

MONTHLY REPORTING CHECKLIST

Submitted by: University of Michigan

Report Month: April 2001

TTP No.: ALO-7-C1-61 (UMichigan)

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

A. How is your project's schedule doing compared to your TTP baseline?

1. As planned

B. How is your project's total cost doing compared to your TTP baseline?

2. As planned

PTS NARRATIVE INPUT CHECKLIST. Check that you have prepared the following narrative inputs:

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).

No significant problems.

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 — the first prototype took its first steps. Results have been encouraging and are leading to refinements. A robust platform based on a commercial ATV has been received, and parts identified and ordered for transforming it to drive under self control. The vision work for navigation is continuing, with work on understanding previously acquired data. One student was accepted for an NSF international summer fellowship to continue his research on this project in South Korea and present his work at the ICRA 2001 meeting being held there.

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.

On budget profile.

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 workscope timeline.

- 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.

OBSTACLE AVOIDANCE

Binaural (coded) sonar techniques

We have completed building five new sonar systems that fully support the firing and triggering needs of our coded sonar technique. Before construction was completed (at the end of April) we worked with our two existing sonar systems, which only partially support the coded firing technique. However, we were able to use these old systems to develop some important new software functions.

With the old boards each sonar is connected to a different scope (the new boards will allow us to connect several sonars to one multi-channel scope), and synchronization is done using digital signals from control computer's I/O ports. The current system works as follows:

- The first sonar fires its coded signal.
- The computer measures the delay time to firing the next sonar, which uses a different coded signal.
- After the second signal is fired the computer measures another delay time and then triggers the scopes using again existing I/O ports for triggering.
- When echoes are perceived, the delay time is added to the Time-of-Flight calculations (different for each scope) according to the firing schedule of each sonar.
- The calculations that find the exact location of the reflectors is performed using all readings from all scopes, similar to the way it was performed when we only had a single scope.

One problem we observed is that the Borland C compiler can address only 16KB of memory using the so-called "Large" memory option. We cannot use the so-called "Huge" memory option because the Pico scopes provide their libraries only for the Large memory model. As a result, we can allocate arrays of only 2000 integers for each sonar. With a sampling rate of 4 microsecond, the 2000 integers can store data for 8 milliseconds - the equivalent of 1.2m of range measurements (i.e., the time for an echo to be fired, reflected and travel back to the sonar). This distance is not sufficient and we need to increase it to about 3m. But we have several options for doing so, we only need to investigate a little further to find the most time effective solution.

Obstacle Avoidance Testbed

We completed a series of test with a commercially available sonar device called "Dimension Master Plus." This device claims that by using a phased array approach it could produce a highly focused sonar "beam." The results of our tests show that the claims of the manufacturer are exaggerated, and that the device produces wide beams under most conditions and narrow beams only under select conditions.

In the course of these tests we further enhanced our testbed by placing a microphone (i.e., another transducer that was rewired to act as a receiver opposite to the transmitting sonar). This way we could visualize the analog waveform of the transmitted signal directly with an oscilloscope. Plotting the strength of the transmitted signal as a function of angle would then reveal the propagation pattern of the sonar. So far we have performed tests with the Polaroid ultrasonic sensor to verify the experimental procedure with the sonar receiver. Our results show that the receiver does indeed show clearly the

location of the main- and side-lobes of the Polaroid sonar, and that the shape of those lobes matches well the calibration graph provided by Polaroid.

POSITION ESTIMATION

Software tool for evaluating bias drift in Gyroscopes

We have developed a software tool that computes the bias drift stability of any gyroscope. It is based on what is known as the *Allan Variance Analysis* and uses stationary gyro readings collected over 2-3 hours at fixed temperatures. This analysis is also useful to estimate the Angle Random Walk (ARW) noise.

In order to verify the performance of the Allan Variance Analysis tool we used this software on our high-quality KVH gyroscopes. The result shows bias drift stability and ARW agreeing with the manufacturer specifications, that is 0.002 deg/sec (0.1 deg/min) and 0.08 deg/rt-hr, respectively.

Low-cost Coriolis Gyroscope

We have completed our in-depth investigation of a low-cost Coriolis gyroscope. We recall for the purpose of this discussion that the most significant error sources for gyroscope are:

- Bias Drift stability
- Non-Linearity in the scale factor
- Temperature Effects

Bias Drift stability

When we tested the Coriolis gyroscope with the Allan Variance Analysis tool we found that its performance is very poor. The bias stability is 0.025 deg/sec (1.4 deg/min) and 1.2 deg/rt-hr. Also, in another experiment, we found that the static bias drift changes with the temperature.

Non-Linearity in the scale factor

In order to investigate the non-linearity in the scale factor of the Coriolis gyroscope, we mounted it on a rotary table and rotated it at constant, known rates. This experiment was performed at a constant temperature. Later the output of the gyro was compared with the rate of turn of the table to calculate the error. From this experiment we found that the scale factor of this gyroscope shows good linearity.

Effects of temperature in the scale factor

This experiment is similar to the previous one but this time we varied the temperature to observe the temperature's effect on the scale factor. The results show that the scale factor remains constant or at least without considerable variation while the temperature changes.

We concluded that the most critical sources of error, the bias stability and ARW, is very large, which make the low-cost Coriolis gyro unsuitable for use as a heading angle reference. However, the gyro is still useful for measuring tilt of a mobile robot, if used together with an accelerometer.

NOVEL MOBILITY CONCEPTS

OmniPede

The OmniPede has taken its first steps! Just like most "firsts steps," the ones the OmniPede took were a little shaky, but they are also very promising. This comes after we nearly completed machining and assembling the three new segments. The new segments are a marked improvement over the first prototype

segment, the friction in the segments is much less and the legs are sturdier. However, we still need to do some work in the machine shop before the OmniPede will walk more steadily. One is a coupling between the segments that will keep the segments from rotating with respect to each other about the axis of the drive shaft. The other is a motor mount to connect the 24 Volt DC motor to the last segment.

Our observations from the preliminary walking are these: The OmniPede used a three-legged gait to make its first steps. The synchronization of the legs is extremely important to the gait, if the legs are out of synch the OmniPede will take one step forward and one step back -- essentially walking in place. By observing the OmniPede walk, the importance of the leg design is very evident. We found that on rough surfaces, such as carpet, the shoveling action of the legs propels the OmniPede forward very efficiently. But for use on smooth surfaces we will have to cover the feet with some high-friction material such as rubber.

One other observation is that the feet are currently too rounded — this makes the OmniPede slightly unstable, allowing it to roll sideways. A smaller radius of the feet will help to keep the OmniPede from rolling.

Different leg designs will help the OmniPede accomplish different tasks. One such task is a burrowing motion that allows the OmniPede to walk through pipes. We have found clear flexible conduit that will work well for testing this walk. After working on the three-legged gate we will perform some tests on this second form of motion. With these first three segments completed and assembled the next few months of work on the OmniPede should be very exciting.

INFRASTRUCTURE

Gorilla Mobile Platform

We have ordered and received a 1/8 HP motor that will drive a gear connected to the steering column of the vehicle. We also selected, ordered, and received gears.

We have completed the design of an odometry system for the platform, using a combination of timing belts and pulleys that will drive shafted optical encoders. Because of space constraints in the vicinity of the rear wheels we decided to have teeth machined onto the outside of the rear brake drums. This will allow us to drive the encoders with a timing belt. We have ordered and received the belts and pulleys.

We tested a way of electronically slowing the vehicle down instead of actuating the provided hand-operated brake. While this method works all right under most operating conditions, it overloads the drive gears during emergency braking and had to be discarded. We then identified and ordered a commercially available solenoid that is strong enough to apply tension to the braking cables and stop the vehicle.

To facilitate the experimentation with the Gorilla we designed and built a makeshift dashboard that houses the control switches, instead of the hard-to-remove plastic chassis of the vehicle.

VISION FOR NAVIGATION AND MAPPING

We are still working toward the experimental validation of the multiview registration algorithm with the ATL basement data set. Intrinsic calibration parameters such as center of projection, focal length and field of view have been extracted, and the data has been adjusted for use with Masuda's view-based thresholding method of registration. Previous tests have strongly suggested that view-based thresholding is superior to distance-based thresholding for registration of partially overlapping views.

We have made some small progress on generalizing the theory of multiview registration to non-rigid (e.g. affine) transformations such as would be used in template matching and image mosaicing. It appears that our theory can be generalized as long as a reasonable metric can be assigned to the space and a method for minimizing about a cycle can be solved.

7. MAJOR ACCOMPLISHMENTS:

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

Our paper: Chung, H., Ojeda, L., and Borenstein, J., 2001, "Accurate Mobile Robot Dead-reckoning With a Precision-calibrated Fiber Optic Gyroscope," was published in the *IEEE Transactions on Robotics and Automation*, Vol. 17, No. 1, February 2001, pp. 80-84.

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.