

MONTHLY REPORTING CHECKLIST

Submitted by: University of Michigan

Report Month: June 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)

6.1.1.1 Literature survey on filtering algorithms

In continuation of our ongoing development of a filtering algorithm for laser rangefinder-produced elevation maps we conducted an extensive search on image filtering algorithms. The purpose of the filter is to "clean" the raw elevation maps, which have erroneous data in them. Erroneous data is produced by, for example, noisy readings from the sensor, artifacts (prevalent in outdoor experiments in direct sunlight), and by the mixed pixels problem that is characteristic in laser rangefinders. This erroneous data must be removed by a filter before the map can be used for navigation purposes. At the same time, a good filter must retain the correct data in the map.

Because an elevation map can be treated as a range image, filtering can be done by conventional range image filters that are described in the literature. Candidates for the filtering operation needed in our application are the Finite Impulse Response (FIR) filter (e.g., a type of averaging filter), adaptive filters, such as the Wiener filter, and the Median filter.

The FIR filter is designed to compute a weighted average of the pixels (grid cell in our case) within the filter window. Although this filter is effective in reducing the height of the erroneous mixed pixels or noise data, it also distorts the surfaces of legitimate objects represented in the map. The Wiener filter is reasonably effective in removing the erroneous mixed pixels and noise data, but it does not remove the artifacts created in our outdoor experiments. According to the literature and our own experiments, the most promising filter is the Median filter. It successfully removed all three types of erroneous data found in our experiments. But the disadvantage of the Median filter is that it also removes the map representation of legitimate, but isolated and slender objects, such as thin poles.

Our new filter, tentatively called the "UM filter," aims at overcoming all of the above problems, and it is quite successful at doing so, as the following performance comparison shows.

6.1.1.2 Filter performance comparison

We conducted a set of experiments to compare our proposed filter with the above described image filters. In these experiments we placed two cardboard boxes of different sizes and three poles with diameters of 25 mm, 15 mm and 9 mm, respectively in the experimentation area. We then manually measured and recorded the ground truth map according to the actual physical location of these objects.

For our experiments the Sick laser rangefinder was mounted on our earlier-described linear motion testbed with integrated tilt table. The tilt table allows for computer-controlled changes in pitch and roll. We then conducted four experiments within this environment, and in each the Sick LRF was subjected to a different motion characteristic: (1) translation only, (2) translation with pitch angle changing during motion, (3) translation with roll angle changing during motion, and (4) translation with pitch and roll angles changing during motion.

For each experiment we recorded the resulting raw map data and then applied each one of our four candidate filters to the data, creating four new, filter-conditioned elevation maps. We then compared the thus-created conditioned maps with the ground truth map, using an index of performance called "Relative Square Error" (RSE) to compute a single numeric indicator for the accuracy of each map. The result were advantageous for our filter, as shown in the following table of results. A smaller RSE value indicates a better match between the ground truth

elevation map and the measured and filter-conditioned elevation map.

Translation
only

Translation
with pitch

Translation
with roll

Translation with pitch and roll

Wiener filter

0.7393

0.7380

0.8078

0.7879

Averaging filter

0.5977

0.6094

0.6457

0.6857

Median filter

0.5901

0.8729

1.0185

0.9735

UM filter

0.3814

0.3618

0.3491

0.6931

Our filter always outperforms the other filters except for the last case. This is because there was a large missing surface in our experiment: the upper "surface" of an open cardboard box. Our filter cannot fill these empty cells for the time being, while the averaging filter may fill them to some extent due to the averaging operation. However, the averaging filter greatly distorted the surface of all the objects. Therefore, it is not suitable for our elevation map enhancement. We expect that the performance of our filter in the last case may be improved using some heuristics to fill the missing surface, and we will work on this issue next month.

6.2 Position Estimation

6.2.1 Crossbow DMU Characterization

After performing our standard calibration procedure we found that the Z-axis gyroscope within the 3-axis Crossbow IMU shows a non-linearity in the scale factor that would introduce errors of about 0.7 deg/sec when the unit is rotating at a rate of 90 to 100 deg/sec; the error is smaller for lower rates of rotation. This non-linearity is present not only in the "Raw Data" mode of the unit, but also in its "Kalman Filter" mode. Our calibration procedure is designed to reduce this rate of rotation-related error dramatically.

In addition, our calibration procedure compensates for errors related to changes in ambient temperature. However, we found that the output signals of our Crossbow IMU do not vary very much with the temperature. This observation is true for both the Kalman Filter mode and the Raw Data mode. For the X- and Y-axis we found that there is an error in the scale factor, however the relationship between the error and the rate of rotation is almost linear in both

axes and thus easy to compensate for. Nonetheless, the error is quite large, about 0.5 deg/sec at 90 to 100 deg/sec rate of rotation.

Our calibration procedure helps define a so-called "compensation function," which can be programmed into software to compensate for non-linearity in the scale factors of all three gyro axes. We tested our compensation function and found that it reduced the amount of error considerably, to a level of under 0.1 deg/sec at any rate of rotation. However there remains a residual error that we believe is related to the large amount of noise present in the signal.

Lastly, in order to complete our characterization study of the Crossbow IMU we want to measure the misalignment between the three gyroscopes. The scientific literature describes software methods that can compensate even minute misalignments but it is not yet clear if these methods can be applied to the Crossbow IMU. Also we are investigating alternatives for reducing or filtering the rather substantial noise levels in the Crossbow, since this appears to be the unit's weakest performance aspect.

6.3 Novel mobility concepts

6.3.1 OmniPede 7-segment version

We completed the assembly of the 7-segment OmniPede. Some joints required additional mechanical work to establish proper connection of the entire system. We resealed the mounting brackets for the pneumatic cylinders to avoid collisions between different elements during motion in 3D space. We adjusted the potentiometers providing the position feedback for the joints to avoid either zero resistance or saturation at the extreme points of each joint's range of motion. We tuned the gait of the OmniPede by adjusting the relative angles between the drive gears to obtain continuous and smooth motion. We fixed a problem of setscrews on the drive shaft spine getting loose too easily and resulting in slippage in the main transmission.

6.3.2 Testing of hydraulic joint actuation

Even though we still think that the optimal method for actuating the joints is pneumatic, we are spending some time investigating the potential for hydraulic actuation. We received the previously ordered hydraulic system components from Leimbach Modelbau. We built a simple hydraulics testbed that consists of a hydraulic compressor driven by a DC motor, two double-acting cylinders, and proportional valves. The valves are driven by small electric servomotors controlled by pulse width modulated (PWM) signals.

Our first tests showed that the hydraulic cylinders provide smoother motion than the pneumatic ones, while their velocity and response time is slower. However, we will continue our tests in order to derive an accurate comparison of the energy-efficiency of the two different fluid power actuation methods.

6.4 Infrastructure

6.4.1 Motor controller board

As already explained in earlier progress reports, we are developing methods for using the popular and very inexpensive off-the-shelf servomotors commonly used in remote control cars or planes under computer control. To date we have completed the design of what we call the "Motor Control Board" (MCB). Each MCB is designed to control two servomotors and many MCBs can be connected to a host PC's Universal Serial Bus (USB). This month we made modifications to our earlier design to facilitate manufacture. We submitted the design files for three boards. We also ordered the various components to populate the PCBs.

6.4.2 R/C-type servos

As we explained last month, we had to redesign the small electronic circuits that are integrated into the R/C-type servos. We completed this redesign of these circuits last month and we have now submitted our PCB designs to the PCB-house for the production of two test-PCBs. We will verify the function of these

test-PCBs before we order a full batch of production PCBs.

6.4.3 Small Machine Shop

We have now transferred the recently purchased machine tools to our new machine shop area immediately adjacent to the Mobile Robotics Lab. High voltage outlets have yet to be installed near the machines before we can use them.

6.5 Optical vision for navigation and mapping.

We have started our work on a method for dealing with degenerate surfaces and ambiguous pairwise matches when doing multiview registration. Our plan is to use the information gained from the pairwise matches to help in our search for the best global registration. Specifically, the search procedure can use the likelihood cost values produced by the pairwise registration to estimate the global cost function, and thereby reducing the search size. Further, once an approximate local minima is found, function approximation can be used to estimate gradient values for a conjugate gradient search.

At this time, an implementation of the pairwise cost function approximation using radial basis functions has been completed. Since this procedure can use the data gathered during the pairwise registration search, we expect to incur negligible overhead. However, some additional modifications are expected to address issues of uneven sampling of the cost function and the increased importance of fitting more likely domain regions. We are also working on the preliminary design of the global search procedure. The idea is to use the knowledge of the underlying structure of the radial basis function approximation to generate hypotheses for each pairwise match, and then perform combinatorial search on combinations of these hypotheses. Unresolved challenges with this approach include difficulties in hypothesis generation and blame assignment.

7. MAJOR ACCOMPLISHMENTS:

Note MAJOR accomplishments during the reporting period; "None" is a valid, occasional entry.

As a sidelight, the University of Michigan. won a \$400K DARPA grant for the integration of our proposed Proprioceptive Position Estimation (PPE) system in an advanced, military-type off-road mobile robot system. Our proposed PPE system is based in large parts on our DOE-funded position estimation work. According to the DARPA program manager making the award, our position estimation work is both unique and essential for DARPA's mobile robotics programs.

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/7-3-02