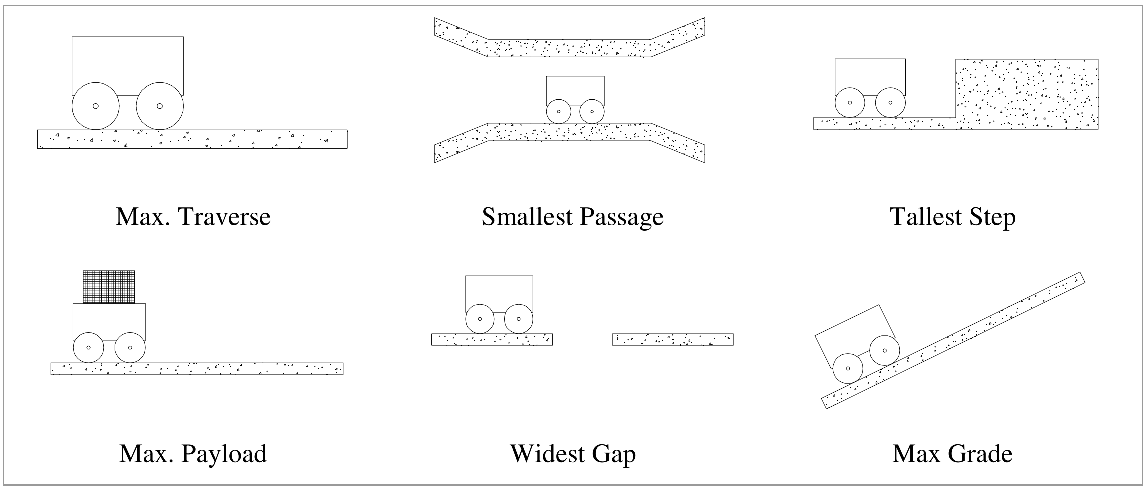


Table 3.2. Geometric difficulties

8. Maneuver capability: the driving ability of the robot increases the robot's ability to travel in confined spaces.
9. Interaction with other systems: the mechanical or electronic systems of the robot should not interfere with each other.
10. Energy necessity: lower energy requirement decreases the size of the power source which will result in a lighter and smaller robot.
11. Reverse fall: the ability to move up side down will allow the robot to accomplish its task after flipping.
12. Falling resistance: from which height the robot can fall and not have any mechanical or electrical problem determine the falling resistance.
13. Usage: depending on the driving method, number of motors and body flexibility, the degrees of freedom needing to be controlled should be less for ease of control.
14. Number and size of motors: the number and size of the motors used on the robot are responsible for determining the battery requirement of the system.
15. Failure durability: if the robot consists of less parts and simple mechanisms, it will have fewer tendencies to fail.
16. Body flexibility: a robot with a flexible body will be able to go thorough confined spaces easier.
17. Programming ease: the software of the robot should be simply written so that they can be easily updated.
18. Manufacturing ease: the physical manufacturing of the robot should be simple to allow mass production of the robot to be cheap.

All items should be easily manufactured and materials of construction should be cheap. On the basis of the 18 criteria, an excel sheet for the evaluation of the possible 15 robot design is formed. Score tables are also constructed to assess each criterion (Table 3.2) For example maneuver capability in one direction is given 1 point while in 6 direction is scored with 10.

Each robot will be evaluated according to the specifications and the three with highest scores will be chosen as the finalists to be designed mechanically.

Table 3.3. Samples of criteria and their values

Falling Resistance	
0.5m>	2
0.5m<1m	4
1m<1.5m	6
1.5m<2m	8
2<	10

Maneuver Capability	
6 Direction	10
5 Direction	8
4 Direction	6
3 Direction	4
2 Direction	2
1 Direction	1

One can realize that each criterion does not affect the selection equally. Thus, weighted percent distribution is used to highlight some crucial parameter and leaving some other in background. Distribution is given in Table 3.3. Other values related with 18 criteria are shown in Appendix A. According to the table success against geometrical difficulties is weighted with 12 percent while only 2 percent is given for manufacturing ease. Calculated points and the highest three scores are seen in Table 3.4. Solutions and calculated points related with 15 designs are shown in Appendix A.

Table 3.4. Weighted percent distribution of design parameters

No	Design Parameters	Weighted Percent
1	Geometrical Difficulties	12%
2	Volume Capacity	8%
3	Weight Capacity	8%
4	Energy Necessity	8%
5	Reverse Fall	8%
6	Usage	8%
7	Failure Durabilit	8%
8	Weight	5%
9	Dimensions	5%
10	Height	5%
11	Maneuver Capability	5%
12	Interaction With Other Systems	5%
13	Falling Resistance	5%
14	Velocity	2%
15	Number of Motors	2%
16	Body Flexibility	2%
17	Programming Ease	2%
18	Manufacturing Ease	2%

Table 3.5. Evaluations table

	6 Wheeled Truck with Lever System			Hower with Moving Control Pannel			Ball Robot		
	Criterion	**Point**	**Weighted Points**	**Criterion**	**Point**	**Weighted Points**	**Criterion**	**Point**	**Weighted Points**
Weight	5-10 kg	5	2,5	5-10 kg	5	2,5	5-10 kg	5	2,5
Velocity	3 m/h<	10	2	1-3 m/h>	5	1	1-3 m/h>	5	1
Dimensions	10x10<20x20	5	2,5	10x10<20x20	5	2,5	10x10<20x20	5	2,5
Height	15cm<20cm	6	3	15cm<20cm	6	3	15cm<20cm	6	3
Volume Capacity	%25-%50	5	4	%25-%50	5	4	%50<	10	8
Weight Capacity	%25-%50	5	4	%25-%50	5	4	%25-%50	5	4
Geometrical Difficulties		10,00	12		2,86	3,43		2,86	3,43
Steps	1,43		0	0,00		0	0,00		0
Pipe	1,43		0	1,43		0	1,43		0
Max slope	1,43		0	1,43		0	1,43		0
Jump (canyon)	1,43		0	0,00		0	0,00		0
Deep Hole	1,43		0	0,00		0	0,00		0
Climbing	1,43		0	0,00		0	0,00		0
Rough Surface	1,43		0	0,00		0	0,00		0
Maneuver Capability	4 direc.	6	3	4 direc.	6	3	4 direc.	6	3
Interaction with Other Systems	nonexistant	10	5	nonexistant	10	5	nonexistant	10	5
Energy Necessity	high	4	3,2	high	4	3,2	high	4	3,2
Reverse Fall	can rise	10	8	can rise	10	8	can rise	10	8
Falling Resistancy	0.5m<1m	4	2	0.5m<1m	4	2	1m<1.5m	6	3
Usage	easy	10	8	easy	10	8	difficult	0	0
Number of Motors	6<	0	0	4-6	5	1	4-6	5	1
Failure Durability	high	10	8	high	10	8	high	10	8
Body Flexibility	non-flexible	0	0	flexible	10	2	flexible	10	2
Programming	easy	10	2	easy	10	2	easy	10	2
Manufacturing	easy	10	2	easy	10	2	easy	10	2
			71,20			**64,63**			**61,63**

3.3. Scheme Drawings

The scheme designs are evaluated with the parameters which yield a list of possible designs and their points. The designs with the first three higher points are studied as a final scheme design (Table 3.5).

Table 3.6. Point-Result table

RANKING	
1. Design: Tracked Robot with Lever System	71,20
2. Design: Hovercraft Robot	64,63
3. Design: Ball Shaped Robot	61,63

3.4. Final Design Limitations

The limitations assigned to the robot were:

1. Size: The robot must be 250x250mm, but there is no initial length limitation.
2. Load: Maximum 8 kg.
3. Control: The robot needs to be remotely controlled.
4. Mission Time: Minimum 2 hours.

When the limitations on the robot are considered with the field, there are some limitations which are not explicitly mentioned. Different terrain types on the test field require the robot to have a durable locomotion system. Falling down and climbing requires suspension system and a climbing mechanism. In order to be able to turn, the robot either should have a steering mechanism. The size of the robot compared to the distance it should climb and the bridge height it should pass under limits use of big wheels or tracks.

CHAPTER 4

TRACKED ROBOT WITH LEVER SYSTEM

4.1. System Requirements

Design stage is the most important part of the project. The dimensions of the robot are so important since the very small areas and holes are formed at the wreckages after the earthquake. The accepted maximum dimension is determined as 250x250mm. But the length of the robot could be longer than the determined 250mm so that to increase its climbing capability. The components that directed the design is divided into two as electronics and mechanics. Because of the perception and charting properties the used sensors, circuits, processors and the covered area and weight of these components are the most important parameters that influence the design. For this reason all required electronic components are determined and table of dimensions and weight is prepared.

Another important subject is the properties and charge duration of the power supply. According to the researches the rechargeable batteries, NiMh or NiCd is preferred. Voltage and the current used in the system is decided by other components' voltage and current used (Table 4.1)

According to the usage area and perception property of employed every electronic component and sensor, the layout on the robot is adjudged so the mechanic design begins according to the total weight.

4.2. Mechanical Design of the Total System

After the sketches and schemes a truck with level system is decided to search and develop as a first design (Fig 4.1). Each part is drawn in Solid Works® 2004.

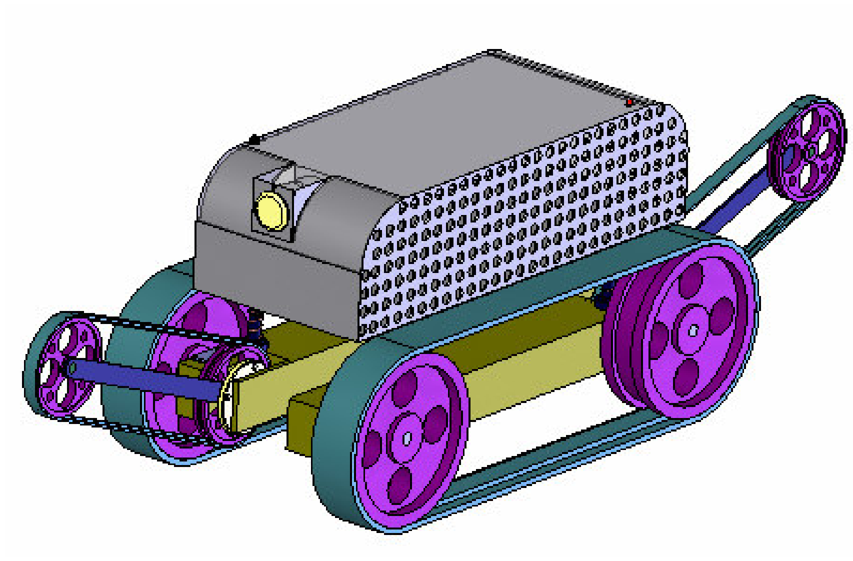


Figure 4.1. Total assembly

4.2.1. Body

4.2.1.1. Control Panel (Upper Body)

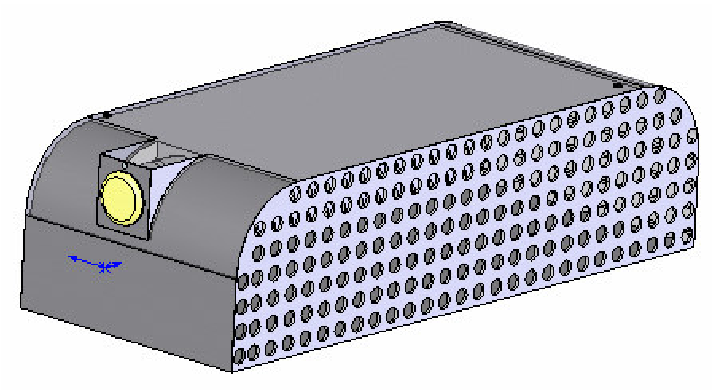


Figure 4.2. Control panel

According to limitations of rescue robot won't exceed 8 kilos, the body must be chosen light material. Aluminum is chosen as the construction material of the body system. Aluminium would be the best material for robots. It is very strong and has the lowest density of all of the common metals available. It is one of the easiest metals to machine. It is easy to obtain and cheap compared to magnesium and titanium.

Ventilation holes, which are important for the air-cooling of the electrical components and circuits, are placed on the sides of the upper stem instead of bottom or top of the robot in order to prevent dust contamination inside the robot (Figure 4.2).

4.2.1.2. Lower Body

The lower body is made by aluminum. It consists of two parts. The longitudinal body design divides the lower body right down the middle and places a passive pivot joint in between the two halves (Figure 4.3). This joint is connected on each end to body, which in turn carries a wheel at each of their ends. This layout allows the body to pivot when any wheel tries to go higher or lower than the rest. This passive pivoting action keeps the load on all four wheels almost equal, increasing mobility simply by maintaining driving and braking action on all wheels at all times. Longitudinal body designs are skid steered, with the wheels on each side usually mechanically tied together like a simple skid steer, but sometimes, to increase mobility even further, the wheels are independently powered. Figure 4.3 shows the basic layout.

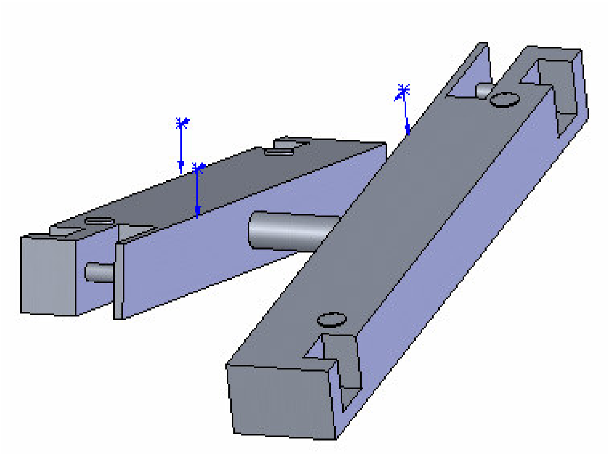


Figure 4.3. Longitudinal body design

4.2.2. Driving Mechanism and Motors

Locomotion is chosen as tracks that give opportunity a large contact area with the ground which supplies improved traction than wheels. Our driving mechanism is a tracked steering system. Design has 4 track belts. Two of them are placed on the right side and on left side. Others are placed in the front side and back side of the robot as an arm (Figure 4.4).

Robot has four driving motors, which provide sufficient torque and velocity to get over the obstacles. By controlling two engines separately robot can move towards to any direction. Furthermore it can turn around itself (Figure 4.5).

Front and back tracks provide high mobility while overtaking the obstacles. Arms are driven with the servo motors. This provides too much mobility advantages while going over the big obstacles (Figure 4.4).

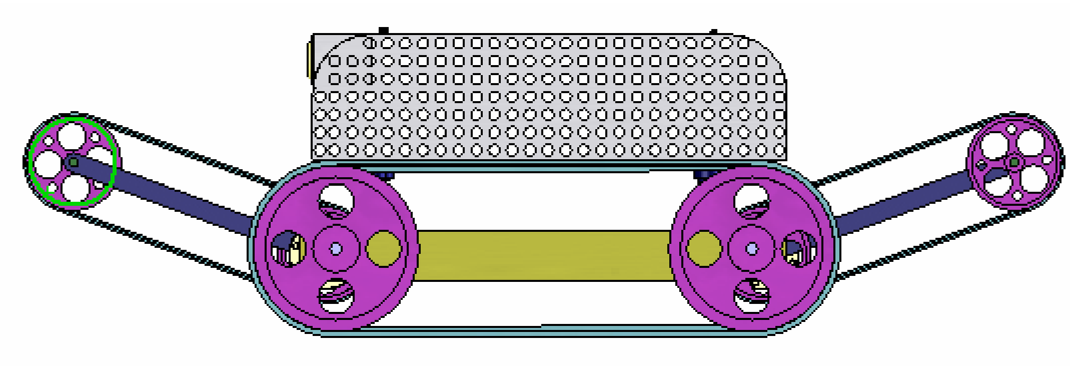


Figure 4.4. Driving system

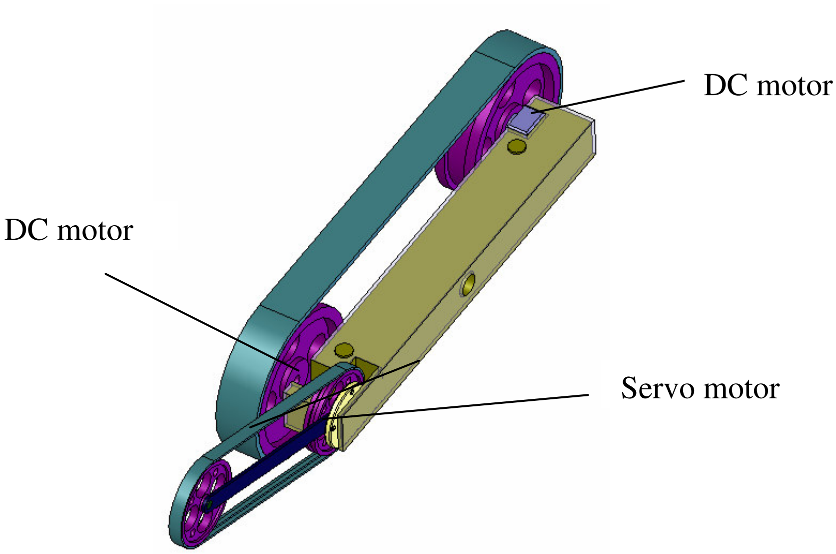


Figure 4.5. Arm System and servo motor

4.2.3. Shock Absorber System

Upper control panel will be placed on the bottom main stem by means of 4 spring parts that give the damper effect against falls as well as adding advanced equilibrium properties while passing through a rough land (Figure 4.6).

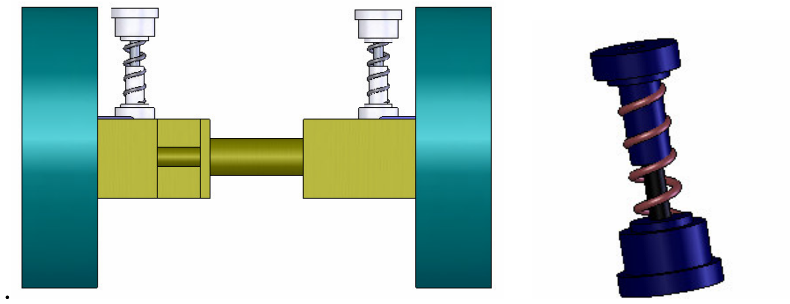


Figure 4.6. Shock absorber system

4.3. Mass Properties

One of the most important parameter is the weight of the robot. Selection of the materials affects this parameter properly. Materials of each part of the design are decided according to density of the materials and their strength. Each part and their pin and connection members are also designed. Weight of the sensors, control unit, motors and gears should be considered.

The weight of the battery would increase the total weight of the robot. According to the duration of the battery charge and the range of the voltage values, battery weights are changed. So the choice of the battery should be decided according to the current values of all electronic components. Table 4.1 shows the parts list and the mass properties of the robot. Total mass of the robot is calculated as 6373,25 gr that is under limitations defined at the beginning of the design.

Table 4.1. Parts list

Part Name	Material	Piece	Volume	Mass	Total Mass
Body Part			mm^3	gr	gr
Upper Body	Aluminium	1	466493,29	1259,53	1259,53
Bottom Body Right	1060 Alloy	1	181159,23	489,13	489,13
Bottom Body Left	1060 Alloy	1	186386,84	503,24	503,24
Front/Rear Arm	2024 Alloy	2	11101,59	31,08	62,16
Spring Upper Part	ABS PC	4	6173,23	6,61	26,44
Spring Bottom Part	ABS PC	4	3452,61	3,69	14,76
Spring	Alloy Steel	4	465,10	3,58	14,32
Wheels					
Wheels	ABS PC	4	300807,50	321,86	1287,44
Arm Wheel	ABS PC	2	24700,46	26,43	52,86
Main Track	Rubber	2	339026,30	339,03	678,06
Front/Rear Track	Rubber	2	22543,01	22,54	45,08
Motors&Gears					
DC Motor	-	4	24739,11	24,74	98,96
Arm Servo	-	2	16485,16	16,49	32,38
Sensors&Control Unit					
Control Unit	-	1	209817,55	71,34	71,34
Battery	-	1	499152,31	1673,00	1673,00
Sensors	-	1	15328,07	14,09	14,09
Pins&Connection Members					
Servo Pin	1060 Alloy	8	142,35	0,38	3,04
Spring Pin	1060 Alloy	4	785,40	2,12	8,48
Connection Members	-	1	785,40	2,12	38,34
		Total Mass			4828,39

4.4. Kinematics Analysis

4.4.1. Steering Mechanism

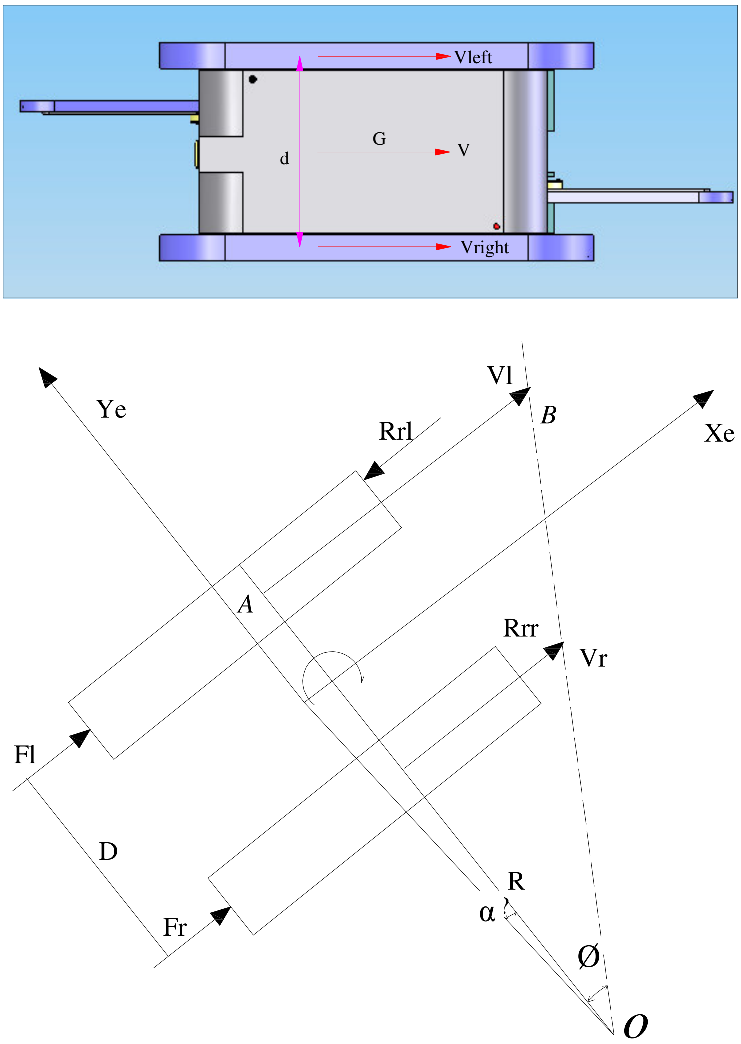


Figure 4.7. Steering of the robot

The local frame of the vehicle is assumed to have its origin on the center of the area defined by both tracks, and its Y axis is aligned with the forward motion direction. Much in the same way as with differential drive, a tracked vehicle is governed by two control inputs: namely the velocity of its left and right tracks (V_l, V_r). Then, the vehicle's forward speed is:

$$V = \frac{V_l + V_r}{2} \tag{4.1}$$

In the absence of track slip, the speeds of the left track V_l and right track V_r would be:

$$V_l = r \cdot \omega_l \tag{4.2}$$

$$V_r = r \cdot \omega_r \tag{4.3}$$

where r is the track rolling radius, and ω_l and ω_r are the angular velocities of the outside and inside track drive. Upon introducing the longitudinal slips i_l and i_r of the tracks relative to the un-deformed soil,

$$V_l = r \cdot \omega_l (1 - i_l) \tag{4.4}$$

$$V_r = r \cdot \omega_r (1 - i_r) \tag{4.5}$$

In the presence of the longitudinal track slip, the vehicle's forward speed is from (Eq 4.1)

$$V = \frac{r}{2}[\omega_l (1 - i_l) + r.\omega_r (1 - i_r)] \tag{4.6}$$

Because of the difference between Vl and Vr, the angle Ø is expressed in the form of an arctangent function.

$$Ø = \arctan \frac{AB}{OA} = \arctan \frac{(Vl - Vr)t}{D} \tag{4.7}$$

where t is time and B is the tread of the vehicle. The time-derivative of Ø can be computed for small time steps as:

$$\dot{Ø} = \frac{\Delta V}{D} \tag{4.8}$$

$$\dot{Ø} = \frac{r[\omega_r (1 - i_r) - \omega_l (1 - i_l)]}{D} \tag{4.9}$$

where Ø is positive anticlockwise when viewed from above. The vehicle's speed may now be decomposed into components in the x_e and y_e directions. The motion of the vehicle is thus described as follows:

$$\dot{x} = \frac{r}{2}[\omega_l(1-i_l) + \omega_r(1-i_r)]\cos\phi$$

$$\dot{y} = \frac{r}{2}[\omega_l(1-i_l) + \omega_r(1-i_r)]\sin\phi \qquad (4.10)$$

$$\dot{\phi} = \frac{r}{D}[\omega_r(1-i_r) - \omega_l(1-i_l)]$$

By introducing the slip angle α, Equation (4.10) can be written as:

$$\dot{x} = \frac{r}{2}[\omega_l(1-i_l) + \omega_r(1-i_r)][\cos\phi(t) - [\sin\phi(t)\tan\alpha(t)]$$

$$\dot{y} = \frac{r}{2}[\omega_l(1-i_l) + \omega_r(1-i_r)][\sin\phi(t) + \cos\phi(t)\tan\alpha(t)] \qquad (4.11)$$

$$\dot{\phi} = \frac{r}{D}[\omega_r(1-i_r) - \omega_l(1-i_l)]$$

4.4.2. Maximum Climbing Angle

If the center of mass is (X, Y, Z)

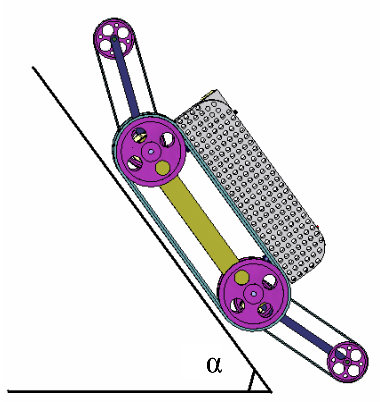


Figure 4.8. Climbing angle

$$\alpha = 90 - \arctan\left(\frac{Y}{Z}\right) \tag{4.12}$$

4.4.3. Maximum Side Angle

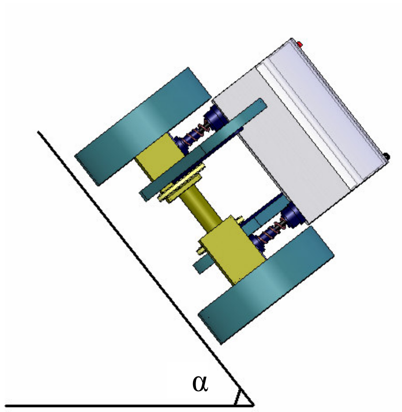


Figure 4.9. Side angle

$$\alpha = 90 - \arctan\left(\frac{Y}{X}\right) \tag{4.13}$$

4.5. Dynamic Analysis

F is the force at the wheel surface and r is the radius of the wheels. Then torque at driving shaft:

$$\tau = F \cdot r \tag{4.14}$$

Total mass of the system is m and g is the gravitational constant where F is the force at the wheel surface takes place as:

$$F = m \cdot g \tag{4.15}$$

$$\tau = m \cdot g \cdot r \tag{4.16}$$

Reduction of the gearbox between driving shaft and the motor is R. From the Eqs (4.14), (4.15) and (4.16), minimum motor torque, this is needed to climb at slope surface:

$$\tau_m = \tau \cdot R \tag{4.17}$$

To calculate minimum torque while accelerating at 1 m/s^2 constant acceleration moving on horizontal surface, angular acceleration of the driving shaft is needed.

$$\alpha = \omega^2 \cdot r \tag{4.18}$$

where ω is angular velocity of the driving shaft and r is radius of the wheels. Then Angular acceleration of the driving shaft is:

$$\tau = I \cdot \alpha \tag{4.19}$$

where I is Inertia of the system, From the Eqs (4.18) and (4.19):

$$\tau = I \cdot \omega^2 \cdot r \tag{4.20}$$

$$\omega = \frac{V}{r} \tag{4.21}$$

$$\tau = I \cdot \frac{V^2}{r} \tag{4.22}$$

where V is velocity of the system, from the Eqs (4.18) and (4.19):

At this situation we need to calculate the minimum torque by calculating the total force needed to accelerate the total system at 1 m/s^2 acceleration. To establish this acceleration need frictional force and Inertia of the rotating parts. Where f is frictional force, then frictional force becomes:

$$Ff = m.g.f. \tag{4.23}$$

After recalling these formulas total torque is become:

$$\tau = (m.a.r) + (\mathrm{I}total.a) + (Ff.r) \tag{4.24}$$

Motor torque becomes from the Eq (4.17):

$$\tau_m = \tau \cdot R \tag{4.25}$$

Final solutions and performance about the design could be seen at Table 4.2 and Table 4.3. According to solutions each criterion and properties are performed under the limitations that are decided at the beginning of the design.

Table 4.2. Final solutions of the criterion table

No	Criteria	Value
1	Weight	5-10 Kg
2	Velocity	3 M/H<
3	Dimensions	20x20<
4	Height	20cm<25cm
5	Volume Capacity	%50<
6	Weight Capacity	%50<
7	Geometrical Difficulties	OK
8	Maneuver Capability	4 Direction
9	Interaction With Other Systems	Nonexistent
10	Energy Necessity	Medium
11	Reverse Fall	Can Rise
12	Falling Resistance	0.5m<1m
13	Usage	Easy
14	Number of Motors	4-6
15	Failure Durability	High
16	Body Flexibility	Non-Flexible
17	Programming	Easy
18	Manufacturing	Easy

Table 4.3. Properties and performance

Properties and Performance	
Length (mm)	890
Width (mm)	250
Height (mm)	250
Weight (gr)	6373.25
Maximum Climbing Angle	44°
Maximum Side Angle	48°
Battery Life (hours)	3

4.5.1. Electrical Systems

One of the aims is to identify the victims' location and their situation. All required information will be derived by the components chosen as temperature, carbon dioxide, distance and range finder sensors. By the evaluation of these cues came from the sensors rescue teams will decide how the victims could be rescued.

With the video camera vision and motion data will be received. If a camera which has capability to take sound signals is used, there will be no need to use microphone. Odometer data from the encoders will be used to measure the amount of slippage that is confronted while driving the data.

4.5.1.1. Sensors

The determined sensors are: HOKUYO URG-0.4LX as laser range finder, SHARP GP2Y0A02YK for long distance measuring sensor, TC 1047 for temperature sensor, MG 811 for CO_2 sensor, SHARP GP2D120 for IR range sensor,

HOKUYO URG-0.4LX as laser range finder: Compact Design; 50x50x70mm (LxWxH), 10gr light weight, Lower power consumption 2.5W, high accuracy ±10mm, high resolution 0.36˚, wide scanning area 240˚

SHARP GP2Y0A02YK for long distance measuring sensor: This sensor has a less influence on the colors of reflected objects and their reflectivity due to optical triangle measuring method. Detecting range is 20cm to 150cm.

TC 1047 for temperature sensor: This sensor is linear voltage output temperature sensors whose output voltage is directly proportional to measured temperature. TC 1047 can accurately measure temperature from -40˚C to +125˚C.

MG 811 for CO2 sensor: This sensor has good sensitivity and selectivity to CO2, low humidity and temperature.

SHARP GP2D120 for IR range sensor: The GP2D120 has special lenses which give it a shorter detection range. This sensor takes a continuous distance reading and reports the distance as an analog voltage with a distance range of 4cm to 30cm.

Table 4.4. Sensor list

Part Name	Model No	Voltage (V)	Current (A)	Ambient Temperature (°C)	Quantity	Total Current (A)
Temperature Sensor	TC 1047	2,7 DC	3,50E-06	-40+125	1	0,0000035
CO_2 sensor	MG811	6 DC	0,2	-20+50	1	0,2
Laser Range Finder	Hokuyo URG-0.4LX	5 DC	0,5	-10+50	1	0,5
Distance Sensor	Sharp GP2Y0A02YK	7 DC	0,033	-10+60	2	0,066
Infrared Sensor	Sharp GP2D120	7 DC	0,033	-10+60	1	0,033
Motor DC	Johnson BC03005	12 V	0,353	-	4	1,412
Motor Servo	Hitec Servo HS-645	12 V	0,353	-	2	0,706
					Total Current	2,92

4.5.1.2. PIC Motor Control

Designed with enhanced PWM, the low cost 18-pin PIC16F716 device supports bi-directional brushed DC motor control. The chip offers four PWM outputs, programmable dead-band control and auto shutdown for enhanced safety. The device also features programmable brown-out reset and four channels of 8-bit analogue to digital conversion.

4.5.1.3. Motors

Johnson BC03005 DC Motor is chosen for driving the rescue robot.

A servo motor includes a built-in gear train and is capable of delivering high torques directly. The output shaft of a servo does not rotate freely as do the shafts of DC motors and stepper motors, but rather is made to seek a particular angular position under electronic control.

To control the robot's arm Hitec Servo HS-645 Metal Geared High Torque servomotor is chosen.

4.5.1.4. Power Supply

According to range of voltage of chosen electronic components, battery voltage should be 12 V (Table 4.2).

It is seem that total current consumption is 3.07 Ampere (Table 4.2). So 6Ah battery could drive the system at least 2 hours and this time is adequate by considering our robot limitations. But to control the robot during 3 hours is important for the rescue operations. Although the weight of the 9 Ah batteries is very high and our limitations about the time is 2 hours, by thinking the importance of the time, 9Ah battery is decided to choose.

The range from 2.7 V DC to 12 V DC varies voltage values of the chosen components. So a regulator circuit, which has four outputs as 2.7V, 6V, 5V and 7V, should be used for driving these components.

Finally DV-12V9500 Ni-MH 12V, 9Ah D-Cell battery is chosen.

Table 4.5. Current and voltage of the components

Part Name	Model No	Voltage (V)	Current (A)	Ambient Temperature (°C)	Quantity	Total Current (A)
Temperature Sensor	TC 1047	2,7 DC	3,50E-06	-40+125	1	0,0000035
CO_2 sensor	MG811	6 DC	0,2	-20+50	1	0,2
Laser Range Finder	Hokuyo URG-0.4LX	5 DC	0,5	-10+50	1	0,5
Distance Sensor	Sharp GP2Y0A02YK	7 DC	0,033	-10+60	2	0,066
Infrared Sensor	Sharp GP2D120	7 DC	0,033	-10+60	1	0,033
Motor DC	Johnson BC03005	12 V	0,353	-	4	1,412
Motor Servo	Hitec Servo HS-645	12 V	0,353	-	2	0,706
Video Camera	Philips PCVC740K	12 V	0,03	-	1	0,03
Pulse Encoder	US Digital E3	5 V	0,03	-	4	0,12
RC	RC SystemV8600A	6 V	0,00001	0+70	1	0,00001
PIC	PIC 16FF716	5 V	0,000014	-	1	0,000014
Ram	256 Kbyte	-	0	-	1	0
					Total Current	3,07

4.5.1.5. Odometer

In order to map the debris during the rescue operations, the robot’s paths should be determined along with the sensors. We need to keep data, which come from the sensors about the robot's movements through velocity measurement. This data could be integrated to give the displacement.

The encoder counts returned from the optical shaft encoders mounted on the drive motors are also used to track the position of the robot relative to its position. These data provide the "sensor input" for the dead-reckoning behaviors.

CHAPTER 5

HOVERCRAFT ROBOT

5.1. Basic Principle

Hovercraft act on the principles of pressure (Figure 5.1). This lead it to describe as “air cushion vehicles” or “ground effect vehicles” (Figure 5.2).

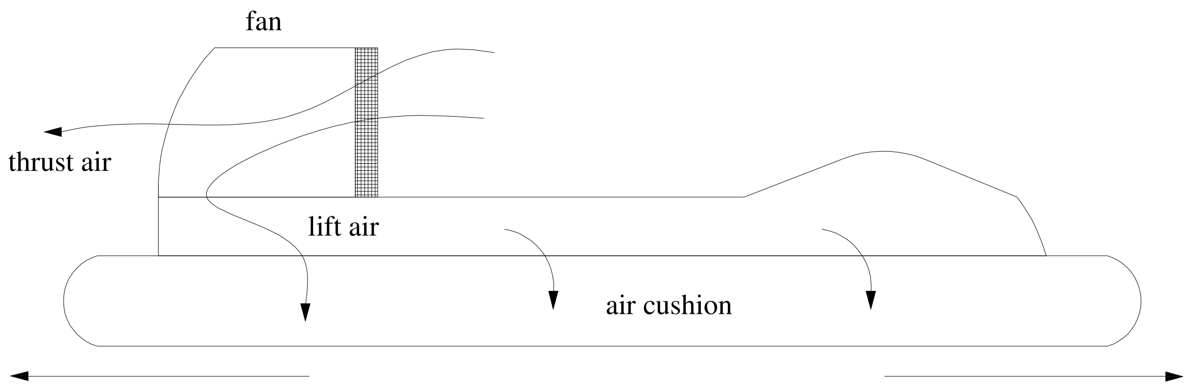


Figure 5.1. Hovercraft robot scheme design

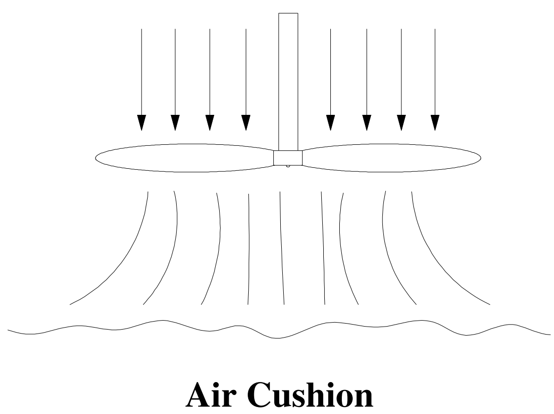


Figure 5.2. Ground effect of the hovercraft

Most light hovercraft used today are called "integrated" hovercraft, that means using only one fan to provide both lift and thrust. The fan is usually mounted vertically using the top two thirds for thrust and the bottom third for lift as shown above. The lift air is directed into the hull by the splitter plate, the air is then fed into the skirt and under the craft. The air under the hovercraft is known as the air cushion. This air cushion leaks away under the bottom of the skirt to provide a film of air which the hovercraft rides on. The steering of the craft is achieved by positioning a rudder in the thrust air stream to deflect the thrust air. Some hovercraft uses two fans, one to supply the lift air and the other to exclusively supply thrust (Hirose and Takayama, 1998)

The hull is normally made from either glass-fiber or plywood or a combination of both. The hull must also provide buoyancy for the craft should it stop on water (Hirose and Takayama, 1998).

Most racing craft use light weight 2 stroke engines as they have a high power to weight ratio. Cruising craft tend to use 4 stroke car engines as they are quieter and more economical.

The engine rpm is normally higher than the fan rpm, therefore a reduction is obtained by toothed belt and pulleys or a reduction gearbox (Hirose and Takayama, 1998).

The purpose of the skirt is to retain the air cushion under the craft; this gives the craft greater hard structural clearance. This is termed the "hover height". There are two main types of skirt in use. The bag skirt and a segmented skirt. Both types are made from a flexible waterproof coated material, usually neoprene coated nylon (Hirose and Takayama, 1998)

5.2. Hovercraft for a Rescue Robot

Any kind of hovercraft type research robot has not been observed in research activities after an earthquake. Hovercrafts as high power carriages, in general, are used for transportation purposes for personnel and / or military applications. Light and small scale ones are considered as a hobby element.

Main reasons for selecting the hovercrafts in research activities under the wreckage are the ease of use and the great advantage in moving against geometrical difficulties of the search area. Also it can be considered as more stable in case of falls thanks to its airbag with respect to the robots that have rigid bodies. In addition to that increasing and decreasing the volume of the airbag, hovercrafts would pass through even smallest holes.

The main reason for having a movable control panel is to give the ability to turn into its original position if it turns turtle. Some manipulation and development in hovercraft airbag design give this important property.

The greatest disadvantage of the designed hovercraft on the basis of the desired loading capacity and dimensions is that the huge amount of the dust created by it. Moreover, it is uncertain that how much we could raise the hovercraft on the undulating land by regulating the air pressure and how its performance and dust characteristics would be under stated conditions.

5.3. Dynamic Analysis of Hovercraft

Calculation of the cushion pressure and airflow required for lifting the hovercraft:
H_l is the hull length of the hovercraft and H_w is the hull weight of the hovercraft, then Approximate lift perimeter is:

$$\text{Lp}= 2\cdot(Hl+Hw) \tag{5.1}$$

where Ag is the amount of air gap takes place in Eq (5.2), total gap area is :

$$\text{Tga}= \text{Lp.Ag} \tag{5.2}$$

Total cushion area is:

$$\text{TCA}= H_l.H_w \tag{5.3}$$

The cushion pressure is found from the craft mass and cushion area,

$$Pc=\frac{total\_weight\_of\_skate\_and\_load}{area\_of\_cushion} \tag{5.4}$$

The lift air volume is found from the escape velocity and total gap area,

$$\text{Lav}= V_e \cdot Tga \tag{5.5}$$

Definition of Pressure

P_0 is the atmospheric pressure and P_a is the absolute pressure in the duct. For the purpose of fan and air movement engineering, static pressure can be considered as the difference between the absolute pressure of the point under consideration and atmospheric pressure.

Static Pressure Ps is defined as:

$$P_s=P_a-P_0 \tag{5.6}$$

where the ρ=1.22 the density of air in Kg/m sq at sea level. The wind has a velocity and therefore a velocity pressure.

Velocity Pressure P_v is found as:

$$P_v=\frac{1}{2}\cdot \rho \cdot V^2 \tag{5.7}$$

As the wind is flowing through the atmosphere without exerting force on anything the static pressure will be zero. In ducted air system, fan imparts a total pressure (P_t) rise, which is then constant throughout the system.

Total Pressure Pt is calculated as:

$$P_t= P_s + P_v \tag{5.8}$$

The cushion pressure (P_c) is a static pressure exerted on the floor under the skate. Suffix 1 presents the conditions within cushion. So:

$$P_{t1}=P_c+P_{v1} \tag{5.9}$$

When the air leaves the cushion: Suffix 2 presents the conditions outside the cushion.

$$P_{t2}=P_{s2}+P_c \tag{5.10}$$

From the Eqs (5.9) and (5.10)

$$P_{t2}=0+P_c \tag{5.11}$$

$$P_{t1}=P_c+0 \tag{5.12}$$

Combining with the Eq (5.7)

$$V_e=\sqrt{\frac{2.P_c}{\rho}} \tag{5.13}$$

This is the escape velocity of the air that is escapes through the hover gap at Pc (cushion pressure). Then by using Eq (5.5) lift air volume of air at Pc could be calculated.

Current of which is needed for the fan is found as:

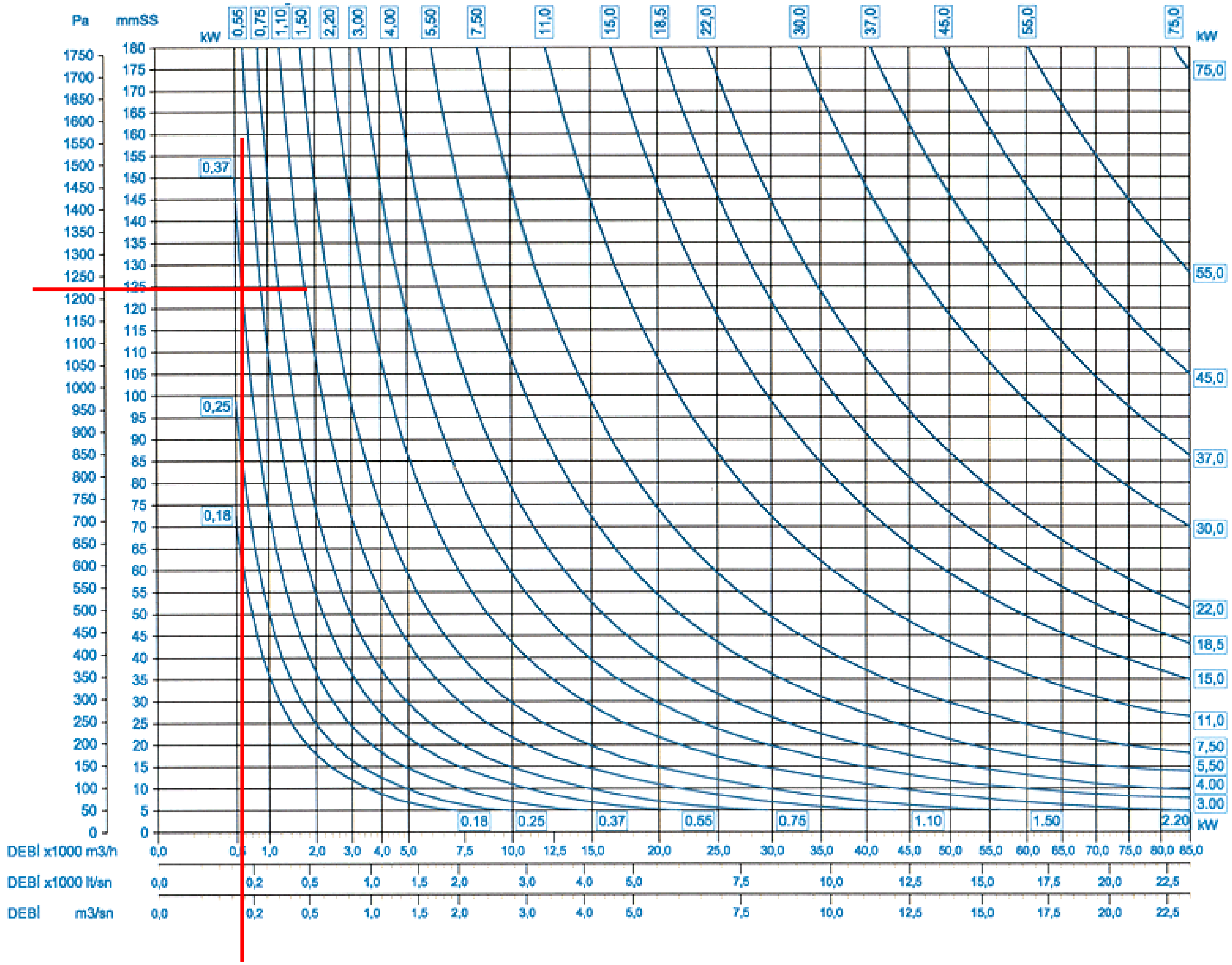
$$I(A)=\frac{P(W)}{V(V)} \tag{5.14}$$

We assume that dimensions are: hull length of the hovercraft is 0.25m, and hull weight of the hovercraft is 0.25m, amount of air gap is 4mm and the weight of the hovercraft is 8 kg. Then the solution table is shown as Table 5.1.

Table 5.1. Hovercraft solutions

Properties and Performance		
Approximate lift perimeter	1	m
Total gap area	0.004	m^2
Total Cushion area	0.0625	m^2
Cushion Pressure	1255.251	Pa
Expected actual air velocity	45.36	m/sec
Lift air volume	0.18	m^3/sec
Estimated lift engine power	0.225	kW
Estimated fan diameter	0.097	m

Table 5.2. Fan selection table (Source: McClain et al, 2005)



Calculations show that the required fan for a hovercraft of dimension 25x $25cm^2$ and 8 kg weight uses 225W, which could only be generated by 18 A current. However, 3 cm thick cables might only supply such a current. This is the critical point that shows designing a hovercraft type robot in order to use search and rescue activities are impossible.

If the power is calculated for the every possible weights of hovercraft (Eq. 5.8):

Table 5.3. Total weights vs. power

Total Weight	Power
5 kg	117 W
3 kg	30 W
2 kg	15 W
1 kg	10 W

If we examine the minimum size of 25x25 hovercrafts, 5 kg hovercraft needs 117W power which requires 12V and 10 Ampere current which is too high for a robot in such dimensions.

Use of appropriate battery is applicable only for 3kg or lower weights because this corresponds to 30W power and 4.6A current. A 2kg battery can supply such a current. Hence, we have 1 kg, which has to cover all the system including the main body, sensors and electrical circuits.

CHAPTER 6

BALL SHAPED ROBOT

The ball robot is a mobile robot based on a ball structure. The locomotion and motion control systems are fully constructed inside a ball. Ball shaped robot has following advantages. It cannot overturn which is the most important specification. Also it is easy to make light weight and strong. The ball vehicle could easily move uphill and has a capability to overrun obstacles.

6.1. Jumping Mechanisms

6.1.1. Magnetic Pistons

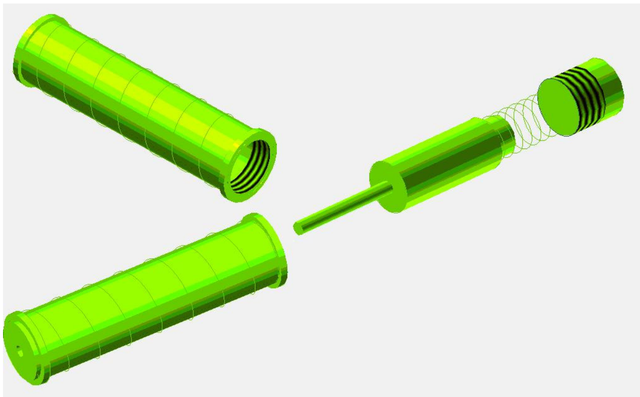


Figure 6.1. Magnetic piston

Jumping mechanism will be working by magnetic pistons. Between the inner and outer surfaces, magnetic pistons which are located separately will be designed. The pistons create a motion to satisfy the jumping function.

6.1.2. Magnetic Pistons Inside The Robot

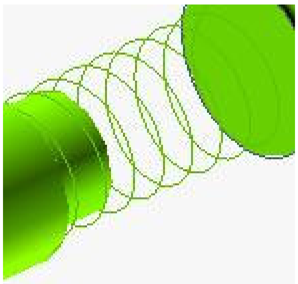


Figure 6.2. Magnetic pistons inside the robot

The magnetic pistons which are located inside the robot, is jumping the robot. This type jumping mechanism needs an elastic cover. But this elastic cover is absorbing the most of the energy. So it is not efficient for the robot.

6.1.3. By Compressing Spring

The spring which is located inside the robot is compressed by the help of the motors. This system has a lover weight than magnetic pistons. Also the size of the spring and the type of the material can be determined by the requirements of the robot. So we can say that the mechanism is more useful in for this situation.

6.2. Dynamic Analysis

6.2.1. Initial Velocity for Jumping Mechanism

For the jumping mechanism firstly initial velocity V_o is defined by the conservation of energy:
where the m is mass of the ball robot, h is the height of the jump and g is the gravity constant, then:

$$m \cdot g \cdot h = \frac{1}{2} \cdot m \cdot V_0^2 \tag{6.1}$$

From the equation (6.1) initial velocity V_o is shown as:

$$V_0 = \sqrt{2 \cdot g \cdot h} \qquad (6.2)$$

6.2.2. Force

We assumed an expansion in the magnetic piston to create the force is shown as x. where the a_0 is the acceleration and t is the time to pass x expansion, then:

$$x = \frac{1}{2} \cdot a_0 \cdot t^2 \qquad (6.3)$$

$$V_0 = a_0 \cdot t \qquad (6.4)$$

By combining two equations (6.3) and (6.4), a_0 is calculated as:

$$t = \frac{2x}{V_0} \qquad (6.5)$$

Then the acceleration is found by the Eq (6.6):

$$a = \frac{V_0 - 0}{t} \qquad (6.6)$$

And the force that is needed is defined as:

$$F = m \cdot a \qquad (6.7)$$

If we assume that:

For a robot with radius of 125mm and jumping height is 500mm. Weight of the robot is 6 kg. and g= 9.81 m/s^2 ;

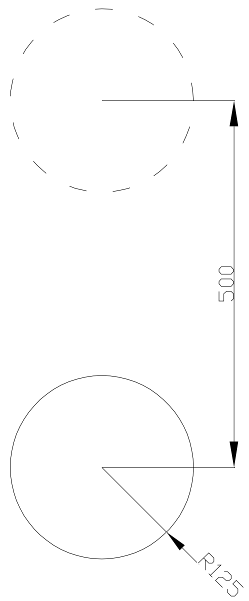


Figure 6.3. Dynamic analysis of ball robot

Table 6.1. Solutions of the ball robot

Properties and Performance			
Initial Velocity	V_o	3.13	m/s
Time to Pass	t	0.0191	s
Acceleration	a	163.87	m/s^2
Needed Force	F	983.22	N

6.2.3. Magnetic Piston Parameters

After finding the force and velocity which is needed, we can calculate the magnetic pistons parameters; A is the cross section area and r is the radius of the spring. Then the A is stated as:

$$A = \pi \cdot r^2 \quad (6.8)$$

where the n is number of turns per unit length, l is the length of the piston, μ_o is the permeability constant, and then L that indicates inductance is shown as:

$$L = \mu_0 \cdot n^2 \cdot A \cdot l \tag{6.9}$$

Then the needed ampere becomes;

$$I = \sqrt{\frac{F \cdot x}{L}} \tag{6.10}$$

where the operating voltage is defined as V and for the current from Eq. (6.10), then the internal resistance needs to be is calculated as:

$$R = \frac{V}{I} \tag{6.11}$$

If we assume that n = 10 / 50 (1/mm) = 200 (1/m), l= 0.03 m, $A = 1.256 \times 10^{-3}$ (Eq 6.8) and μ_o = 1.26 x 10^{-6} N/Amp^2

Table 6.2. Solutions of the ball robot

Properties and Performance			
Inductance	L	1.89 x 10^{-6}	Nm/Amp^2
Current	I	3950	Amp
Operation Voltage	V	24	V
Internal Resistance	R	0.00607	Ohm

Because the internal resistance of ball robot is very low, this force cannot be created at internally powered small robotic applications.

The most important parameter is the weight of the system in current and resistance calculations. Hence this robot can be used in space studies. For example, in Pluto where gravitational acceleration is 1/6 of that of earth the weight of the ball will be 0,4 kg instead. Then, robot of that weight would only require 1.016 x 103 ampere and 0.024 ohm Table 6.3.

Table 6.3. Comparison of the center of gravity with the earth

Planet	Gravity	6 kg weight in earth
Mercury	%37	2.2
Venus	%90	5.4
Mars	%37	2.2
Jupiter	%251	15.1
Saturn	%105	6.3
Uranus	%88	5.3
Neptune	%111	6.7
Pluto	%6	0.4

CHAPTER 7

LOCALIZATION, NAVIGATION AND MAPPING

Localization, navigation and mapping are three important problems of robotics. It is necessary to know the position of robot, while it is moving, this called as the localization problem. The navigation problem is to compute a new path. Furthermore if the robot moves, it has a new position so this is the mapping problem.

The approaches for environment representation are separated in three groups: geometric, topological and hybrid. Most of the topological maps are occurred by recognizing places and recording them as references. These data are taken from vision sensors that detect main components of the image and colors.

Geometric maps and topological maps can be combined as hybrid maps. Another method is Simultaneous Localization and Mapping – SLAM also known as Concurrent Map Localization – CML. This methodology solves localization, navigation and mapping problem relying on a topological approach.

7.1. Environment Representation

Topological is the adjacency-graph based representation of the environment composed by nodes or states and links. Geometric is the metric representation of the environment landmarks position with respect to a referential. The metric representation also includes the common grid maps or hybrid (topological maps containing sub-topological and metric maps in each state) (Bernardino et al, 2004).

A topological map represents the environment with no metric information. Instead of it the map expresses a functional relationship among relevant features (Bernardino et al, 2004).

7.2. Localization

The robot estimated location is the map's state that is most likely to have produced the observations acquired by the robot sensors during a given time interval. As a result of the measurements uncertainty, the robot position estimation can not be performed using deterministic criteria. As a result, the main issue of the localization problem is to find the state that minimizes the uncertainty, given the observations (Bernardino et al, 2004).

7.3. Navigation

Using a topological approach also develops the navigation. Topological map is based on the robot location at each time. The navigation procedure is based on finding the best way to reach a goal, a state in the topological map, given the current robot's state. To reach the goal state, the robot moves through other places and this caused uncertainty. The navigation algorithm provides the best sequence of states from the current state to the goal. Nevertheless, the robot reaches a state not integrated in the sequence so the topological navigation has to figure a new sequence if the robot fails the sequence.

7.4. Mapping

Dynamic Expectation and Maximization algorithm is the main points of the mapping problem. Features have to support different scenarios but not every type of feature is essential to a particular scenario, this requiring a feature selection criteria (Bernardino et al, 2004).

The main thing for the robot is to build a map of environment and settle on its own position in the map while moving around simultaneously. The problem is examined by an estimation-theoretic view. Estimation algorithm which provides an estimate for the map and robot pose is on the main goal. This is taken from two sensor inputs: The first one is odometry, The second one is the observation of environment features which is called as landmarks. The optimal solution is based popular approaches like Kalman Filter.

7.5. Simultaneous Localization and Mapping

Simultaneous Localization and Mapping (SLAM) is the process of building a map of the environment while simultaneously using this map to provide localization information. The algorithm works by generating estimates of the relative localization between landmarks. It can be shown that the precision of these estimates increases monotonically and that the vehicle location estimate becomes bounded. This means that a vehicle can start at an uncertain location in an unknown environment and incrementally build a convergent map while maintaining bounds on platform error. Seminal work suggested that as successive landmark observations take place, the correlation between the estimates of the location of such landmarks in a map grows continuously. They also showed how the absolute accuracy of the map reaches a lower bound defined only by the initial vehicle uncertainty

Simultaneous Localization and Mapping (SLAM) addresses two important problems in robotics: Robot localization "Where am I?" and Robot mapping "What does the world look like?" Main aim is to simultaneously estimate both map and location of the robot. SLAM is formalized as:

Where s_t is the probability of robot being at position, θ is map features that within environment represented as map, z^t is given knowledge of the observations, u^t is the control inputs and n^t is the data associations ($n^t : f(z_i) \rightarrow \theta_i$,) then:

$$p(s_t, \Theta \mid z^t, u^t, n^t) \tag{7.1}$$

There are lots of main approaches to solving SLAM. Kalman Filtering Approach commonly used with SLAM.

7.6. Kalman Filtering Approach

Kalman filters are used for tracking features and from the locations of the tracked image features. The Kalman filter is a recursive estimator. This means that only the estimated state from the previous time step and the current measurement are needed to compute the estimate for the current state. One of the advantages of KFA is to be a simple to implement. Other one is to have a big advantage for working well in practice. Disadvantages of KFA are to assume Gaussian Probability distributions, linear motion model and time complexity $O(n^3)$.

Kalman filter (KF) has been used to solve the SLAM problem. These approaches permit to show the convergence properties of the filtered system; at least, for the linear case.

7.7. Implementation of Tracked Robot

7.7.1. Mobile Robot System

The robot is equipped with two pallets which are driven by four wheels. Each wheel moves with one motor. Internal robot control estimates the robot's velocity. The estimate is based on the wheels' angular velocities measured by encoders. From the estimated velocity, the robot's odometric position could be integrated. The robot is equipped with a camera system mounted on an upper body of the robot.

7.7.2. Landmark Detection

There are a lot of different types of landmarks and methods for landmark detection. They are distinguished as artificial that is deployed for localization and natural landmarks such as walls, edges, door etc.

HOKUYO URG-0.4LX as laser range finder, SHARP GP2Y0A02YK for long distance measuring sensor, SHARP GP2D120 for IR range sensor are used for detection of debris to find out any evidence that could be used as a landmarks such as walls or edges. Infrared sensors are chosen against all other moderately affordable methods because of their reliability, range of operation, and ease of use.

Also micro-camera is placed on upper body to supply the images on real time. This will be effective for obstacle detection, object recognition, scene analysis and human-robot interaction.

We need to keep data which come from the sensors about the robot's movements through velocity measurement. This data could be integrated to give the displacement.

The encoder counts returned from the optical shaft encoders mounted on the drive motors are also used to track the position of the robot relative to its position. These data provide the "sensor input" for the dead-reckoning behaviors.

7.7.3. Landmark Identification

Landmark identification algorithm means to recognize a detected landmark as a landmark already represented in the map. In other words, the algorithm matches landmark observations with landmarks in the map including the decision to define unmatched landmarks as new.

During the implementation the measurements are taken from odometry and landmark observations. A landmark observation yields the position of the landmark relative to the robot's pose at some point of time. The odometry defines the relative robot pose between two successive points of time.

Because the robot will move through an unknown region under the debris, the uncertainty of its pose will get arbitrarily large, because the odometric error accumulates over time. The uncertainty can be reduced by fusing the odometry with several measurements of a new landmark.

CHAPTER 8

CONCLUSIONS AND FUTURE WORKS

The essence of this thesis is the proposal of a new type of three rescue robots and their mechanical designs. All robots are designed to replace human rescue teams and to rescue the victims after disasters.

First design considers pallet track with lever system which has got the highest score hence the highest performance on the basis of the 18 evaluation parameters. Similar studies are also performed in previous studies. It has better performance than the others from some aspects. Apart from other tracked robot designs designed with the rigid body which are currently used for rescue operations; Rescue robot in this study is designed with the longitudinal body design. Main body is formed by two separate bodies, which have the ability to move independently from each other, and combined with a pin of quite hard material. Thus the pallet would move on the flat surface while the other is on the rough surface. Control panel placed on such flexible construction is put on four spring parts in order not to lower moving capability. These springs also absorb the impacts caused by falls. Robot performs ascent and descent activities by means of two arms mounted on front and back sides.

In addition, sensor systems for rescue operations needed to applications of autonomous all-terrain mobile robots are evaluated and feasible sensor combinations are determined.

Also this robot could be used as rescue robot against nuclear plant accidents that affects the human body by radiation source. All the information about the damage could easily be taken by the sensors and camera. Because this robot is designed by considering all geometric difficulties, usage for the other accidents or terror attacks will be uncomplicated and useful. In addition, this robot could be used both earth and planets. Driving system, which provides high maneuver capability, gives opportunity to move under the complicated environment.

For the future work, artificial intelligence studies for mapping and localization implementations could be started. An additional arm might also be designed to remove the possible blocks and barriers in further studies. Dimensions of the robot will become small by using light materials for the body and development of the semi conductors technology. When the body is designed as a waterproof construction, this robot could be used for the lots of purpose under sea.

Secondly hovercraft design is studied. Hovercrafts have not been designed for rescue and search purposes. The main reasons for deeply studying this choice are barriers can be passed through by rising the hovercraft and flexible body can be obtained by regulating the cushion pressure which blow up/blow down the air cushion. However calculations performed on the basis of the average weight (8kg) determined for rescue robot shows us than 225W fan in required to raise this weight 4mm.

On the other hand, use of such a fan that requires 18 A current is inapplicable. Thus, hovercraft type robots cannot be used in search and rescue activities because the most appropriate hovercraft design should be 2 kg or lower; however, these can be only used as hobby element for lots of competitions.

Hovercrafts of greater dimensions will lead to high dust formation due to the use of powerful fans. Instead of earthquakes, these would be used in floods or rescue activities in ship accidents.

Ball type is the third design and 6 kg weight robot is thought to move by electromagnetic pistons. However, design calculations shows that required current is too high and inside resistance is too low. Use of materials with so small values of inside resistance is not applicable for such small robots.

The most important parameter is the weight of the system in current and resistance calculations. Hence this robot can be used in space studies. For example, in Pluto where gravitational acceleration is 1/6 of that of earth the weight of the ball will be 0,4 kg instead. Then, robot of that weight would only require 1.016 x 103 ampere and 0.024 ohm.

Development of studies on superconductors would let to use robots with electromagnetic pistons. But such kind of ball robots could be used for projects that are related with the searches about planets and space studies.

All three designs are evaluated for understanding the capability and performance under the debris. It is seen that, hovercraft robot and ball shaped robot is not suitable for this purpose. But the tracked robot is appreciated as a rescue robot. By helping of this robot to locate injured victims and life triangle in debris enables us to rescue the victim in the shortest time with minimum injury. That is very important subject for the Turkey of where the earthquakes are the most probable disasters.

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APPENDIX A

CRITERION POINTS and EVALUATIONS TABLE

Criterion points are used for evaluating of the 15 designs. Because each design has lots of advantages or disadvantages, these tables help us to understand the best design by scientific approach (Table A.1).

The scheme designs are evaluated with the parameters which yield a list of possible designs and their points. All 15 designs and their evaluation could be seen in Table A.2.

Table A.1 Samples of criteria and their values

Weight	
5 kg>	10
5-10 kg	5
10 kg<	0

Velocity	
1 m/h>	0
1-3 m/h>	5
3 m/h<	10

Manufacturing Ease	
easy	10
difficult	0

Programming Ease	
easy	10
difficult	0

Number of Motors	
4>	10
4-6	5
6<	0

Volume Capacity	
%25>	0
%25-%50	5
%50<	10

Maneuver Capability	
6 direction	10
5 direction	8
4 direction	6
3 direction	4
2 direction	2
1 direction	1

Geometrical Difficulties	
Steps	1,43
Pipe	1,43
Max Slope	1,43
Jump (canyon)	1,43
Deep Hole	1,43
Climbing	1,43
Rough Surface	1,43

Table A.1 (cont.)

Dimensions	
10x10>	10
10x10<20x20	5
20x20<	0

Weight Capacity	
%25>	0
%25-%50	5
%50<	10

Interaction With Other Systems	
existant	0
nonexistant	10

Reverse Fall	
can rise	10
cannot rise	2

Usage	
easy	10
difficult	0

Body Flexibility	
flexible	10
non-flexible	0

Height	
<10cm	10
10cm<15cm	8
15cm<20cm	6
20cm<25cm	4
25cm<	2

Falling Resistance	
0.5m>	2
0.5m<1m	4
1m<1.5m	6
1.5m<2m	8
2<	10

Energy Necessity	
very high	2
high	4
medium	6
low	8
very low	10

Failure Durability	
high	10
low	0

Table A.2 Evaluations table

	6 Wheeled Truck With Pallets			8 Wheeled Truck		
	Criterions	**Point**	**Weighted Points**	**Criterions**	**Point**	**Weighted Points**
Weight	5 kg>	10	5	5 kg>	10	5
Velocity	3 m/h<	10	2	3 m/h<	10	2
Dimensions	10x10<20x20	5	2,5	10x10<20x20	5	2,5
Height	15cm<20cm	6	3	15cm<20cm	6	3
Volume Capacity	%25-%50	5	4	%25-%50	5	4
Weight Capacity	%25-%50	5	4	%25-%50	5	4
Geometrical Difficulties		4,29	5,14		4,29	5,14
Steps	0,00		0	0,00		0
Pipe	1,43		0	1,43		0
Max slope	1,43		0	1,43		0
Jump (canyon)	0,00		0	0,00		0
Deep Hole	0,00		0	0,00		0
Climbing	0,00		0	0,00		0
Rough Surface	1,43		0	1,43		0
Maneuver Capability	2 direction	2	1	3 direction	4	2
Interaction with Other Systems	nonexistant	10	5	nonexistant	10	5
Energy Necessity	medium	6	4,8	medium	6	4,8
Reverse Fall	cannot rise	2	1,6	cannot rise	2	1,6
Falling Resistancy	0.5m<1m	4	2	0.5m<1m	4	2
Usage	easy	10	8	easy	10	8
Number of Motors	6<	0	0	6<	0	0
Failure Durability	high	10	8	high	10	8
Body Flexibility	non-flexible	0	0	non-flexible	0	0
Programming Ease	easy	10	2	easy	10	2
Manufacturing Ease	easy	10	2	easy	10	2
	Total Point		60,04	Total Point		61,04

Table A.2.(cont.)

	6 Wheeled Truck with Lever System			Front Design Resembling Plane Tip, Air Inflated Pickup Truck With 6, 180		
	Criterions	**Point**	**Weighted Points**	**Criterions**	**Point**	**Weighted Points**
Weight	5-10 kg	5	2,5	5-10 kg	5	2,5
Velocity	3 m/h<	10	2	1-3 m/h>	5	1
Dimensions	10x10<20x20	5	2,5	10x10<20x20	5	2,5
Height	15cm<20cm	6	3	15cm<20cm	6	3
Volume Capacity	%25-%50	5	4	%25-%50	5	4
Weight Capacity	%25-%50	5	4	%25-%50	5	4
Geometrical Difficulties		10,00	12,00		4,29	5,14
Steps	1,43		0	0,00		0
Pipe	1,43		0	1,43		0
Max slope	1,43		0	1,43		0
Jump (canyon)	1,43		0	0,00		0
Deep Hole	1,43		0	0,00		0
Climbing	1,43		0	0,00		0
Rough Surface	1,43		0	1,43		0
Maneuver Capability	4 direction	6	3	5 direction	8	4
Interaction with Other Systems	nonexistant	10	5	nonexistant	10	5
Energy Necessity	high	4	3,2	high	4	3,2
Reverse Fall	can rise	10	8	cannot rise	2	1,6
Falling Resistancy	0.5m<1m	4	2	0.5m<1m	4	2
Usage	easy	10	8	easy	10	8
Number of Motors	6<	0	0	6<	0	0
Failure Durability	high	10	8	high	10	8
Body Flexibility	non-flexible	0	0	flexible	10	2
Programming Ease	easy	10	2	easy	10	2
Manufacturing Ease	easy	10	2	easy	10	2
	Total Point		71,20	Total Point		59,94

Table A.2.(cont.)

	3 Segmented Snake with Two Pallet in Each Segment			6 Wheeled 3 Spined Snake		
	Criterions	**Point**	**Weighted Points**	**Criterions**	**Point**	**Weighted Points**
Weight	5-10 kg	5	2,5	5-10 kg	5	2,5
Velocity	1-3 m/h>	5	1	1-3 m/h>	5	1
Dimensions	10x10<20x20	5	2,5	10x10<20x20	5	2,5
Height	10cm<15cm	8	4	10cm<15cm	8	4
Volume Capacity	%25>	0	0	%25>	0	0
Weight Capacity	%25>	0	0	%25>	0	0
Geometrical Difficulties		7,14	8,57		7,14	8,57
Steps	1,43		0	1,43		0
Pipe	1,43		0	1,43		0
Max slope	1,43		0	1,43		0
Jump (canyon)	0,00		0	0,00		0
Deep Hole	0,00		0	0,00		0
Climbing	1,43		0	1,43		0
Rough Surface	1,43		0	1,43		0
Maneuver Capability	6 direction	10	5	6 direction	10	5
Interaction with Other Systems	nonexistant	10	5	nonexistant	10	5
Energy Necessity	high	4	3,2	high	4	3,2
Reverse Fall	can rise	10	8	cannot rise	2	1,6
Falling Resistancy	0.5m<1m	4	2	0.5m<1m	4	2
Usage	difficult	0	0	difficult	0	0
Number of Motors	6<	0	0	6<	0	0
Failure Durability	low	0	0	low	0	0
Body Flexibility	non-flexible	0	0	non-flexible	0	0
Programming Ease	easy	10	2	easy	10	2
Manufacturing Ease	easy	10	2	easy	10	2
	Total Point		45,77	Total Point		39,37

Table A.2.(cont.)

	Bug With 6 Feet, Each Foot With 3 Joints			**Bug With 6 Feet, Each Foot With 2 Joints**		
	Criterions	**Point**	**Weighted Points**	**Criterions**	**Point**	**Weighted Points**
Weight	5-10 kg	5	2,5	5 kg>	10	5
Velocity	1 m/h>	0	0	1 m/h>	0	0
Dimensions	10x10<20x20	5	2,5	10x10<20x20	5	2,5
Height	15cm<20cm	6	3	15cm<20cm	6	3
Volume Capacity	%25>	0	0	%25>	0	0
Weight Capacity	%25>	0	0	%25>	0	0
Geometrical Difficulties		5,71	6,86		5,71	6,86
Steps	1,43		0	1,43		0
Pipe	1,43		0	1,43		0
Max slope	1,43		0	1,43		0
Jump (canyon)	0,00		0	0,00		0
Deep Hole	0,00		0	0,00		0
Climbing	0,00		0	0,00		0
Rough Surface	1,43		0	1,43		0
Maneuver Capability	4 direction	6	3	4 direction	6	3
Interaction with Other Systems	nonexistant	10	5	nonexistant	10	5
Energy Necessity	medium	6	4,8	medium	6	4,8
Reverse Fall	cannot rise	2	1,6	cannot rise	2	1,6
Falling Resistancy	0.5m>	2	1	0.5m>	2	1
Usage	easy	10	8	easy	10	8
Number of Motors	6<	0	0	6<	0	0
Failure Durability	high	10	8	high	10	8
Body Flexibility	non-flexible	0	0	non-flexible	0	0
Programming Ease	easy	10	2	easy	10	2
Manufacturing Ease	easy	10	2	easy	10	2
	Total Point		50,26	Total Point		52,76

Table A.2.(cont.)

	Bug with 6 Feet, Each Extandable Foot with 3 Joints			**Car With 4 Spinned Joints**		
	Criterions	**Point**	**Weighted Points**	**Criterions**	**Point**	**Weighted Points**
Weight	5-10 kg	5	2,5	5 kg>	10	5
Velocity	1 m/h>	0	0	3 m/h<	10	2
Dimensions	10x10<20x20	5	2,5	10x10<20x20	5	2,5
Height	15cm<20cm	6	3	15cm<20cm	6	3
Volume Capacity	%25>	0	0	%25-%50	5	4
Weight Capacity	%25>	0	0	%25-%50	5	4
Geometrical Difficulties		10,00	12,00		2,86	3,43
Steps	1,43		0	0,00		0
Pipe	1,43		0	1,43		0
Max slope	1,43		0	1,43		0
Jump (canyon)	1,43		0	0,00		0
Deep Hole	1,43		0	0,00		0
Climbing	1,43		0	0,00		0
Rough Surface	1,43		0	0,00		0
Maneuver Capability	4 direction	6	3	4 direction	6	3
Interaction with Other Systems	nonexistant	10	5	nonexistant	10	5
Energy Necessity	medium	6	4,8	high	4	3,2
Reverse Fall	cannot rise	2	1,6	cannot rise	2	1,6
Falling Resistancy	0.5m<1m	4	2	0.5m<1m	4	2
Usage	easy	10	8	easy	10	8
Number of Motors	6<	0	0	6<	0	0
Failure Durability	high	10	8	high	10	8
Body Flexibility	non-flexible	0	0	non-flexible	0	0
Programming Ease	easy	10	2	easy	10	2
Manufacturing Ease	easy	10	2	easy	10	2
	Total Point		56,40	Total Point		58,73

Table A.2.(cont.)

	Hovercraft with Fixed Control Panel			Hower with Moving Control Pannel		
	Criterions	**Point**	**Weighted Points**	**Criterions**	**Point**	**Weighted Points**
Weight	5-10 kg	5	2,5	5-10 kg	5	2,5
Velocity	1-3 m/h>	5	1	1-3 m/h>	5	1
Dimensions	10x10<20x20	5	2,5	10x10<20x20	5	2,5
Height	15cm<20cm	6	3	15cm<20cm	6	3
Volume Capacity	%25-%50	5	4	%25-%50	5	4
Weight Capacity	%25-%50	5	4	%25-%50	5	4
Geometrical Difficulties		2,86	3,43		2,86	3,43
Steps	0,00		0	0,00		0
Pipe	1,43		0	1,43		0
Max slope	1,43		0	1,43		0
Jump (canyon)	0,00		0	0,00		0
Deep Hole	0,00		0	0,00		0
Climbing	0,00		0	0,00		0
Rough Surface	0,00		0	0,00		0
Maneuver Capability	4 direction	6	3	4 direction	6	3
Interaction with Other Systems	nonexistant	10	5	nonexistant	10	5
Energy Necessity	high	4	3,2	high	4	3,2
Reverse Fall	cannot rise	2	1,6	can rise	10	8
Falling Resistancy	0.5m<1m	4	2	0.5m<1m	4	2
Usage	easy	10	8	easy	10	8
Number of Motors	4-6	5	1	4-6	5	1
Failure Durability	high	10	8	high	10	8
Body Flexibility	flexible	10	2	flexible	10	2
Programming Ease	easy	10	2	easy	10	2
Manufacturing Ease	easy	10	2	easy	10	2
	Total Point		58,23	Total Point		64,63

Table A.2.(cont.)

	Mono Tank			**Chain Tank**		
	Criterions	**Point**	**Weighted Points**	**Criterions**	**Point**	**Weighted Points**
Weight	5-10 kg	5	2,5	5-10 kg	5	2,5
Velocity	3 m/h<	10	2	3 m/h<	10	2
Dimensions	10x10<20x20	5	2,5	10x10<20x20	5	2,5
Height	15cm<20cm	6	3	15cm<20cm	6	3
Volume Capacity	%25-%50	5	4	%25-%50	5	4
Weight Capacity	%25-%50	5	4	%25-%50	5	4
Geometrical Difficulties		2,86	3,43		2,86	3,43
Steps	0,00		0	0,00		0
Pipe	1,43		0	1,43		0
Max slope	1,43		0	1,43		0
Jump (canyon)	0,00		0	0,00		0
Deep Hole	0,00		0	0,00		0
Climbing	0,00		0	0,00		0
Rough Surface	0,00		0	0,00		0
Maneuver Capability	2 direction	2	1	2 direction	2	1
Interaction with Other Systems	nonexistant	10	5	nonexistant	10	5
Energy Necessity	medium	6	4,8	medium	6	4,8
Reverse Fall	cannot rise	2	1,6	cannot rise	2	1,6
Falling Resistancy	0.5m<1m	4	2	0.5m<1m	4	2
Usage	easy	10	8	easy	10	8
Number of Motors	4-6	5	1	4-6	5	1
Failure Durability	high	10	8	high	10	8
Body Flexibility	non-flexible	0	0	non-flexible	0	0
Programming Ease	easy	10	2	easy	10	2
Manufacturing Ease	easy	10	2	easy	10	2
	Total Point		56,83	Total Point		56,83

Table A.2.(cont.)

	Ball Robot		
	Criterions	**Point**	**Weighted Points**
Weight	5-10 kg	5	2,5
Velocity	1-3 m/h>	5	1
Dimensions	10x10<20x20	5	2,5
Height	15cm<20cm	6	3
Volume Capacity	%50<	10	8
Weight Capacity	%25-%50	5	4
Geometrical Difficulties		2,86	3,43
Steps	0,00		0
Pipe	1,43		0
Max slope	1,43		0
Jump (canyon)	0,00		0
Deep Hole	0,00		0
Climbing	0,00		0
Rough Surface	0,00		0
Maneuver Capability	4 direction	6	3
Interaction with Other Systems	nonexistant	10	5
Energy Necessity	high	4	3,2
Reverse Fall	can rise	10	8
Falling Resistancy	1m<1.5m	6	3
Usage	difficult	0	0
Number of Motors	4-6	5	1
Failure Durability	high	10	8
Body Flexibility	flexible	10	2
Programming Ease	easy	10	2
Manufacturing Ease	easy	10	2
	Total Point		61,63