MONTHLY REPORTING CHECKLIST

Submitted by: University of Michigan Report Month: July 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 on the Sick laser range scanner map-building resulted in a map taken from a moving mobile platform and a comparison of map-building algorithms. Work to upgrade an earlier generation gamma camera benefited from the arrival of new electronics, and new efforts are exploring more efficient imaging techniques. Work continues in the area of optical sensing.

☐ **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.

6.1 Obstacle avoidance

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

This month we focused our efforts on refining our new filter algorithm for reducing noise and other misreadings in the grid-type 2.5-dimensional elevation maps produced by our forward and downward looking Sick laser rangefinder. We then conducted an extensive set of carefully designed experiments, in which artificial obstacles of exactly known dimensions were placed at surveyed locations in the indoor experimental area. This allowed us to develop accurate ground truth maps that were subsequently used to compare the different tested filters with good accuracy. As in the previous month's experiments, we used the Relative Square Error as a performance index for each experiment.

The filters used in this comparison study were the so-called "Wiener Filter," "Average Filter," "Median Filter," and "CWM Filter." The comparison of our filter, tentatively called "UM Filter" with these other filters is meaningful because these other filters are widely cited in the scientific literature on grid-type map-building and computer vision.

With the artificial obstacles we built 11 obstacle courses. The Sick laser rangefinder was mounted on our linear motion testbed that passed through each of the 11 obstacle courses. In addition we overlaid roll and pitch rotation over the linear trajectory, so that each obstacle course was traversed in the following modes of motion: (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 omit the detailed results of these experiments here but state in summary that the UM Filter consistently outperformed the four other tested filters. In the translation and roll and pitch experiment our filter consistently outperformed the Wiener Filter, albeit only marginally so. The UM Filter outperformed all other filters under all conditions by a wide margin.

While our extensive experimentation is useful for developing and tuning our filter algorithm, we are mindful that in order to be definitive, experiments must be performed outdoors and with natural urban obstacles, such as trees, bushes, grass, etc. The problem with such a natural urban environment is that it is exceedingly difficult and time consuming to produce accurate ground truth maps, against which the filter results can be compared. We are planning on addressing this issue in an exhaustive manner: we intend to develop an automated ground truth measuring system. We will report on this effort in future progress reports.

6.2 Position Estimation

6.2.1 Crossbow IMU Characterization

To conclude the characterization of our new Crossbow IMU we modified our rate table and its control software to allow for vibration-free characterization of the three IMU gyros at very low rates of rotation. Until now we could not reliably measure rates of rotation smaller than |10°/s|. The modification to the rate table was a change of the reduction gear ratio from 4:1 to 24:1. After calibrating the IMU's gyros at these lower rates, we observed that the predominant source of error at low rates is the large amount of noise as well as large bias drift errors. To try and reduce these errors we will have to perform a formal analysis, but we haven't done so yet.

6.2.2 Crossbow IMU testing

We also prepared our Pioneer robot's onboard computer for actual experiments with the Crossbow IMU mounted on the platform. Specifically we had to modify the low level part of the control program to enable and optimize the serial communication between the Crossbow unit and the onboard computer. We integrated a real time serial communication module with our already existing real-time control software. We also performed the necessary changes in the Matlab software currently used for off-line analysis of experimental data. We are now ready to conduct an extensive set of real motion experiments with the robot traveling over smooth terrain 9at first), and later over rugged terrain.

6.3 Novel mobility concepts

6.3.1 OmniPede 7-segment version

This month we focused our efforts on getting the now fully assembled seven OmniPede segments to walk together. For this purpose we installed temporarily a Maxon geared DC motor that was available at the lab. While this motor is underpowered for the purpose it still allowed us to conduct several meaningful experiments. Although the motor is underpowered, a high gear ratio allowed turning the main drive shaft (the “spine”) of the OmniPede at a rate of 56 rpm. Within each segment there is a further reduction gear stage, so that 10 revolutions of the drive shaft are needed to produce one full step cycle for each foot. The resulting walking speed with the underpowered Maxon motor was about 1-1.3 cm/sec depending on surface. Next month we will order the permanent electric motor for the OmniPede, which we expect to produce five times greater speed at the same torque, so that the full walking speed will reach 5-7 cm/sec. Another selection criterion is that the same motor should directly drive the air compressor for the (most likely) pneumatic joint actuators, and also, through a gearbox, the drive shaft of the robot.

All walking experiments were conducted this month without the joints between the segments actuated (as we reported in earlier progress reports, we are still experimenting with different joint actuation methods). Therefore the segments were rigidly linked to each other in their center position, so that the whole OmniPede had a fixed shape of an elongated cylinder and the walking motion was strictly straight forward.

We performed the walking experiments on three different surfaces: a flat horizontal indoor floor, a slightly sloped concrete ramp, and on gravel. Our primary goal with these experiments was to establish clear specifications for the motor torque requirements under more realistic conditions. We obtained this data from the experiments and were able to define the required specifications for the permanent motor that we will order next month.

Another result of the experiments was the reinforcement of the long-lingering insight that the OmniPede must have a skin. We were aware for since the beginning of the project that a skin was needed for the purpose of water and dust proofing the mechanism. However, we now realized another important need: when the OmniPede walks on gravel, then the (intentionally) out-of-phase motion of the legs causes opposite feet on neighboring segments to move away from each other during one part of the walking cycle and toward each other during another part of the cycle. As the feet slightly sink into the gravel, they tend to compress the gravel when two feet move toward each other. However, since gravel can’t be compressed, the feet get stuck. A skin would prevent the feet from sinking into the gravel and thus eliminate this problem.

Finding a suitable skin material will likely be a challenge because there are conflicting requirements. On the one hand the skin has to be very elastic to avoid constant expenditure of energy only for stretching the skin whenever feet move away from each other. On the other hand the skin should not be too flabby, in order to prevent feet from sinking into gravel, sand, or other loose surface materials.

6.4 Infrastructure

6.4.1 Motor Controller Board

We received from the printed circuit board (PCB) house the prototype 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 rotation drive motor. We populated

these three different PCBs with the electronic components and tested them. We detected and fixed some minor bugs on the prototype PCBs and then confirmed that all boards worked flawlessly.
We corrected our electronic design files for the three different PCBs and produced the final PCB designs. We resubmitted the final designs files to the PCB house to have the final PCBs manufactured in the final quantities of 2 Motion Control Board PCBs, 8 steering servo-type PCBs, and 8 drive servo-type PCBs.

6.4.2 Motor Controller Board USB drivers

As reported earlier, our new MCBs will be physically interfaced to a PC using the now ubiquitous Universal Serial Bus (USB) ports. One advantage of this approach is the almost unlimited expandability of the USB interface and its relatively high speed. We have now completed the development of the PC-based low-level USB drivers that will communicate with the MCBs running under real-time Linux.
We also completed the interface code running on the MCB's microcontroller. This code defines the behavior of the control loops for the speed of the drive servo and the steering angle of the steering servo, and it implements the USB protocol on the MCB side. The microcontroller code reads the feedback control data from the servos' potentiometer and encoder,a s well as data from three optionally available analog inputs. All data is then sent to the PC using the USB interface.

6.5 Vision for Navigation and Mapping

Following up on global search, we have done some research on global search methods. Besides stochastic search such as simulated annealing, there is an entire class of deterministic global search methods. The prototypical deterministic method is called DIRECT, which relies on (possibly unknown) Lipschitz constraints to trade off between exploring new parts of the search space against exploiting known local minima. More modern variants of this idea use deterministic search together with "kriging", which is a kind of radial basis function approximation. These techniques then hypothesize where a global minima might exist which will minimize the total curvature of the kriging function approximation.

We then discussed this problem with Michael Sasena in Mechanical Engineering, who is an expert in global search. Apparently, what we have been trying to do with simultaneous optimization and fitting of the likelihood function is a relatively new idea (since 1998 or so), even within the field of optimization. He feels that for the 2-view matching version of our problem, DIRECT might be enough and that a full fit of the kriging approximation might incur too much overhead, but he was less certain about the multiview case.

Armed with this new insight, we implemented some trials of using DIRECT to optimize the match of 2 views. Early trials using DIRECT were moderately successful, succeeding in matching easy view pairs and failing in matching the more difficult pairs.

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

Upon a request by the National Research Council (NRC) Johann Borenstein reviewed a 600-page report on the state-of-the-art in mobile robotics for military applications. This report was solicited by the NRC and included detailed recommendations on research directions for military mobile robotics. While the content of the report itself is confidential and may not be cited, knowledge of the recommendations will allow us to identify mid- and long-term research directions that will be beneficial to both DOE and the military, thereby making more effective use of our research resources.

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/5-6-02