Modified Hardware Design for Cooperative Mobile Robots*

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Abstract - *This paper describes the latest changes in the basic design of our mobile robot, ACE Rover I[2], but before that the original design of the ACE Rover I is discussed in brief. The proposed rover called ACE Rover I is a four-wheel drive, four wheel steering, all-terrain autonomous rover. The first design had a lower level, which contained the wheel motors with encoders, a steering motor, tilt switches to determine surface inclination, bumpers to sense if the robot has bumped into an obstacle, an array of batteries, and four IR sensors to avoid abrupt surface changes such as drop-offs. The upper level has eight IR sensors to avoid large obstacles, an analog compass to determine direction, and the controller circuit board. The modified hardware design now has a sliding suspension system attached to the wheel unit, so that the robot can prevent mechanical failures due to shocks and vibrations in rugged terrain. With the introduction of the suspension system, we had to rethink the method of transmitting torque to each wheel. The prospect of adding a sonar ring or a vision system is also discussed in the paper. Towards the end of the paper, a brief description of previous approaches to localization and path planning with the available sensors on the ACE Rover I is given.*

Keywords: mobile robots, suspension system, robot motion, sonar sensors, obstacle avoidance, localization

1 Introduction

In the recent years mobile robots have had wide applications in the areas of security, region surveillance, and material handling. These tasks usually involve a team of two or more mobile robots cooperating in the field of operation to achieve the assigned goal. The more specialized a task the more the complexity, and design and implementation issues in the mobile robot. This also depends on the environment to which a mobile robot is confined. Mobile robots designed for indoor applications are restricted to a specific area of operation, and have a simpler mechanical design, while those designed for outdoor applications deal with a large uncertainty of terrain, and thus have more degrees of freedom (DoF) and more factors to consider for their mechanical design. However, it is interesting to know that the complexity of algorithms defined for applications like localization, path planning, convoying, manipulation, etc is similar and hence the design of a controller circuit board with fast computation power can be the same. With this consideration our focus in this paper has been biased to the issues concerning the mechanical design of mobile robots and methods to make them robust to varying terrain.

Our pursuit of designing a team of mobile robots for an all-terrain navigation and surveillance application led us to our first design of ACE Rover I. It is a four-wheel drive, four-wheel steering, all-terrain autonomous rover. The first design of ACE Rover I was strictly for the basic application of obstacle avoidance in indoor environments. The design was divided into a lower level and an upper level. The lower level contained the wheel motors with encoders, a steering motor in the middle, tilt switches to determine surface inclination, bumpers to sense if the robot has bumped into an obstacle, an array of batteries, and four IR sensors to sense abrupt changes in the surface like cliffs, steps, etc. The lower level has watertight seals around its perimeter, so that the robot can move partly submerged in water, or mud. The wheel motors are the Animatics 2315 smart motors, which have an onboard controller, and allow motion at about 7 cm/sec. An IR sensor is placed at the front, back, and sides of the robot, tilted at 22.5° to detect drop-offs.

Manufacturers of commercial all-terrain mobile robots do not consider the uncertainties inherent with all-terrain navigation, and as a result their mechanical design is

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[2] This work was supported, in part, by NASA Ames Grant No. NAG-2-1547

monotonous. These mobile robots exhibit imprecise motion, which contributes to the gross error inherent to the sensors mounted on them. Our design of independently driven, independently steered wheels for the ACE Rover I improves precision in robot motion, and we believe that ACE Rover I would thus perform far better than its commercial counterparts. However, after some initial work, we realized that few modifications are necessary to make the ACE Rover I more robust to mechanical failures, and we have suggested them in this paper.

The original design of ACE Rover I has been discussed in detail in the next section. Section III suggests the modifications in the mechanical design of ACE Rover I, and section IV explains the need to replace the IR sensors at the upper level with sonar sensors. The prospect of adding a vision system is also mentioned in section IV. Section V describes some previous work done with the available sensors on the robots towards the application of localization and path planning. Section VI concludes the paper with a summary and intended future work.

2 Design of ACE Rover I

This section gives an overview of the first design of ACE Rover I. A more detailed description can be found in [1].

2.1 Lower Level and Wheel Drive System

The lower level contains four batteries, four wheel-drive units (one for each wheel), IR sensors, and touch sensors, see figure 1. The lower platform is made of a carbon fiber wrap with a foam core. It has several holes drilled into it for mounting bolts, IR sensors, wheel shafts and touch switches.

The batteries are currently a 12v, 1.2-amp hour cells made by Power Sonic. Each of the four batteries will provide enough power to run one motor under heavy load for about 30 minutes.

Each drive unit contains a wheel motor, an encoder and redundant seals to maintain a watertight environment inside the base if the motor seal failed. The motor is an Animatics 2315 Smart Motor, and it draws between 1.1 - 3 amps depending on the load applied to the wheels. The encoders are quadrature-encoders integrated with the motor.

The IR sensors at the lower level are to monitor the surface on which the robot is traveling for drop-offs, and there is one IR sensor mounted on each base wall at an inclination of 22.5°.

The touch switch is a linear activated switch made by micro switch. It closes its contacts with a shaft that moved parallel to the switch contacts so that no pressure is places on the contacts.

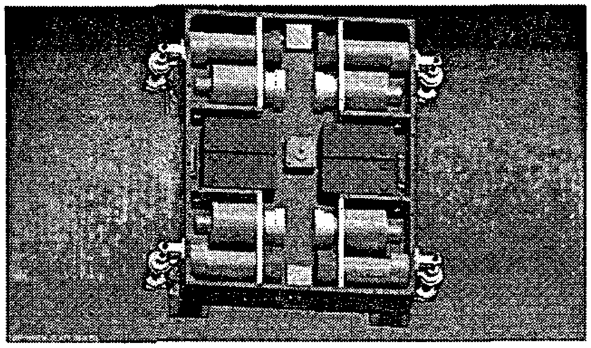

Figure 1. Lower level and wheel drive system

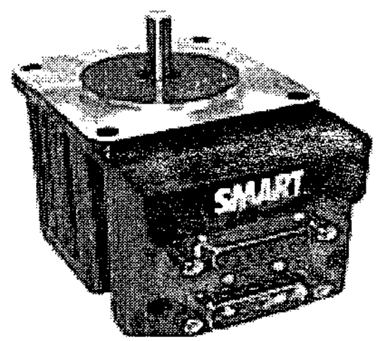

Figure 2. Wheel drive unit in the lower level

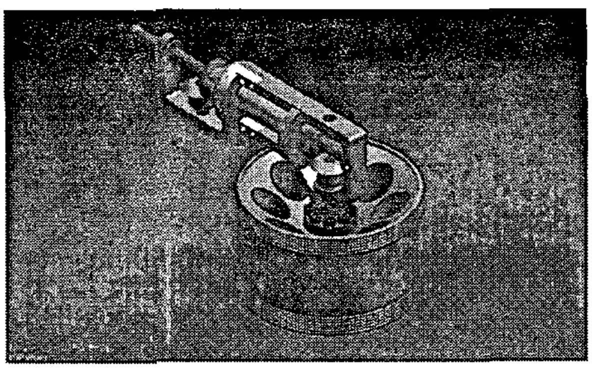

Figure 3. Wheel unit

2.2 Wheel Unit

The wheel unit gives the rover four-wheel drive, four-wheel steering capability. It has a shaft tube, which houses a wheel shaft and a steering shaft. The wheel shaft has two gears, one at either end, which takes power from the wheel motor and transmits it to the wheel shaft. Inside the wheel shaft is a bearing. The steering shaft rotates inside this bearing, and transmits power from the steering drive motors (part of the steering system). Each of the

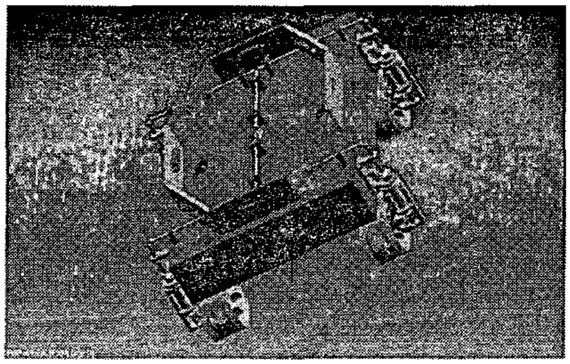

Figure 4. Upper level

shafts is held in place with snap rings. A wheel support is clamped to the wheel unit mount with a wheel support lock. This arrangement turns on a ring and groove system, which allows the wheel unit to turn freely about its own axis, but will not let it move up or down.

We suggest two types of wheels that can be attached to the wheel unit. A wheel for hard surfaces like concrete, stone, etc will have its surface covered with small pyramids of size 1/16"x1/16 x1/16", whereas a wheel for soft surfaces like mud, sand, etc will have several small spikes on its surface treaded into place.

2.3 Upper Level

The upper level contains the steering system, a compass, the controller circuit board, tilt switches, a RF unit and other electronic accessories.

The steering system is made up of six 1/8" shafts, thirteen miter gears, twelve supports to house nylon bearings and a stepper motor to drive the system. The steering motor is in the center of the rover and mounted to the bottom of the center plate (divides the upper and lower levels). It has a miter gear attached to it that drives the steering motor shafts. The steering motor shafts are lateral shafts that drive the steering drive shafts. The steering drive shafts are longitudinal shafts that start from the center of the rover, pass through the upper level wall and connect to the wheel unit. Shaft power for steering is transmitted from the steering motor, to the steering motor shafts through a set of miter gears. It is then transferred to the steering drive shafts via a second set of miter gears, and finally to the steering shafts on the wheel units via a third set of miter gears. Each shaft has two supports and bearings. The supports consist of a lower support, which is fixed to the center with two screws and a nylon bearing, and a top support, which is fixed to the lower support with two screws. The bearing is held in place between two e-clips. The steering drive shafts also pass through a double O-ring seal on the corner wall plates. These seals add additional support for the shafts.

The upper walls consist of eight plates that are welded together. Each plate has a rectangular slot for the IR sensors. Once the plates are welded together they will be bolted to the center plate, and a top cover will be made to seal the upper level and cover the electronics. The top cover will have holes for the antenna (for an RF link) and a wiring for solar cells to pass through.

3 Modified Mechanical Design

The original design of the ACE Rover I as explained above is believed to improve precision in robot motion, but we realized lately that in order to build a robust all-terrain autonomous rover, the mechanical design should be resistant to mechanical failures. This is very important for fail-safe operation of a mobile robot in hazardous environments.

In our latest design we have a sliding suspension system attached to the wheel unit, so that the robot can resist mechanical shocks due to change in the terrain, or while rolling over small obstacles, or while getting down from an elevated surface. The suspension system is designed in a way so as to allow suspension only in the vertical direction.

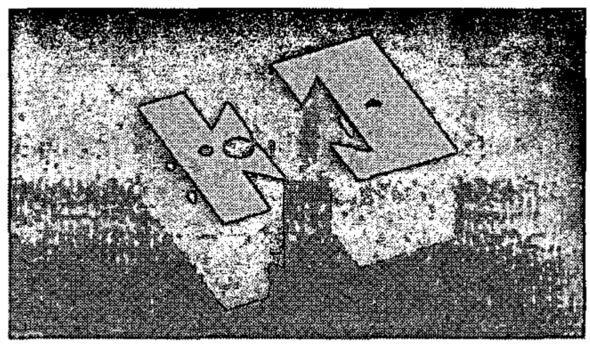

Figure 5. The sliding suspension unit

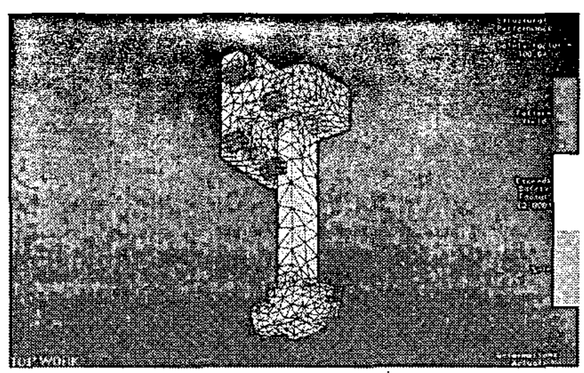

Figure 6. Evaluation of safety factor

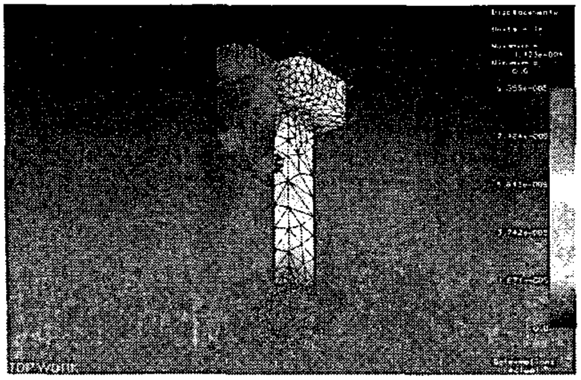

Figure 7. Evaluation of structural displacement

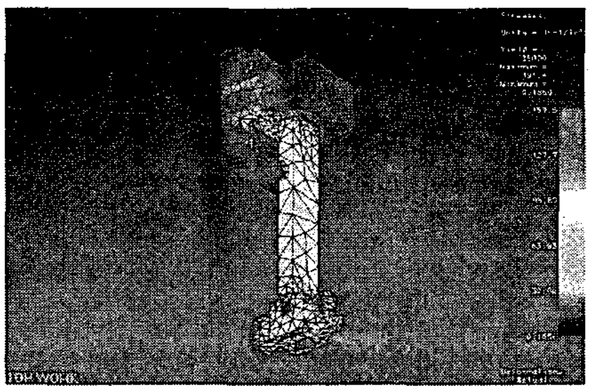

Figure 8. Evaluation of stress

Unlike conventional suspension systems like those used in automobiles, we have designed a suspension system with two blocks, where the block with a damping component and which is attached to the wheel unit slides inside another block, which is attached to the robot, see figure 5. This arrangement protects the suspension system against debris entering inside the damping component. The entire unit is easy to manufacture, and can protect the ACE Rover I against mechanical failures due to high stress on connections and power transmission points. We also did a structural performance analysis of the sliding suspension unit, and the results are shown in figures 6, 7, and 8 respectively. In all of these figures red indicates severe conditions, and blue indicates mild conditions on different portions of the sliding suspension unit. It is apparent that the design of the sliding suspension unit is fail-safe, and it can thus be incorporated into the mechanical design.

With the introduction of the suspension system, we had to rethink the method of transmitting torque to each wheel. This can be now be done by either having a flexible (flex) shaft, or by having a self-contained wheel drive unit. A flex shaft allows torque to be applied even if the shaft is bending or having vertical motion. On the other hand a self-contained wheel drive unit could fit inside each wheel directly driving it. A self-contained wheel drive unit has the advantage that the wheel drive motors with encoders could now be removed from the lower level, thus creating extra space for additional batteries, and allowing longer run time. The original design could accommodate 4 12V, 1.2 Amp-hr cells, and with the modified design we will be able to accommodate 6-8 cells. This arrangement would also lower the center of gravity of the ACE Rover I, making the robot less susceptible to turning over at small inclinations. These options also prevent the moving parts from exposure to rocks, debris, sand, and dust, which could cause mechanical blockage during robot motion.

It should be noted that having a suspension system would increase the contact of the wheels with the ground, even while traveling over slightly varying terrain, and would thus reduce non-systematic errors in the odometry. In our case the number of independently driven wheels is more than the 3 DoF of the ACE Rover I, and the ACE Rover I can thus be classified in the category of over-constrained mobile robots [8]. As a result, the odometry can also be corrected as suggested in [8].

4 Modified Upper Level

As mentioned before, the upper level has a front and rear array of IR sensors to avoid large obstacles, an analog compass to determine direction, and the controller circuit board. We have sustained our original controller circuit design [1] to have the aJ-100 chip for our Intelligent DEVS (IDEVS) application code written in DEVS-Java [6], and two PIC micro-controllers for reading the various sensors, and actuating the corresponding transducers respectively.

Eight IR sensors along the periphery of the upper level are enough for obstacle avoidance, but IR sensors transmit a narrow beam, and thus eight IR sensors would generate an extremely sparse representation of the environment, which is not desirable for localization and navigation in mobile robots. A solution is to increase the number of IR sensors, but instead we decided to replace the IR sensors with a front and rear array of eight sonar sensors each. Sonar sensors transmit a cone of ultrasonic waves, and thus cover a wider range, which can be used for fast obstacle avoidance or fast navigation of the ACE Rover I towards the goal. Sonar based localization is possible in indoor environments with time of flight (ToF) data obtained from each sensor in the sonar ring [7].

Although sonar ToF data, along with odometry data could be sufficient for structured indoor environments, it would not work for outdoor and open environments [3]. A good solution is to have a vision system. A vision system is typically used with all-terrain mobile robots for field or planetary exploration and navigation, since it provides detailed information of the surrounding environment and it is cheaper than range sensors like the laser scanner.

However the addition of a vision system and issues concerning it is left for future work.

5 Application to Localization and Path Planning

With our current design we intend to implement programs for building surveillance, and localized motion of mobile robots in structured environments like rooms and hallways, which usually have common features in every building or construction. Localization requires a previously built map of the environment, or simultaneous map building with robot motion. Sonar data from two or more adjacent sensors are combined for feature identification of cylinders, walls, and corners, and these features are then used to build a topological map of the environment [7]. Range data from sonar is also used to build grid-based maps, where smaller grid sizes aid optimal path planning [4]. Another method of localization of robots is useful for traveling in hallways, and it does not require a priori map or a concurrent map of the environment. This method uses a rule-base to detect typical hallway features like T-junctions, 4-way intersections, alcoves, dead ends, etc. In such methods a robot is given commands like 'go to the third alcove at the left', 'stop at the first alcove at the right after the 2nd 4-way intersection', etc [9].

At times sonar data and odometry data are fused together to develop a probabilistic model of the environment, and then a discrete Kalman filter is used to get an optimal estimate of the robot position. Such a sensor fusion is also used for online calibration of odometry. A lot of work has been done based on this sensor fusion, and all of the above ideas are proven approaches to mobile robot localization and path planning, but implementing them or developing new techniques with sonar and odometry is left for future work.

6 Conclusion

Although a lot of research has been done in the design of mobile robots, the contribution to develop a robust all-terrain autonomous rover is rare. While most of the work has been dedicated to the development of new algorithms, and study of theoretical and practical aspects of various robotic tasks, we believe it is equally important to consider the design and development of a fail-safe team of mobile robots to implement these concepts with minimum error in the sensor data and maximum precision in motion. In this paper we started with a description of our first effort to design a mobile robot with precision in motion. We then mentioned how the performance of the robot can be improved over a longer period of time with modifications in the mechanical design. We mentioned the importance of a suspension system in the mobile robot, and we suggested the design of a sliding suspension system successfully implemented in the mechanical design of our ACE Rover I. In the middle of the paper we have also stressed the importance of sonar sensors and a vision system to all-terrain mobile robots, and we actually replaced the IR sensors in the original design of the ACE Rover I with a front and rear array of sonar sensors. The potential methods towards mobile robot localization and path planning, which were developed earlier at various universities, are mentioned in the last section of the paper. In the future, we intend to manufacture the ACE Rover I with the specified changes, and implement previous algorithms for localization and path planning developed at different universities and our research group at the University of New Mexico.

Special Acknowledgements

We especially thank Paul Swiderski and Ben Masefield at the department of Mechanical Engineering, who helped us develop the sliding suspension unit, and test it for structural performance analysis. They both have been actively involved in this work since the last six months.

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