MONTHLY REPORTING CHECKLIST

Submitted by: University of Michigan _______ Report Month: August 2002

TTP No.: ALO-7-c1-61 (UMichigan)

EARNED VALUE ANALYSIS DATA. *Check* ***one*** *box in Line A and* ***one*** *box in Line B.*

☐ 1. SIGNIFICANT ISSUES/PROBLEMS/CONCERNS:
Note if there are any problems; otherwise, state "None." Report only problems considered "showstoppers" or fatal flaws (i.e., a lack of funding will cause the project to be shut down).

None

☐ 2. CORRECTIVE ACTION:
If a significant issue/problem/concern in Section 1 above is described, this section is required; otherwise state "None needed."

None needed

☐ 3. SUMMARY ASSESSMENT:
This should be a BRIEF paragraph summarizing the overall status of the project. This section is a synopsis of the entire report.

During this past month, work has continued in robust navigation, sensing, and radiation imaging. The novel OmniPede vehicle is progressing well — particularly in completion of additional segments and actuators. Work using the Sick laser range scanner for map-building resulted in maps taken from the Gorilla mobile platform and work continues with comparison of map-building algorithms. Work to upgrade an earlier generation gamma camera is proceeding rapidly with all 16 elements functional, and new efforts are exploring more efficient imaging techniques. Work in the area of optical sensing is completed with the defense of our doctoral student.

☐ **4. COST VARIANCE:**
If you checked number 4 or 6 in the Earned Value Analysis section, ***you must provide an explanation here.*** **Explain funding issues such as variances, carryover, commitments, incorrect FIS data. Avoid using only the words "Within budget." Some narrative is preferred.**

Within budget.

☐ **5. SCHEDULE VARIANCE:**
If you checked number 3 or 5 in the Earned Value Analysis section, ***you must provide an explanation here.*** **Note if the project is on schedule, ahead of schedule, or behind schedule. If behind, explain what is being done to bring the project back on schedule.**

On schedule.

☐ 6. TECHNICAL STATUS:
This is likely to be the longest section of the narrative and describes the technical accomplishments during the reporting period. Provide enough detail to inform, yet avoid extensive details that can confuse the reader.

6. TECHNICAL STATUS FROM THE UNIVERSITY OF MICHIGAN

6.1 Obstacle avoidance

6.1.1 Elevation Map-building with the Sick laser rangefinder (LRF)

This month we performed a large series of experiments to refine our map building methods. Specifically, we added six additional well defined obstacle courses, for a total of 17. As in earlier experiments, we moved the laser rangefinder, mounted on our roll-pitch-linear motion table, through the obstacle course in four different modes: (1) translation only, (2) translation and roll, (3) translation and pitch, and (4) translation and roll and pitch. Roll and pitch rotation was limited to fixed rates of 37.5°/sec, while translation was fixed at 1 m/sec.
We performed these 17x4=68 experiments and obtained 68 sets of data. We modified the experimentation program to require less human interaction, that is, the program automatically sequenced the runs in the above four modes of motion for each obstacle course. We also measured the physical locations of the obstacles, to produce a ground truth map for each of the 17 distinct obstacle courses. We have now completed the data collection stage of this large-scale experiment. Next month we will focus on the data analysis work.

6.1.2 Demo for DOE site visit

In preparation for the DOE site visit on Sept. 4th we designed a map-building demo. For the first time in our demos we are using the Gorilla platform, which we had converted earlier from a human drive electric utility vehicle to a fully computer controlled robotic platform. For this demo to work we had to implement basic communications between the two onboard computers. One computer controls the vehicle and will eventually run our position estimation system; the other is dedicated to the laser rangefinder and obstacle negotiation. Because this is the first time since “robotizing” the Gorilla that it is actually being used under computer control and for actual experiments we uncovered several hardware problems. We have now resolved these problems and the demo is running.

6.2 Position Estimation

6.2.1 Crossbow IMU testing

We performed experiments to test the performance of our position estimation system using the Crossbow IMU. These experiments were predominantly aimed at comparing the two modes of operation of the Crossbow, called “Raw Data” mode and “Kalman Filter” mode. We applied our earlier developed compensation function (which compensates for changes in temperature and non-linearity on the scale factor) when working in the Raw Data mode. In the Kalman Filter mode the Crossbow applies its own, internal compensation function supplied by the manufacturer. The results of these experiments showed that the Raw Data mode in conjunction with our in-house developed compensation function outperformed the Crossbow’s built-in Kalman Filter mode by a substantial margin.

We should emphasize, however, that the Crossbow-assigned name “Kalman Filter” mode is misleading, because no traditional Kalman filtering technique is applied when observing only the Z-axis gyroscope output (as is the case when running on horizontal, non-rugged terrain). True Kalman filtering is meaningful only when traveling over rugged terrain, where rotation around the X- and Y-axes affects the Z-axis measurements. Under these conditions the Kalman Filter fuses the data from all three gyro- and all three accelerometer-axes in a supposedly optimal way. We believe that our Fuzzy-Logic Expert navigation (FLEXnav) system-based method will produce better results, but we haven’t compared performances of the two methods on rugged terrain, yet.

We are hopeful that in one or two month from now we will be able to run a comparison between true Kalman Filtering as implemented in the Crossbow IMU by the manufacturer and our FLEXnav system-based method. We will run this experiment on rugged terrain, where both the Crossbow's Kalman Filter and our FLEXnav system will be equally challenged.

During the experiments we found that the Crossbow IMU is sensitive to radio frequency (RF) interference or electric noise, which is a common problem with Coriolis-based gyros. For now our solution is to suppress these problems by using a Mu-metal enclosure for the IMU to isolate the RF interference, and a separate power supply for IMU to eliminate the electric noise.

6.2.2 Independent wheel encoders

In the off-the-shelf Pioneer AT and in similar platforms each of the four wheels is equipped with its own drive motor. However, the two wheels on each side are physically linked by a non-slip chain. The benefit of this approach is that the available torque for the wheels is doubled (versus just using one motor per side). We have long believed that odometry can be improved by separating the two drive motors on each side and equipping each with its own encoder. The benefit of this approach is additional information through redundant encoders. The disadvantage is that sometimes only the torque of a single motor (per side) is available to propel the vehicle. This is because of the suspension-less design of the Pioneers where one wheel – or briefly even two –can be "in the air" momentarily as the vehicle travels over rugged terrain. Obviously, the torque of a motor connected to a wheel that's in the air is unavailable for propulsion.

We have now re-fitted one of our two Pioneers with the chains that link the wheels while the other Pioneer continues to operate with four unlinked wheels. Next month we will conduct a series of experiments to quantify the odometric benefits of the unlinked wheel design.

6.3 Novel mobility concepts

6.3.1 New OmniPede motor

We ordered and received a new, substantially more powerful electric motor for the OmniPede. This motor not only powers all the legs of the OmniPede via the drive shaft spine, but we dimensioned it so that it will also drive an onboard air compressor for the pneumatic joint actuators. On its front side, the motor has a planetary reduction gear connected to the drive shaft spine. On its rear side the motor shaft protrudes so that it can drive an air compressor there without the reduction gear. This solution saves space and provides the needed power efficiently and with as little weight as possible.
In the course of experimentation with the powerful new motor we discovered technical problems with the OmniPede's drive mechanisms. If resistance applied to the legs causes a larger axial force in one of the worm gears, then the gear can be pushed against its axial retainer with such force that the retainer breaks and the whole worm gear gets pushed out of the segment. In some other segments the same problem of axial overload caused the metal worm gear to cut into the meshing plastic gears. These problems suggest the need for a clutch or at least a designed failure mode that acts as a clutch.

6.3.2 Hydraulic joint operation

For our investigation of hydraulic power for actuating the joints between the OmniPede segments we built a simple hydraulic testbed. Using the testbed we can now move a load with hydraulic cylinders under computer control and under repeatable conditions. Closed-loop proportional-integral-differential (PID) position control is enabled by feedback potentiometers and implemented on a PC. The testbed also employs a flow measurement transducer to estimate the power consumption of the hydraulic compressor during the experiments. The realized trajectories are smoother than those obtained with pneumatic actuation, but the response is much slower because of the slow flow of the hydraulic fluid. This is a function of the hydraulic pump, and can thus be changed, but only at the expense of higher power requirements for the operation of the pump. We will run some more experiments to gather data that will allow us to compare pneumatic with hydraulic actuation, but it seems unlikely that we will use hydraulic actuation on the OmniPede.

6.3.3 OmniPede skin

As discussed in last month's report, we foresee the necessity for a skin for the OmniPede. To address this problem we conducted some preliminary experiments with an off-the-shelf product, called "duct hose," of the appropriate diameter. In the preliminary tests we used this duct hose with a diameter sufficient to fit around the segments, but not around the legs. We cut windows into the hose to allow the legs to protrude to the outside. Ultimately we will try to fit a highly flexible skin around the feet, thus completely encasing all parts of the OmniPede.

6.4 Infrastructure

6.4.1 Motor Controller Boards

We received from the printed circuit board (PCB) house the *final* PCBs for our Motion Control Board (MCB) and the modified servo control boards (SCBs). We recall that we developed two different versions of SCBs: one version that uses the servo in its off-the-shelf intended functions as a steering servo, and the other version that uses the servo as a continuously rotating drive motor. We populated with electronic components six SCB PCBs for drive servos, six PCBs for the steering servos, and the main MCB PCB. Populating the PCBs is a very tedious and difficult task because we designed the PCBs for surface mount technology to save space. Typical resistors for surface mount technology are about 1.5 mm long, and dealing with such small components is difficult. We then tested all boards and confirmed their proper functioning.

6.4.2 Mobile robot fleet

We returned to full functionality the second Pioneer AT at our lab. That platform had not been in use since 2000. We now have two fully functional Pioneer ATs at our disposal. We also converted several laptop computers to Linux, for the purpose of using them as onboard computers. We further developed a Linux-based USB interface for off-the-shelf joysticks and installed this functionality on all onboard computers.

6.5 Radiation imaging

During the past few months, effort has been concentrated on the implementation of the theoretical detector performance estimation. This work has generated a very positive outcome. A first draft of a paper regarding using these methods was finished and sent to a few researchers on campus for review. A final version will be submitted to IEEE transactions on nuclear science early next month. These results will be applied to the proposed gamma camera design.

The procurement of hardware for our prototype camera is also in good shape. We have received a 5-inch PSPMT from Hamamatsu and the readout electronics are currently being tested. The current estimate is that we are going to have the system in our laboratory in late September.

☐ 7. MAJOR ACCOMPLISHMENTS:
Note MAJOR accomplishments during the reporting period; "None" is a valid, *occasional* entry.

For the beginning of the Fall 2002 Term in early September we have accepted two new graduate students to replace the two students that graduated in April 2002. Prospective Ph.D. student Atreya Chatterjee has a B.Sc. from a university in India and an M.Sc. in Mechatronics from North Carolina State University. M.Sc. student Malik Hansen has a B.Sc. in Mechanical Engineering from the University of Michigan. We selected these two students from an overwhelmingly large pool of 300 or so prospective graduate students that applied directly to the Mobile Robotics Lab for Research Assistantships since the beginning of 2002.

Mr. Greg Sharp became Dr. Greg Sharp last month. He successfully defended his thesis which represented his contributions to this project related to vision for navigation. He is currently weighing a position at Massachusetts General Hospital.

MILESTONES. *Check that you have updated the status of your milestones.*

☐ 1. MILESTONE STATUS UPDATES:
Make sure you have provided a brief, one- or two-sentence comment on each active milestone and completion/new forecast date as appropriate.

/pm 9-3-2002