URPR Quarterly Report
University of Michigan
4/1/2003 – 6/30/2003

1 Administrative details

- Grant contract number: **DE FG04 86NE 37969**
- Period of performance (current contract year): **6\1\2002 – 5\31\2003**
- Period of this report: **4/1/2003 – 6/30/2003**

2 Financial details

- Grant budget for current contract year: **$862,500**
- Estimated amount invoiced this reporting period: $230,000

3 Technical overview

3.1 Brief summary of university's technical emphasis/area(s) of expertise

Subtask 1: Vehicle control and navigation techniques – This task aims at the development of an obstacle negotiation system for mobile robots. Specific emphasis is on the use of affordable laser rangefinders in an obstacle negotiation system that performs reliably in semi-structured environments such as typical DOE sites.
Subtask 2: Vehicle precision position estimation – This task aims at the development of a position estimation system for mobile robots. Our emphasis is on dead-reckoning, that is, position estimation without external references or beacons.
Subtask 3: Development of novel mobile robot platforms – Our specific emphasis is on so-called hyper-mobility robots that can crawl into, slither through, or penetrate niches and crevices in collapsed man-made structures or otherwise hard-to-reach areas.
Subtask 4: Development of novel radiation sensors and imagers – This task aims at the development of novel radiation sensors and radiation cameras that can locate and identify particular radioisotopes over a wide range of energies.

3.2 Five-year plan goals for current contract year

Subtask 1: New optical range sensors integrated into outdoor navigation system
Subtask 2: Positioning system further enhanced using external reference sources
Subtask 3: 6-segment OmniPede built and pneumatic control system improved
Subtask 4: Upgrade CSPD-II radiation imaging camera for improved spatial resolution and depth information.

3.3 Goals/milestones met year-to-date

Subtask 1: Vehicle control and navigation techniques

i. We concluded our extensive characterization study of the Sick laser rangefinder
ii. We completed the modification of our Gorilla vehicle to fully automated operation

iii. We are building a second platform for initial experiments with the Sick laser rangefinder. This work was not anticipated in the original 5-year plan but has become necessary because of difficulties associated with running the large Gorilla platform outdoors, during the cold Michigan winter.

Subtask 2: Vehicle precision position estimation

We diverted our attention from the original goal of integrating GPS into our position estimation system to two fundamentally new ideas. We implemented those ideas with considerable success. We feel that the innovations resulting from our pursuit of those two new ideas warrant the postponement of the originally proposed GPS integration, especially in light of the fact that GPS is conventional technology, and its integration is mostly an engineering task.

These were the two new ideas we worked on:

1. *Odometry with multiple redundant encoders*. We developed a rule-based method for deciding on which encoder's data to use in a multi-wheel system with redundant encoders. A paper on this method and our results were presented at an SPIE conference during April 2003.
2. *Accelerometry*. We added an accelerometer in the direction of driving. The innovation with this accelerometer lies in the way it is combined with odometry, in a method we call "*Accelerometry*." In this method odometry is used most of the time, while high-drift accelerometer-derived data is ignored. However, if temporary all-wheel slippage is detected, then accelerometer-derived position data is used for that brief period. More technical details are given in Section 4.

Subtask 3: Development of novel mobile robot platforms

We exceeded most goals.

iv. We built a 7-segment prototype of the OmniPede.
v. We invented a substantially improved version of the OmniPede, called OmniTread. We built a single segment prototype of the OmniTread.
vi. We tested several pneumatic actuators: cylinders, bellows, and McKibben muscles.
vii. We developed a novel control method that minimizes compressed air consumption in pneumatic cylinders.

Subtask 4: Development of novel radiation sensors and imagers

We completed the upgrade of the CSPD-II radiation imaging camera for improved spatial resolution and depth information. We have completed making the CSPD-2 fully functional using individual anode wire readouts and larger detection area (i.e., efficiency) using a high-Z pixellated scintillation crystal. A paper on the results has been submitted to an international conference.

3.4 Goals remaining

Subtask 1: Integrate Sick laser rangefinder and its control program with the real-time position estimation system.
Subtask 2: Integrate GPS with our existing position estimation system.
Subtask 3: Complete study of different pneumatic actuators and make final decision on actuators to be used for OmniTread.
Subtask 4: Publish images and performance parameters of upgraded imager in archival journal and IEEE technical conference. Include point source and extended source images taken by camera published in archival journal.

4 *Technical Accomplishments*

4.1 Summary of this quarter's accomplishments

4.1.1 Subtask1: Vehicle control and navigation techniques

Figure 1 shows a block diagram of our proposed Obstacle Avoidance for Semi-structured Environments System (OASES). Last year we completed extensive work on the blocks labeled "Real time data acquisition," "Map building and Filtering," and "Terrain Map Registration." Earlier this year we developed (currently in simulation only) algorithms for the blocks labeled "Global Map Registration and Retrieval" and "Terrain classification & traversability analysis." The block labeled "Proprioceptive Pose Estimation" is completed in its basic form, but it is still subject to ongoing improvements.
In the quarter of this reporting period we worked on the block labeled "Modified VFH*."

4.1.1.1 Modified VFH and motion-context based obstacle negotiation method*

One key problem we addressed this quarter was that in the original, sonar-based VFH algorithm the robot could enter a local condition in which it would loop endlessly. This condition is different from the well-known "trap" conditions that are inherent in local obstacle avoidance algorithms. The difference lies in the fact that in the endless-loop problem of the original VFH algorithm there is no real geometric cul-de-sac. Rather, the original VFH algorithm causes continuing indecision when small changes in position result in algorithm variables fluctuating between values below or above a threshold.

To solve this problem, we developed a method that decides on an appropriate action by considering the immediately proceeding motion, i.e., a short-term memory. Besides the development of the method itself, we were able to prove mathematically that this method converges globally, i.e., that the robot can always arrive at the target. We are omitting here a detailed description of this method because of space limitations.
In order to evaluate the performance of our obstacle negotiation algorithms we developed an index of performance that includes not only distance traveled but also the amount of roll and pitch the robot would be subjected to on a given trajectory. For this purpose we developed a numerical method for computing the true roll and pitch angle of the robot during the trip. Figure 2 shows the trajectory and the changes in roll and pitch of the vehicle.

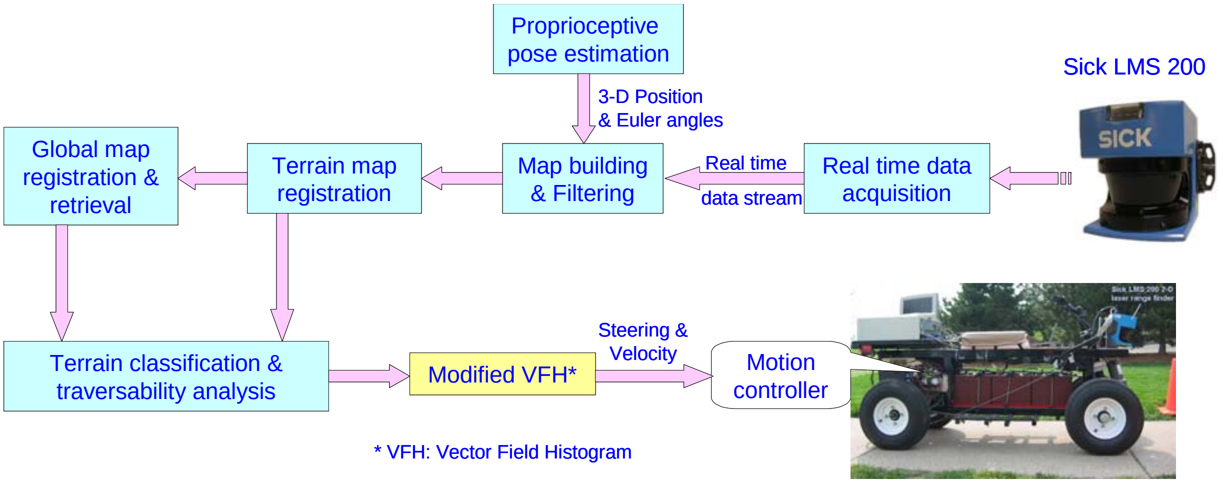
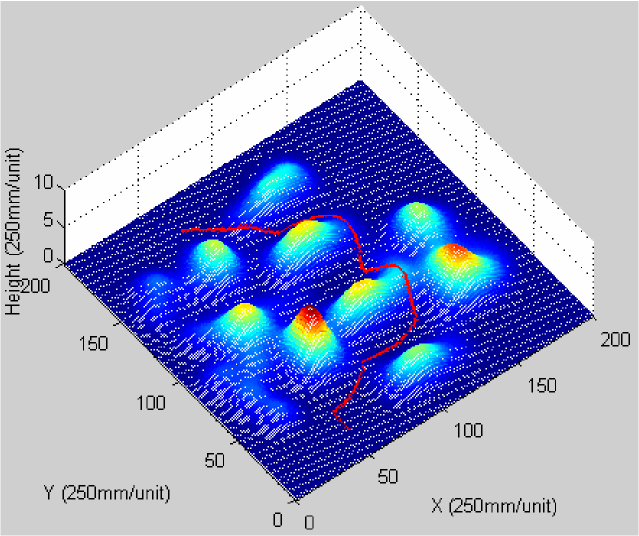
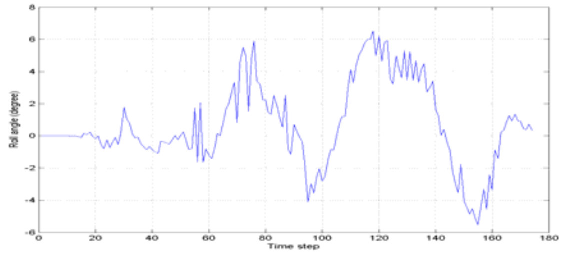


Figure 1: Block diagram of our proposed obstacle negotiation system.

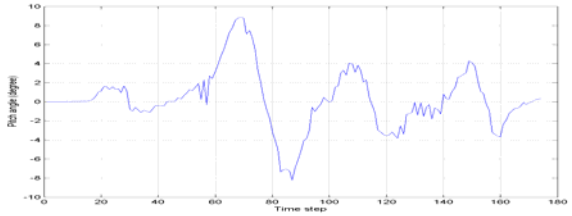
We have almost completed the manuscript for a journal paper on our new obstacle negotiation method. The paper includes an extensive literature survey on obstacle negotiation algorithms, a detailed description of our method, a mathematical proof of convergence, and many simulation results.



(a) Navigation task



(b) Roll angle of the vehicle



(c) Pitch angle of the vehicle

Figure 2: A navigation task and the vehicle's roll and pitch angle during the navigation

4.1.1.2 Directional traversability analysis

We revisited the block labeled "Terrain classification and traversability analysis" in Figure 1. We did so because we found that the VFH algorithm provides a very convenient way for performing the needed directional traversability analysis. In the past, the Traversability Index (TI – an indicator for how easy it would be for the vehicle to traverse the cell) of each cell in an elevation map was based on the slope of the plane fitted into a terrain patch surrounding that cell. The one problem with that earlier approach was that it is actually an estimate based on the worst case.

With our revised VFH-based traversability analysis, the POD[1] is calculated in polar coordinates, so that each cell in the same sector corresponds to the same heading. Therefore, we can compute the roll and pitch of the robot based on that heading information. This way, a cell in the elevation map may have different TIs in different directions, which allows us to compute the TI more accurately. We have completed this work and ran simulations, which show that the algorithm works well. Figure 3 depicts a terrain map for the robot moving in +Y direction.

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[1] In the VFH method a POD is a scalar that describes the likelihood of encountering an obstacle in a certain direction. In the VFH method the space around the robot is represented in a so-called Polar Histogram, which is divided into 72 5-degree sectors. Based on the sensor-produced terrain map, each sector is assigned a POD value.

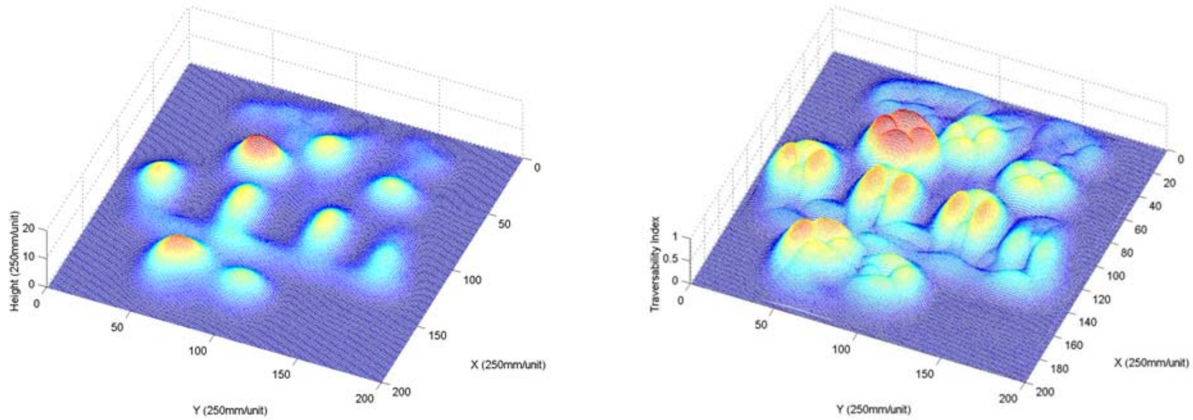

Figure 3: Directional traversability analysis: left: an elevation map generated by the simulator; right: traversability map for the robot moving in +Y direction.

4.1.1.3 Segway RMP and obstacle negotiation

Our lab received one of the first few units of the robotic version of the revolutionary Segway Human Transport (HT) machine (see Figure 4). While the Segway Robotic Mobility Platform (RMP), shown in Figure 5, was made available to us as a loan under an existing DARPA project, we are free to use it for other research if doing so enriches scientific community's knowledge about this new vehicle. It is therefore our plan to first install and test our Obstacle Avoidance for Semi-structured Environments System (OASES) on the Segway RMP, rather than on the originally intended Gorilla platform.

Figure 4: UM researcher Johann Borenstein steadies a camera on a Segway HT platform to obtain preliminary data on motion stability.

Segway platforms are statically unstable, but, thanks to their ingenious design, can be stabilized dynamically under the physical principles of the inverted pendulum. One of the key requirements for stabilization is thus that the center of mass be located as high as possible over the ground – quite the opposite of conventional vehicle technology. This important design consideration allows us to place our main obstacle avoidance sensor, the heavy Sick laser rangefinder (LRF), as high up on the vehicle as is desirable for obstacle avoidance, where "higher is better." The Segway RMP and the Sick LRF are thus an ideal combination, and we intend to advance the capabilities of this high-tech duo in our research.

Figure 5: UM Researchers tirelessly testing the abilities of the innovative Segway RMP platform. In the 5-hour experiment shown here we evaluated the RMP's vibration-damping with the help of fluid containers.

4.1.2 Subtask 2: Vehicle precision position estimation

This quarter we continued our focus on the development of accelerometer-compensated odometry (ACO – previously referred to as "Accelerometry"). To summarize and recall the features of this innovative method for improving odometry:

- **Purpose**: Detect and correct odometry errors even under conditions of temporary all-wheel slippage.
- **Approach**: With the ACO method odometry is used *most* of the time for measuring linear displacement - but accelerometer-derived displacement-data is injected during *temporary* all-wheel slippage.
- **Problem with conventional approaches**: It is well known that accelerometers are not useful for measuring linear displacement in mobile robots because their inherent bias drift, which results in large position errors *after the necessary double integration of measured accelerations.*
- **ACO approach**: During short periods (t < 5 sec) accelerometer drift is almost constant. Thus, ACO injects accelerometer data that replaces odometry data during short periods of all-wheel slippage. In order for this to work, ACO has two functional components, that cooperate as shown in Figure 6:
  - Module 1: All-wheel slippage detection
  - Module 2: Accelerometer data injection

We describe some of the more interesting experimental results in this report.

4.1.2.1 All-wheel Slippage (AWS) Detection

We began work on all-wheel slippage (AWS) detection during the last month of the current reporting period and we expect to continue working on this subject for the next few months. Our general approach is that AWS detection will be based on observing many different sensor modalities in real time. An expert arbitration system is then used to decide whether the AWS flag should be raised for the current sampling interval, based on our observations.

Here are some of the conditions we intend to monitor for AWS detection

Comparison of data from encoders with torques measured by ammeters

When a motor-powered wheel slips, then this event is usually associated with a drop in motor current because less torque is required for slipping than for "gripping." This method is not effective on certain specialized robots, since their motors have ultra-high reduction gear-ratios that result in the motor not

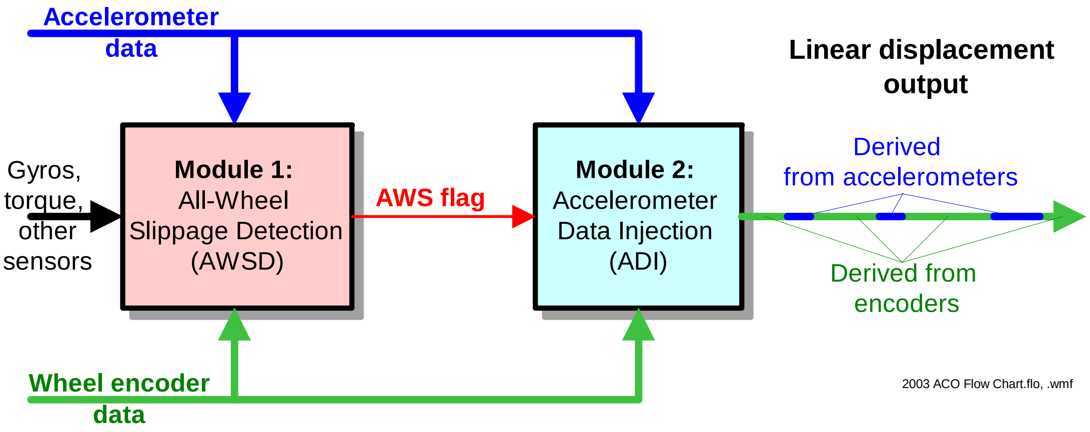

Figure 6: Block diagram of the functional components in an Accelerometer-compensated Odometry system.

“feeling” much of a difference in torque when the wheel transitions between slipping and gripping.

Comparison of encoder data with accelerometer data

While accelerometer-derived linear displacement data becomes rapidly unusable because of the double integration of acceleration measurements affected by drift, linear speed can be computed through a single integration. Thus, linear speed derived from accelerometer data is reasonably accurate for much longer than linear displacement data. We can thus compare the linear speed derived from each encoder with the linear speed of the robot body, as derived from accelerometers. Alternatively, one can compare the linear acceleration derived from each wheel encoder with the rather exact measurement of acceleration (since no integration is required) measured by the accelerometer.

Comparison of odometry data with accelerometer and gyro data

The comparison of the previous paragraph becomes more complex when the robot body is undergoing translation and rotation. Nonetheless, using onboard gyros and accelerometer data, the location of the so-called Instantaneous Center of Rotation (ICR) of the robot body can be computed based on the rate of rotation and linear speeds measured by the gyros and accelerometers. From the ICR one can compute the one linear speed that each wheel has to maintain under no-slip conditions. If the actual linear speed of the wheel as measured by the encoder differs from the linear speed prescribed by the ICR, then the wheel is slipping or skidding.

Comparison of encoder data with last known good speed

In most mobile robots, (but not in robots with extremely high gear reductions) the following observation is true. When a powered wheel starts slipping, then the wheel's rotational speed measured by its encoder becomes larger than what would correspond to the last known good linear speed of the robot. This is true while operating on horizontal terrain or uphill slopes. On downhill slopes, wheels are more likely to skid than to slip, and thus the rotational speed of a wheel starting to skid becomes smaller than the last known good linear speed of the robot.

Next quarter we will present experimental results from evaluations of these proposed methods.

4.1.2.2 Accelerometer Data Injection (ADI)

The Accelerometer Data Injection (ADI) function assumes that the AWS Detection function raises the AWS-flag for the duration of all-wheel slippage events. ADI attempts to remove the bias drift of the accelerometer as much as possible for the duration of the all-wheel slippage event. To do so, ADI compares the accelerometer data with encoder data from the last moment before all-wheel slippage began, and again immediately after all-wheel slippage ended. From these two measurements bias drift can be estimated assuming that bias drift is linear in the short (t< 5 sec) period of all wheel slippage.

From among the hundreds of experiments we performed with the ADI method, we show some representative results here.

In one key experiment we ran the Pioneer AT along a 4-meter straight-line path through our sandbox. All-wheel slippage (AWS) was introduced by holding the robot back, physically with a string attached to its rear end. In this experiment AWS was induced four times during the run.

Since AWS detection and ADI are not yet integrated, we detected AWS by comparing the independent encoders on each side the of the 4-wheel drive Pioneer with this (conservative) rule:

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If encoder_front count differs
from encoder_rear count by more
than one tick in a sampling
interval and if the same is true
for other side, then AWS = true.
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Figure 7 shows the position errors resulting from measurements with:

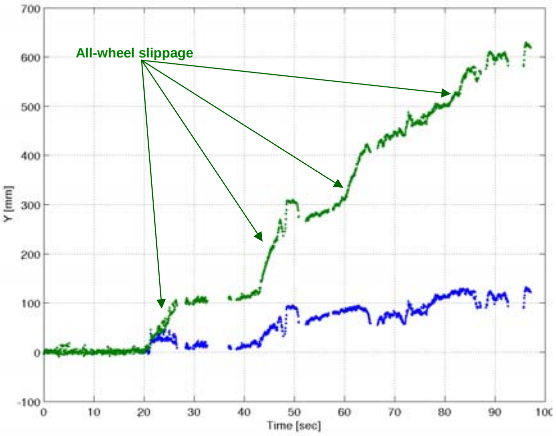

Figure 7: Position errors resulting from measurements with:
a. Encoders only (green), b. ACO method (blue)

a. Encoders only (green), b. ACO method (blue). The ground truth was known in this experiment from the sonar absolute position sensor that we reported on in the last quarterly report. The plot in Figure 7 shows the results of a single run, for each instance of the run.

Figure 8 shows the final position errors for multiple runs along the 4-meter straight path in the sandbox with all-wheel slippage (AWS).

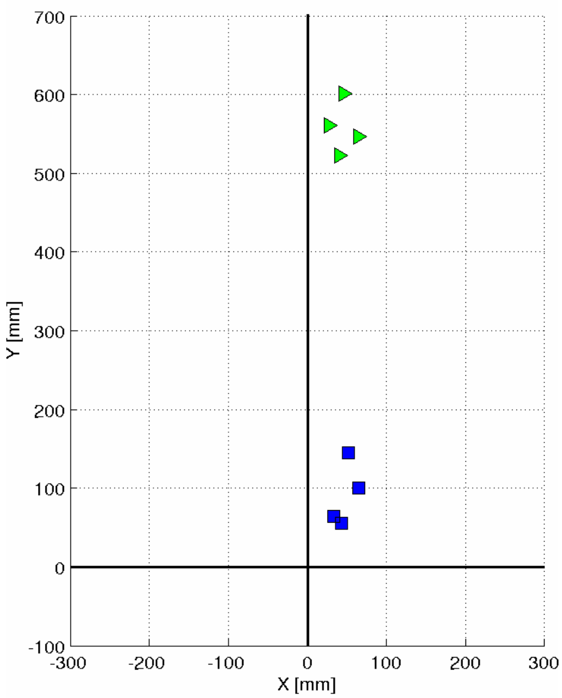

Figure 8: Final position errors for multiple runs along the 4-meter straight path in the sandbox with all-wheel slippage (AWS). Encoders only (green triangles); ACO method (blue squares).

4.1.3 Subtask 3: Development of novel mobile robot platforms

This quarter we made substantial progress in our development of the OmniTread serpentine mobile robot for extremely rugged terrain (see Figure 9). Our goal is to build an innovative hyper-mobility platform capable of traversing or even penetrating the rubble of a collapsed building. Our motivation for rapidly progressing with this project was reinforced this quarter by the significant attention our project received from government security agencies (see Section 4.2 for more details on that).

4.1.3.1 OmniTread Segments

We continued our efforts to reduce the weight of the OmniTread segments and to improvement the drive system in terms of reliability. After our latest round of weight reduction measures, a segment with bellows, pneumatic components, electronics, and all joint hardware weighs about 5.6 lbs. The one segment that will hold the electric motor will weigh 6.6 lbs (last quarter we reported the weight of a segment to be 5.7 lbs with motor, but that was without any of the bellows, pneumatics, electronics, and joint hardware). Among the most effective weight reduction measures is the remaking of the tank track sprockets that were part of the R/C tank kit used in our current prototype. We copied the sprocket tooth design and had these sprockets laser-cut out of aluminum. The new sprockets are around 60% lighter then those of the original kit. Nonetheless, laser-cutting the sprockets by a commercial machine shop is still less expensive than purchasing the sprockets from the vendor of the kit.

While testing our prototype segment on more difficult ground, we found that our prototype segment failed on sand. We systematically categorized the different causes of failure on sand, analyzed the problems, and developed solutions for all problems. One of the more interesting solutions came from one of our Summer students, who is an Industrial Designer. He made very effective, sculptured dust covers in a vacuum forming process for plastics that will protect the gearbox from sand and rocks. The process is fast, simple, and inexpensive. Although we haven't yet tested the dust covers in operation, our opinion is that this measure will be very effective, especially in conjunction with the following improvement.

In addition to the dust covers, exhaust air from the pneumatic system can now be rerouted to the dust covers that enclose the gearbox. This will create a small positive

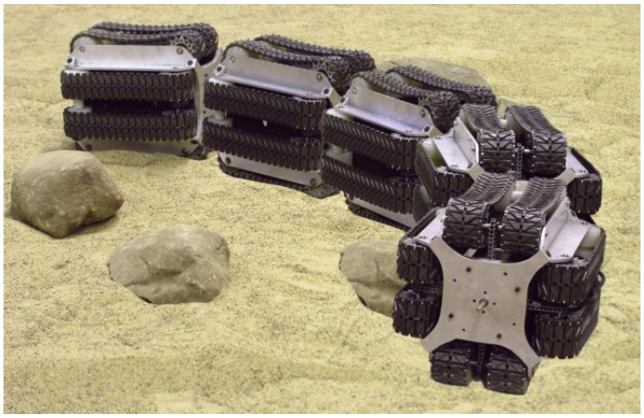

Figure 9: Artist's rendition (photo-montage) of a complete 5-segment OmniTread.

pressure inside the gear box, much like in a clean room. Furthermore, by directing the air exhaust from the pneumatic joint actuators to specific locations we can blow sand off the gears if it entered the dust cover despite the positive pressure inside.

Along with the changes in our prototype segment we kept all CAD drawings of the segment up to date. We have also begun manufacturing additional parts needed to assemble four more fully functional OmniTread segments.

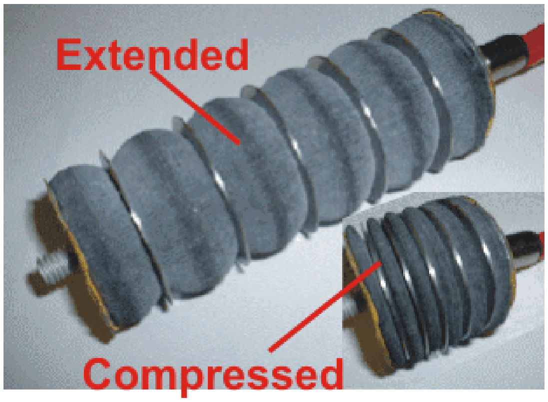

Figure 10: Our redesigned bellows with steel shim reinforcements can handle pressures of up to 80 psi safely.

4.1.3.2 OmniTread Bellows

After last quarter's initial, very promising results with the pneumatic bellows, and after further in-depth study of these devices, we decided to use bellows for the joint actuation of the OmniTread. We also redesigned our bellows, which we make in-house, to allow them to safely handle up to 80 psi of pressure. One key improvement over our earlier design was to replace the weak reinforcement strings that were meant to prevent the bellows from expanding outwards like balloons. Our new reinforcement is made of 0.025" thick stainless steel shims that we lathed down to reduce weight (see Figure 10). These rings are practically un-breakable and they do not slide around as the strings did. The quality of the bellows has also become more consistent as all the shims are identical while the reinforcement strings were often of varying quality.

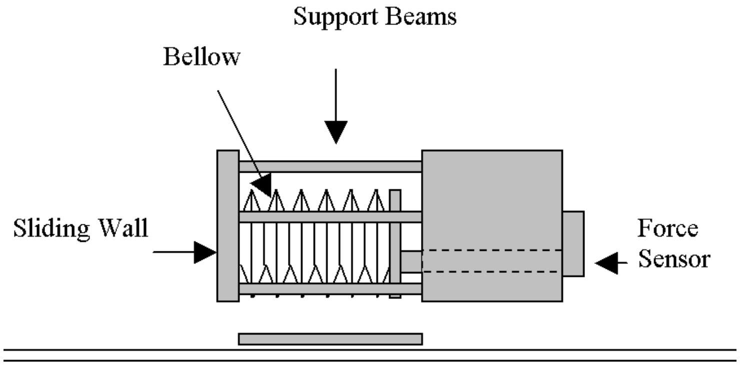

Figure 11: Force and endurance test-bed for bellows.

To study the force characteristics of the bellows at different pressures and lengths, we build a special test-bed designed especially for force measurements, as shown in Figure 11. In the force test-bed the length of the bellow can be adjusted by moving the sliding wall. While doing so, a force sensor allows us to monitor how the force generated by the bellow varies with pressure. Four longitudinal supports beams around the sides of the bellow prevent it from buckling and assure that the bellow's force acts axially where we can monitor it. Another test-bed for studying the bellows between non-parallel walls, as is the case in the OmniTread, is almost completed.

The current parallel-wall test-bed was also used for durability testing of our in-house made bellows. For that purpose we built a transparent but secure enclosure from Plexiglas.

4.1.3.3 OmniTread Joints Actuation Test-bed

We built a new test-bed for evaluating the OmniTread's joint actuators. This test-bed, shown in Figure 12, comprises five dummy segments that are connected by four fully functional, bellow-actuated 2-DOF joints. The joints actuation test-bed has been completed with all the electronics and pneumatic control components in place, as well as with 16 fully functional bellows that we designed and constructed in-house. All pneumatic components were designed or built to handle pressures of up to 80 psi. Since the dummy segments are lighter than the real OmniTread segments, we added lead weights to them to give them the same weight as that of a real segment. As soon as the remaining four OmniTread segments are assembled we can very quickly replace the dummy segments in the test-bed with the actual segments, thereby completing a fully functional 5-segment prototype in very little time.

4.1.3.4 Control electronics for OmniTread Joints

We were able to attract to our project a group of four undergraduate EE students, who were looking for a Term Project on embedded controllers. The students designed, built, and implemented a complete distributed control system capable of controlling four 2-DOF pneumatically actuated joints, for a total of eight controlled joints. The control system uses the CAN bus-interfaced controllers we described in the last quarterly report.

Figure 12: The new OmniTread joints actuation test-bed is made of five dummy segments and four fully functional 2-DOF joints.

4.2 Summary of relevant publications/presentations (journal publications, symposia presentations, etc)

1. Our paper: Ye, C. and Borenstein, J., 2003, “A Novel Filter for Terrain Mapping,” Submitted to the IEEE Transactions on Robotics and Automation, was conditionally accepted for publication. We made the revisions and we are about to resubmit the paper.
2. Johann Borenstein presented two papers at the 2003 SPIE Aerosense Symposium in Orlando, FL, April 21-25, 2003. Both papers will be included in the Proceedings of the UGV Technology Conference.
    a. Ye, C. and Borenstein, J., 2003, “A new terrain mapping method for mobile robots obstacle negotiation.”
    b. Ojeda, L. and Borenstein, J., 2003, “Reduction of Odometry Errors in Over-constrained Mobile Robots.”
3. We filed a “Continuation in Part” Patent applications on our OmniTread hyper-mobility platform. A “Continuation in Part” is an extension to an existing patent, in the case here an extension of our recently issued patent:

Borenstein, J. and Long, G. A., “Apparatus for Obstacle Traversion.” U.S. patent #6,512,345, issued January 28, 2003. (Rights Assigned to the University of Michigan)

4. We disclosed two new inventions to the University of Michigan Technology Management Office for patentability assessment.
    a. Borenstein, J. and Ojeda, L., “Accelerometer-compensated Odometry,” filed: April 28, 2003 - UM File# 2494.
    b. Borenstein, J. and Granosik, G., “Integrated, Proportionally Controlled, and Naturally Compliant Universal Joint Actuator with Controllable Stiffness.” expected filing date June 30, 2003.
5. We submitted the following papers to the IEEE Nuclear Science Symposium and subsequent publication in the archival Journal IEEE Transactions on Nuclear Science:
    a. Lee, Wonho, and Wehe, David K., “3D Isotopic Imaging Using Motion of a Compact Gamma Ray Imager”, submitted for IEEE 2003 NSS/MIC Conference in Portland, OR, October 2002, and publication in TNS.
    b. L. J. Meng and D. K. Wehe, “A Nuclear Environmental Imager Using Clustered Non-Redundant Array Coded Aperture,” submitted for IEEE 2003 NSS/MIC Conference in Portland, OR, October 2002, and publication in TNS

4.3 How accomplishments contribute to DOE goals

Subtask 1: Vehicle control and navigation techniques

All mobile robots require obstacle avoidance capabilities in order to move around safely. The foremost problem in the implementation of this capability is that current sensor technology is either inadequate or too expensive for most routine DOE applications in semi-structured environments. Affordable laser rangefinders that scan the environment from side to side in a single plane (so-called 2-DOF scanners) are useful only in structured indoor environments. On the other hand, for outdoor and/or for rugged-terrain environments 3-DOF scanners costing on the order of $100K must be used. Such high-priced sensor systems make the technology unfeasible for routine robotic clean-up and monitoring tasks. There is thus an urgent need for a powerful yet affordable (~$10K) obstacle avoidance system that performs reliably in semi-structured environments such as typical DOE sites.

The accomplishments of this quarter contribute towards the goal of building a reliable but affordable obstacle avoidance system for semi-structured environments.

Subtask 2: Vehicle precision position estimation

This task aims at the development of a position estimation system for mobile robots. Our emphasis is on dead-reckoning, that is, position estimation without external references or beacons. Such as system is fundamentally important in mobile robotics applications that can’t rely exclusively on external landmarks or beacons, such as GPS.

Our specific efforts this quarter aimed at improving our existing position estimation system to provide greater accuracy under conditions of all-wheel slippage. Such conditions are highly probable in typical DOE environments, especially for those with mud, sand, debris, or fluids are present on the ground.

Subtask 3: Development of novel mobile robot platforms

For the last few years and for the foreseeable future our efforts will aim at the development of a so-called hyper-mobility robots that can crawl into, slither through, or penetrate niches and crevices in hard-to-reach areas.

Our currently best candidate for this job is the OmniTread serpentine robot. Efforts during the current quarter aimed at further developing this highly innovative mechanism. The OmniTread will be able to traverse (and thus carry sensor payload into) debris-filled radioactive facilities and radioactively contaminated locations like Chernobyl.

Subtask 4: Radiation Sensors and Imaging Cameras

Novel radiation sensors and radiation cameras that can locate and identify particular radioisotopes over a wide range of energies are needed in any DOE environment containing hazardous radioactive materials. This topic is of interest to DOE for war high-energy physics, astrophysics, Non-Proliferation, and environmental cleanup.

4.4 How accomplishments contribute to other national goals (government, industry, etc.)

Subtask 1: Vehicle control and navigation techniques

Our goal of building a fully functional but affordable obstacle negotiation system for mobile robots is of great interest to the U.S. military, and of some interest to industry. Our efforts in this area are leveraged by

a small grant from the University of Michigan's Automotive Research Center (ARC), which is funded by TACOM (U.S. Army).
The accomplishments of this quarter contribute towards the goal of building a reliable but affordable obstacle avoidance system for semi-structured environments.

Subtask 2: Vehicle precision position estimation

Our goal of building a very accurate proprioceptive (=dead-reckoning-based) position estimation system for mobile robots is of immediate interest to the U.S. military. Our efforts towards the development of such a system were leveraged from 1998-2000 by a ~$400K grant by DARPA under the TMR program and are now again leveraged by a ~380K grant from DARPA under the MARS program. The current DARPA grant will bring our position estimation system close to commercialization. We offered our system to prospective participants in the "DARPA Grand Challenge" 2004 and we were already contacted by two prospective contestants.

Subtask 3: Development of novel mobile robot platforms

Our development of the OmniTread serpentine mobile robot is of immediate interest to DARPA and other government security agencies. Potential applications include urban search and rescue and clandestine operations. We know from sources close to DARPA that DARPA is considering launching a research program on serpentine robots. Three representatives of government security agencies visited our lab in June 2003 for one day to assess the potential of the OmniTread serpentine robot. After their in-depth testing of our prototypes the declared that the OmniTread was the most advanced serpentine robot under development in the U.S.

Subtask 4: Radiation Sensors and Imaging Cameras

The need for radiation sensors and imagers transcends DOE facility applications. DHS is concerned with the ability to pevent or respond to a radioactive event. Of critical importance is the ability to localize and isolate hazardous situations involving radioactive materials. Other security agencies share the same concerns. Within DOE, Nonproliferation has this responsibility.

5 Issues and problems

- Cost—budget shortfalls, cost over-runs, etc
    i. Michigan is currently spending at a rate in excess of the annual funded amount. This excess will cut into the carryover balance as planned. Without the FY03 funding in place, UM is currently spending exclusively from funds carried over from previous years.
- Performance—missed milestones, revisions in technical tasks, etc.
- Other

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