URPR Quarterly Report
University of Michigan

1/1/2003 – 3/31/2003

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: **1/1/2003 – 3/31/2003**

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 waste storage or remediation 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 will be presented at an SPIE conference in 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

Upgrade 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.

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 Subtask 1: Vehicle control and navigation techniques

This quarter we continued our work on the characterization of the Sick laser rangefinder (LRF) and we concluded this extensive effort. We also began the next significant stage of our work toward an LRF-based obstacle negotiation solution for mobile robots.

4.1.1.1 Laser rangefinder (LRF) characterization

Reflectivity data

The LRF documentation provided by the manufacturer (Sick) is insufficient for an in-depth study on the reflectivity of objects and how this data is processed in the LRF. Our attempts at getting this information from Sick failed, due to lack of responsiveness on Sick's part. We therefore tried to shed light on this issue ourselves. Specifically, we investigated these issues:

Field of view– We performed experiments aimed at finding out how many bytes of data the LRF sends out per revolution if *both* range and reflectivity information are sent (under normal conditions the LRF only sends range data). We wrote a special program under RTLinux to accomplish this. We were able to find out that the maximum data rate is 500 bytes per revolution. This translates to 121 pairs of range and reflectivity values. The LRF's field of view is thus 120° and not 180° as is the case when only range values are sent back to the control computer.

Scaled or direct reflectivity versus range – The LRF can send two types of reflectivity information: scaled reflectivity and direct reflectivity. The former is useless for mobile robot as the relation between the scaled reflectivity and the true range is not sufficiently well defined. However, the direct reflectivity value decreases linearly with the increase of range, provided that the range $R > 800$ mm. If $R < 800$ mm, then the reflectivity value is affected by imperfections in the coaxial optical alignment of the transmitter and the receiver and thus not reliable. This makes the reflectivity information a useful parameter for the detection of mixed pixels (see next bullet) for ranges of $R > 800$ mm.

Mixed pixel problem – We further investigated the mixed pixel problem, this time in an effort to detect and correct mixed pixel errors. We designed an experiment, in which we used a black object as the target and a white object as the background. We moved the target in 1-millimeter increments in lateral direction toward the center of the field of view of the LRF. At each of the 22 lateral position we took 1000 samples and we plotted the average against the positions. This showed clearly when mixed pixels occurred, because there is an abrupt change in both the range and reflectivity value. We recall that mixed pixels is the problem in which part of the laser beam hits the edge of a foreground object and the other part passes by the object and is reflected off the background. The result of this problem is that the LRF reports ranges that lie between the distance to the foreground object and the background. In mapping applications these readings are (incorrectly) shown as objects, where there really are none.

After we showed with the above-described experiment that abrupt changes in measured reflectivity are an indicator for mixed pixels, we can now consider identifying mixed pixels by checking for abrupt changes in reflectivity. However, it is not yet clear whether this method will be suitable to map building applications, because abrupt changes in reflectivity can also result from legitimate objects, such as thin vertical poles.

4.1.1.2 Terrain analysis and path planning

In order to move closer toward our goal of performing obstacle negotiation, we developed an approach to terrain analysis, based on the 2.5-D grid map (also called "elevation map") constructed in real-time by the Sick LRF and our mapping program.

The terrain analysis aims at assigning a Traversability Index (TI) to each pixel in the elevation map. This process is implemented pixel by pixel as follows:

a. Define a terrain patch (a 9×9 square of pixels, in our case) around pixel (i, j).
b. Fit a plane to the patch by means of a least-square estimator (LSE). Calculate the roll and pitch angles of this plane and the residual (the physical significance of these parameters is: roll and pitch represent the slope of the terrain patch, while the residual indicates the roughness of the terrain patch).
c. Construct a function that accepts the roll, pitch, and residual as inputs and determines the TI for pixel (i,j).

We completed the software for the Terrain Analysis and began development of another major software component, the path planner. Our aim is to develop a method, that is loosely based on the Vector Field Histogram (VFH) method. We recall that the VFH method was developed years ago at our lab under DOE funding, but only for use on flat indoor terrain. Work on our new, so-called Modified VFH (MVFH) algorithm, will be completed during the next quarter. Preliminary experiments with the MVFH based on simulations look promising.

4.1.2 Subtask 2: Vehicle precision position estimation

In recent months we reported on the successful development of our Expert System-based method for the correction of odometry errors in robots with redundant encoders (i.e., a 4-wheel drive Pioneer AT robot with four wheel encoders). We achieved very good results with this method, as long as at least one wheel maintains traction with the ground without slippage. The next question, of course, is what to do if all encoder-equipped wheels are slipping at the same time.

4.1.2.1 The Accelerometry method

In the beginning of this reporting period we tackled this problem with a new idea, tentatively called "Accelerometer-enhanced Odometry" or "*Accelerometry*." Accelerometry aims at using accelerometer data to compensate for odometry errors during short periods of all-wheel slippage. The hypothesis for this approach is the following: Everybody knows that it is not feasible to derive linear displacement information from accelerometer data. That's because acceleration data needs to be integrated twice to yield position information, and, consequently, the large drift rates inherent to accelerometers results in huge errors after double integration. Our approach is thus to use odometry data *most of the time* and accelerometer-derived data only during those short periods when all-wheels are slipping. We expect this approach to yield good results as long as all-wheel slippage is limited to a few seconds, as is typically the case under most off-road conditions.

In the following sub-sections we discuss our accomplishments with this innovative approach to date.

Accelerometer calibration

Our first step with any new sensor modality is careful calibration of the sensor. To do so we conducted a series of experiments where the accelerometer was moved between two points 200 mm apart, with arbitrary accelerations. The idea was to find the accelerometer's scale factor indirectly by measuring the final distance after integrating the accelerometer readings twice. This method seems to be effective as long as the surface is completely flat and the movement of the accelerometer is smooth.

Acceleration estimation

In this group of experiments the robot was moved along a straight line between two points 20 meters apart. Even though all these initial experiments where performed on a 2D surface, the body of robot is not horizontal all the time and gets tilted due the deflation of the tires. It is thus necessary, in order to estimate the true robot acceleration, to use attitude information to subtract the gravity component. We measured the attitude with our already existing Inertial Measurement Unit (IMU) and subtracted the thus measured gravitation component from the raw accelerometer data. This approach yielded the very effective elimination of accelerometer measurement errors due to accelerometer tilting.

Accelerometer bias compensation using encoder readings

In our analysis of accelerometer experiments we found that the accelerometer output is usable only for very short periods of time – less than one second. It is possible to extend this time, if encoder information during the time the robot is *not* slipping is used to compute the bias drift of the accelerometers. If the correct bias drift at the last instance just before all wheels are slipping is known and applied to correct the accelerometer readings during all-wheel slippage, then the usability of the accelerometers is extended to about three seconds.

Retroactive bias drift correction

We found an additional way of extending the usable time of the accelerometers even further, by reprocessing accelerometer data as soon as reliable encoder data is present again, as follows:

- During the time encoder data is reliable, we can keep track of and continuously correct the bias drift of the accelerometers.
- When all-wheel slippage occurs we start using the accelerometer data with its bias drift correction set to the value derived from the last good encoder readings.
- As soon as all-wheel slippage ends, we measure the speed as reported by the encoders and compare it with the speed derived from accelerometer data at that instance. Due to drift there will be a difference between the speeds measured by the encoders and the accelerometer. We then retroactively and proportionally adjust the drift correction parameters of the accelerometer, so that its speed measurement matches the encoder-based speed measurement at the instance all-wheel slippage ended. We then retroactively recomputed the position of the robot for the period of all-wheel slippage, using the retroactively corrected bias drift.

We performed numerous experiments with this approach and found that we could consistently and reliably use accelerometer data for up to five seconds.

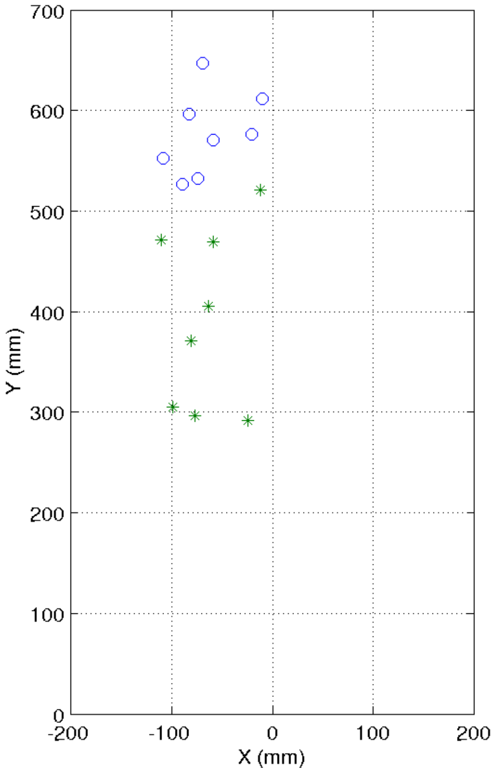

Figure 1: Final position error computed using
a. encoders only (blue circle)
b. Accelerometry (asterisk)

Experimental results

In order to put our new Accelerometry method to the test, we ran the robot along a straight line between two points 20 meters apart. For experimental purposes we produce all-wheel slippage by gently holding the robot back with our hands several times during the 20-meter trip. The ground was concrete floor covered by nylon sheeting and a thin layer of sand. This floor cover easily produced partial and all-wheel slippage. We held the robot for less than 5 seconds every time. The results achieved to date (see Figure 1) show an average error of 600 mm without our Accelerometry method, and an average error of 400 mm error with the Accelerometry method.

We believe that we can still substantially improve these results by computing a more accurate scale factor, using a better way of detecting wheel slippage, and by using a higher quality accelerometer and gyros. We will pursue these improvements during the next reporting period.

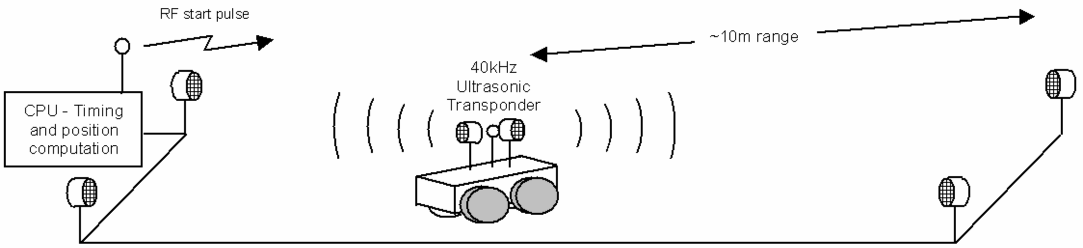

Figure 2: Schematic diagram of our new absolute position estimation system

4.1.2.2 Absolute position measurement system

In the course of our work on Accelerometry and other position estimation-related experiments, we ran repeatedly into the need for having a reliable and accurate real-time ground truth position measurement systems. In the past we tried to work around this problem by considering only the start and end point of a journey and comparing the robot's computed position with the accurately surveyed start and end point. However, oftentimes it is necessary to compare the robots computed position with the ground truth position, in real-time during travel. This is particularly so in the case of our Accelerometry experiments, where we would like to see if our onboard system correctly detects all-wheel slippage.

To this end we designed and built a real-time absolute position measurement system using ultrasonic sensors. (see Figure 2) The system measures time-of-flight for 40 kHz ultrasonic pulses. A sonar transmitter onboard the robot is triggered by an RF pulse, which is generated by a stationary, off-board timing computer. The timing computer transmits an RF pulse for 250 microseconds and repeats that signal every 30ms. In response to he RF signal the ultrasonic output oscillator of the on-board transponder is turned on for the duration of the RF pulse. The transponder produces 10 ultrasound pulses during that time. An array of at least two stationary ultrasonic receivers is mounted at surveyed locations in the lab. Ultrasound signals received by these receivers are amplified and filtered. The receivers then send a TTL pulse to the timing computer, which samples these TTL pulses via its parallel port at a frequency of up to 300 kHz. Once the timing computer detects the beginning of valid TTL pulses it computes the distances corresponding to the time-of-flight measured by each receiver and triangulates the robot's absolute position accordingly.

The current effective range of our system is approximately 10 m and our preliminary results suggest that we can expect a resolution of about 10 mm. This project is not yet completed, we are still modifying code to improve resilience to noise and detect other types of misreadings.

4.1.3 Subtask 3: Development of novel mobile robot platforms

We completed the first prototype segment of our new OmniTread sinuous (=serpentine) robot (see Figure 3). We found that its speed and energy efficiency is about one order of magnitude greater than that of the OmniPede. As a result, we decided in early March 2003 to halt further work on the OmniPede and focus on the OmniTread instead. Consequently, we have now restructured our research efforts into two mayor thrusts: (1) development of a pneumatic actuation system for the joints connecting the segments of the OmniTread, and (2) development of the OmniTread segments. The headings in this section reflect these two thrusts.

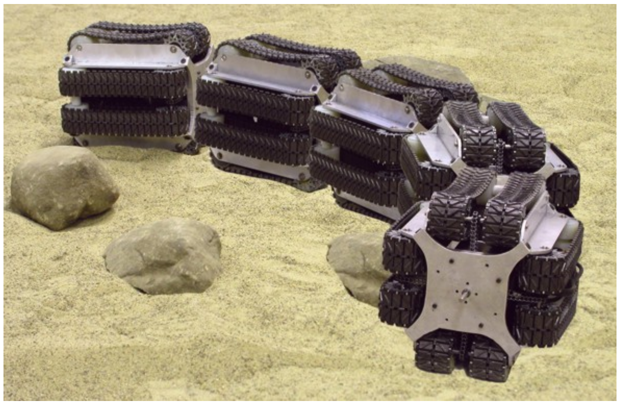

Figure 3: Artist's rendition (photo-montage) of a complete 5-segment OmniTread.

4.1.3.1 Pneumatic actuation system

By far the most commonly used actuator for pneumatic power is the air cylinder. Much less frequently used actuators are pneumatic bellows and so-called McKibben muscles (we reported on those in earlier reports). We are now investigating pneumatic bellows because they have some unique properties that make them ideally suited to the OmniTread, as discussed below.

Pneumatic bellows

Our focus in the last few months has been on the evaluation of bellows and their utility with respect to actuating the joints of the OmniTread. We started out by looking for commercially available elastic actuators, which can extend from 1” resting length to a length of 4” at maximum extension. The diameter of the bellows had to match the limited space between the OmniTread’s segments. We found that there are only two types of pneumatic bellows: air springs and metal bellows. Air springs are made of rubber and sealed by corrosion-resistant metal retainers at each end. Unfortunately even the smallest of these products are too big and too stiff for our needs. The smallest one we found had a minimum length of 1.5” and a diameter of 2.75”.

The other type of commercially available bellows, metal bellows, is made from copper, bronze, or steel but is too stiff for our requirements. Even smaller metal bellows with thin walls are available as elements of pneumatic control circuits. They are more flexible but they are sensitive to even moderate mechanical impact.

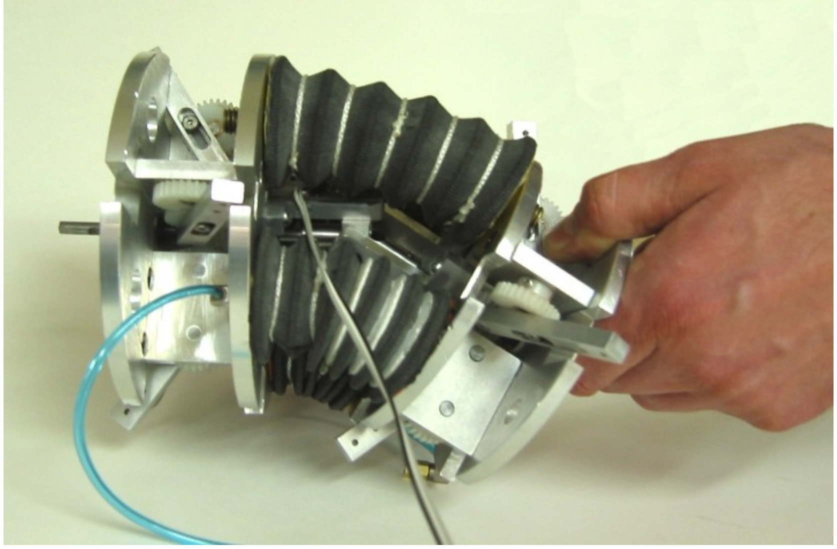

Figure 4: Bellows used as joint actuators. Here seen between two OmniPede segments, during early testing.

After finding off-the-shelf bellows unsuitable, we pursued another solution. We tested different types of airtight elastic protective rubber tubing usually used for covering moving mechanical parts like axels or stick shifts in cars. Some were too elastic and, when inflated with as little as 10 psi, grew radially like a balloon. More suitable was a type of molded neoprene-coated nylon tubing, which worked safely at higher pressures. When we reinforced these tubes with nylon rings around their midsections they behaved well at pressures up to 50 psi. However, being designed as protective tubing this product has no sealed end caps that would allow them to work as actuators. We had to seal the ends and build fittings at the lab. We used off-the-shelf flat spacers and off-the-shelf bolts to build end caps, and we sealed them hermetically with rubber and silicon sealant. We drilled a concentric hole through one of the end-cap bolts to provide an inlet for compressed air. The thus constructed bellow actuator has tested successfully with pressure up to 30 psi with no leakage. To achieve even higher pressure ratings we changed the method of sealing the end caps. We found that using epoxy glue instead of silicon sealant increased the working pressure to up to 50 psi with no leakage. In summary, we were able to build an elastic pneumatic actuator (i.e., a bellow-based actuator) that can generate over 90 lbs (400 N) of axial force while weighing only 2 oz (57 g). This compares favorably to the maximum force of 15 lb (66 N) attainable from the 7/16-in bore air cylinders we had used in the past, and which required harder-to-generate 100 psi of air pressure.

Our self-made bellows expand from 1.1” to 4” in length and from 1.5” to 1.8” in diameter. This bellow actuator has additional desirable features: unlike pneumatic cylinders it has no significant friction. Rather, because of its elasticity it behaves more like a soft spring. Furthermore, rubber bellows are similar to pneumatic cylinders with large cross section areas that can apply large force with small pressure. Bellow actuators have thus a large power density and force-to-weight ratio. Their *actuation strain* (i.e., the ratio between maximum extended length to minimum length when fully contracted) is larger than 1, which is the mechanical limitation for cylinder-type actuators. In our case the maximum actuation strain is about 3 and could be increased further. It is limited by the risk of elastic buckling of the charged bellow, which is a limit to the maximum extended length that can be achieved. The disadvantage of bellows is that they are unidirectional actuators, so we require two of them to drive a single joint. And because of their larger diameter bellows consume more air, although at lower pressure.

Testbed

We built a test-bed consisting of two segment end plates. The segment end plates have between them the drive shaft spine that will run through the whole length of the OmniTread, and a universal joint. Four of the above described bellows fit nicely into the space between the segments end plates. Since all four bellows are identical and have the same spring coefficient, they produce equal moments around the articulated joint and thus a naturally stable mechanical system that tends to assume a straight alignment of the segments regardless of whether the bellows are all charged, exhausted, or closed.

We applied the same control system that we used when we tested the pneumatic cylinders. Two diagonally opposite bellows work on the same joint, and they can be treated as two chambers of the same cylinder. The control law required some tuning to account for different dimensions and the spring nature instead of friction in the cylinders. After this tuning the behavior of the bellows with regard to actuation of the joints was comparable to that of the previously tested pneumatic cylinders. The position control loop worked properly. We also determined that the force provided by the bellows produces a sufficient moment to lift two OmniTread segments.

In summary, the experiments conducted on the testbed were very encouraging and we decided to extend the testbed to comprise a mockup of five OmniTread segments. Since the purpose of the testbed is to experiment with the joint-actuators, the segments themselves are not operational. They only have the outside dimensions and weight of a real segment. We are currently in the process of making the joints and bellows to complete the test-bed so that the control system can be implemented.

OmniTread microcontrollers

It is our intention to control the OmniTread joints with distributed microcontrollers connected in series, via a so-called CAN-bus. In this architecture one microcontroller controls all pneumatic elements and feedback elements of one 2-DOF joint. For the development of the distributed control system we use a CML 12S-DP256 prototyping board from Motorola. So far we established communication via the CAN-bus and we implemented feedback via position sensors. In parallel we designed electronic boards to fit the limited space in the OmniTread segments.

The hardware requirements of the control system are determined by the I/O needs of the actuator components and feedback sensors. Each degree of freedom (DOF) requires four digital signals to control the four needed on-off valves for two bellows. We also need to sample three analog signals: two from pressure transducers and one from the rotary position sensor. Two neighboring DOF (i.e., one 2-DOF joint) are grouped together and are controlled by one microcontroller MC9S12DP256B from Motorola. Every controller realizes closed loop position and stiffness control of a joint. On each local controller board is one microprocessor, one CAN bus transceiver, and support electronics. Each local controller is connected to four manifold boards, which contains valve drivers, pressure sensors, and conditioning circuits.

The distributed microcontrollers communicate with a main control computer via the CAN-bus. The main controller will synchronize the behavior of the distributed joint controllers to perform basic tasks like turning the robot body, lifting up the lead segments, or stiffening or loosening select joints. Additionally the main microcontroller will communicate with an off-board computer via wire or wireless serial communication.

4.1.3.2 OmniTread development

We have now completed the first prototype segment (see Figure 5) and we are currently making improvements to the design as we discover shortcomings. We have also been engaged in reducing the weight of the segment, which is currently 5.7 lbs including the motor.

The initial design called for the use of timing belts as the tracks, but after some tests using this approach we decided that they were too stiff and therefore not appropriate. We searched for alternatives and found that the tracks for a remotecontrolled model tank made by Tamiya matched our design criteria and was cheaper than the timing belts. We also found that these treads were indeed much more flexible, since they consist of independent plastic links held together with pins. Furthermore our machining time is reduced because the Tamiya sprockets designed for the tracks fit well. The OmniTread prototype segment is now capable of traveling at 26 cm/s. Power consumption is reasonably low at 9 Watts and should scale linearly as more segments are added. The largest power drain is predicted to come from the pneumatic pump which drains 35 Watts even at 0 (zero) psi (and more at the intended pressure of 50 psi). This has forced us to consider using a clutch mechanism to engage the pump only when it is needed to replenish the air tanks. In this line of thought we are also considering using a clutch to connect the motor to the drive train, in which case the air-tanks can be filled even when the OmniTread is not moving. We are currently looking at some appropriate clutches and deciding what alternatives are available.

OmniTread Improvements

We have spent a lot of time working on lightening the chassis of our prototype segment by removing material where it is not needed. We have also been lightening the pulleys at the rear, removing about 20% of the weight. The tracks are the heaviest components, weighing 31% of the total segment weight but there is nothing we can do to them to reduce weight. The motor is also contributing to the weight of the current prototype, even though there will only be one motor for all five segments intended to make up the complete OmniTread system. On the other hand, in the complete system every segment will have to carry some extra component, such as batteries and air tanks which will still be fairly heavy.

We have also been working on developing a simple and lightweight suspension mechanism to distribute the weight of the segment along the tracks. The suspension uses a thin and stiff metal bar bent into the form of a torsional spring that pivots around the chassis fixture and goes through the pulleys. From there it is bent into a symmetric configuration and is fixed to the other side of the chassis. By adjusting the thickness of the metal bar and the length of the pivot arm one can adjust the suspension to suit the environment and weight of the segment. This system only uses one idler wheel but the same concept can be applied to many more if that is desired.

4.1.4 Subtask 4: Development of novel radiation sensors and imagers

During this reporting period, work continued on the photomultiplier electronics. The electronics was custom designed and built by IDE AS from Norway for our particular application. This photomultiplier will be attached to the new scintillating crystal that has been ordered during this reporting period. We're still seeking the best choice for a first array detector. The first prototype will likely use CZT as this scattering element for higher energies, and an absorber for lower energies. We now have a small linear array of CZT to use in the prototype version.

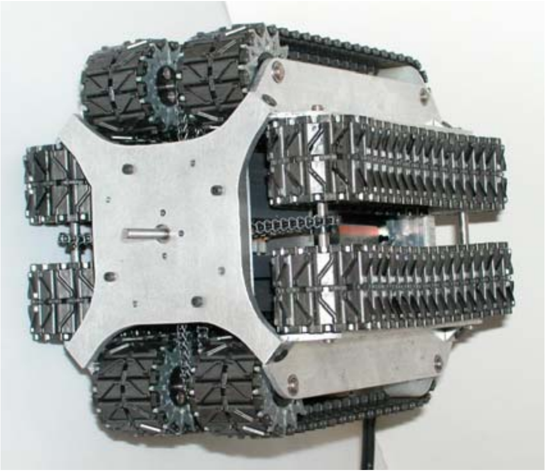

Figure 5: Single-segment prototype of the OmniTread (unedited photo).

Also during this reporting period, the upgraded CSPD-II imager has been tested successfully. We have acquired images of sources and are refining the system model used for image reconstruction. Angular resolution is now only a few degrees, which is quite good for this geometry. We are continuing these experiments, and will begin looking at developing a three-dimensional radiation field image using the mobility of the camera.

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

Figure 6. The CSPD-II upgraded camera takes an image of a radioactive source while a graduate student works on the next generation hybrid camera in the background.

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

1. We submitted the following two papers for publication in Journals:
   a. Ye, C. and Borenstein, J., 2003, "A Novel Filter for Terrain Mapping." Submitted to the IEEE Transactions on Robotics and Automation.
   b. Ojeda, L. and Borenstein, J., 2003, "Methods for the Reduction of Odometry Errors in Over-constrained Mobile Robots." Submitted to Autonomous Robots (Journal).
2. The U.S. Patent Office issued this patent for the OmniPede hyper-mobility sinuous robot:
   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)
3. Johann Borenstein participated in the DARPA Grand Challenge conference in Los Angeles, CA, on Feb. 22nd, 2003 (see http://www.darpa.mil/grandchallenge/). The purpose of the conference was to enthuse and inform prospective competitors about the Grand Challenge mobile robot race from Los Angeles to Las Vegas in Spring 2004. Purpose of our participation at the conference was to inform prospective competitors about our position estimation system, with the goal of getting involved in the competition as a supplier of technology. We believe that there are substantial public relation benefits in participating at the contest, even if only in a supporting role.

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, rugged-terrain environments

3-DOF scanners costing on the order of $100K must be used. Such high-priced sensor systems make the technology infeasible for routine robotic activities. 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 if 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 sinuous robot. Efforts during the current quarter aimed at developing this highly innovative mechanism. The OmniTread will be able to traverse (and thus carry sensor payload into) debris-filled radioactive facilities and highly contaminated unstructured locations.

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. UM has developed a series of cameras which can localize and identify sources of gamma radiation. Further camera development is needed for a gamma camera which can perform imaging tasks over a wider range of energies and field intensities to meet DOE applications. Since DOE field engineers (e.g., Hanford) have requested the ability to see radiations at high and low energies, localize and identify isotopes, and determine dose rates in the environment, UM has designed and constructed a prototype hybrid camera which simultaneously utilizes mechanical collimation to image low energies (Pu, U-235) and electronic collimation for high energies (U-238, steel, fission products).

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 sinuous mobile robot is of immediate interest to DARPA and the CIA (according to a DARPA source). Potential applications include urban search and rescue and clandestine operations. We know from sources within DARPA that DARPA is considering starting a research program on sinuous robots. Indeed, a DARPA manager has consulted with us on possible specifications for such robots. We further believe, based on communication with that same DARPA manager, that our OmniTread is likely the most advanced sinuous robot under development in the U.S.

Subtask 4: Development of novel radiation sensors and imagers –

The ability to sense, localize, and identify radioactive materials has become increasingly important in recent years. Sensors with better energy resolution and imagers with better spatial resolution are the goal of this task. This same goal is shared by DOE's NNSA (Nuclear Nonproliferation R&D), the Department of Homeland Security, DTRA, NASA (astrophysics), NIH (nuclear medicine), and other national security agencies.

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.
- Performance—missed milestones, revisions in technical tasks, etc.
- Other