PTS MONTHLY CHECKLIST

Submitted by: UNIVERSITY OF MICHIGAN Report Month: January 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 "show-stoppers" 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, worked his continued in robust navigation, sensing, and radiation imaging. A new indoor obstacle avoidance algorithm has been implemented and tested. The novel OmniPede vehicle is continuing development, with construction completion anticipated by May 2002. The quality of the vision research is reflected in the recent acceptance for publication in IEEE PAMI, the premier journal of this field. The work on the radiation imager continued, with a modest improvement identified for a near field application, but larger improvements are being sought.

☐ **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.

OBSTACLE AVOIDANCE

Strategic Planning

Based on discussions with other experts, review of the scientific literature, and in-depth considerations of UM's strengths in the area of obstacle avoidance, we have defined a clear path of progression in our research for the next 18 months and beyond. The result of this strategic planning effort is documented in UM's newly revised URPR Renewal Proposal for FY02. One particularly significant aspect of this plan is the identification of a niche research area within the broader area of mobile robot navigation.

We call this niche area "indoor obstacle negotiation" and it means navigation on predominantly solid, man-made grounds that may be cluttered with debris. The challenge with indoor obstacle negotiation is that some of the debris should be avoided, while other debris can be traversed by the robot's wheels. Obstacle negotiation differs from conventional indoor obstacle avoidance in that the latter models the world as strictly two-dimensional, so that any sensed protrusion above ground level is considered an obstacle that needs to be avoided. Indoor obstacle negotiation is also different from outdoor/off-road obstacle negotiation in that the latter requires the detection of negative obstacles (i.e., ditches), and extremely rugged terrain (bushes, tall grass, water-filled holes, mountainous ground, etc.). This type of outdoor obstacle negotiation is extremely challenging and many experts agree that this general problem cannot be solved in the foreseeable future. We believe that indoor obstacle negotiation is of particular relevance for DOE remediation and dismantlement efforts.

Binaural (coded) sonar techniques

During this month we designed a full coded sonar system consisting of eight sonars. Based on the excellent performance of the Pico digital scope with our current 2-sonar test setup, we decided to keep using this scope for all sonars instead of designing our own analog-digital converter. Each Pico scope has two input channels therefore we need four scopes. One problem is that the Pico software can control only three scopes simultaneously. For this reason we will cut back and use only six sonars in our experimental system.

In addition to the global control architecture, some changes to the printed circuit boards of the sonar module are required. Currently the sonars operate either as transmitters or receivers. We have modified the boards to allow for the sonars to act as both transmitter and receiver.
We have begun working on another modification, aimed at automating a firing schedule for the sonars. We have investigated two options:

- inclusion of an internal timer for each sonar that will control the firing schedule instead of letting the computer take care of this task. According to this method the computer would need to generate a single signal for each sonar to start firing according to a pre-determined schedule and then receive the echoes from the Pico scopes. However, this approach would require major hardware changes to the current system.
- Another approach is to have the CPU control the complex firing pattern for each individually coded signal fired by the sonars. This approach requires some rather complex interrupt-driven timing

routines, since the time resolution required for accurately controlling the coded signal generation is on the order of ±20 μs.

After reviewing these two option it appears that we will implement the second option.

Obstacle Avoidance Testbed

We made further progress toward automating the obstacle avoidance testbed. We have now integrated in our control system a small pan/tilt table that will be used to orient and re-orient a single sonar transducer under computer control.

We programmed the testbed to perform the following automated action sequence based on user-specified parameters:

1. Orient the pan/tilt unit in the desired heading.
2. Fire the sonar at the object and wait for an echo
3. Move the object an incremental step
4. Repeat 3. until the total specified distance has been traversed
5. Re-orient the pan/tilt for a new heading
6. Repeat steps 2-5 until all pan/tilt ranges have been swept

The program writes the data to a data file, which can be imported into Excel for analysis. We will also write a different version of this sequence in which the sonar readings are taken on the fly, while the object is moving.

We also updated the mechanical structure of the testbed. Specifically, we mounted limit switches and support brackets on the testbed. There are now three limit switches connected to the motor controller. One limit switch is used to precisely locate a home position for the motion platform. The other two limit switches protect the motor controller from erroneous commands that would produce a “hard stop” at the end of the rail.

We further added support brackets to the linear motion table that allow the testbed system to be a stable, freestanding unit. A pedestal that is holding the pan/tilt sonar mount is now attached to the linear motion rail.

New Indoor Obstacle Avoidance System

We have revisited and further improved our earlier ideas on improving the EERUF firing method. Our focus was on replacing the original, so-called Structured Firing Algorithm (SFA) with what we call a Random Firing Algorithm (RFA).

We have now conducted extensive tests in order to quantitatively evaluate and compare these two algorithms. For these experiments we used a sonar ring with 10 ultrasonic sensors and we tested two versions for each of the two firing algorithms:

- Fast SFA at 12 Hz and Slow SFA at 6 Hz, and
- Fast RFA at 8 Hz and Slow RFA at 6 Hz.

We tested each of these four settings in tens of different locations. At each new location the *true* distances to the objects was first measured firing one sonar at-a-time very slowly (every 100 ms, resulting in a rate of 1 Hz for all 10 sonars) to assure the echo would abate before firing the next sonar. After this baseline test, each of the four firing algorithm/versions was run for 20 seconds and the results recorded for subsequent analysis. The experiments were done in two different locals: a. inside a cluttered room and b. in an open area. Based on the results of these tests we have drawn the following conclusions:

- *Effective firing rate* – We have to define this new term to adequately express the results. Both versions of EERUF, SFA and RFA, detect and reject crosstalk readings. However, once a reading is rejected it is obviously not usable any more. If, for example, EERUF was to reject 40% of readings generated with the Fast SFA (firing rate = 2 Hz), then the effective firing rate would be 12 * 60% = 7.2 Hz.

The Slow RFA yielded the highest effective firing rate in cluttered environments, about 20-30% higher than that of the worst method, Fast SFA.

- *Partial jamming* – We observed in our experiments an effect we call "partial jamming." With either SFA (fast or slow) we notices that with certain obstacle constellations it was possible that two, three, or even four *adjacent* sonars were continuously rejecting readings. As a result, the direction of the robot supposedly "protected" by these "jammed" sonars was in effect entirely unprotected. This condition was supported by the structured (i.e., repetitive) nature of the SFA firing.

  In contrast, because the RFA method fires completely at random, rejection of crosstalk readings is more arbitrarily distributed among different sonars.

Future considerations: There is a clear relationship between the typical distance between sonars and objects and the amount of crosstalk. That is, for larger distances we find more crosstalk. It may be possible to exploit this observation for better results.

Position Estimation

Based on discussions with other experts, review of the scientific literature, and in-depth considerations of UM's strengths in the area of position estimation, we have defined a clear path of progression in our research for the next 18 months and beyond. The result of this strategic planning effort is documented in the UM's newly revised URPR Renewal Proposal for FY02.

Novel mobility concepts

OmniPede

We have now completed major revisions to the prototype segment that we received and tested last month. One of the more important changes is to eliminate some of the gears by substituting belts and pulleys. We have specified suitable belts and pulleys and ordered them. These should help reduce both the weight of the segment and the friction that must be overcome by the motor. We have also specified the other hardware that will be needed for the next two segments, such as the gears, shoulder bolts, drill rods, and set screws. This way all the components will be on hand when the three new segments are delivered. We also revised the design for mounting the pneumatic cylinders that actuate the 2-DOF joints between the segments. We found that the cylinders we had specified earlier were too large.

In parallel to these efforts, the new student working on this project is continuing to familiarize himself with the Unigraphics software package that we used to create our earlier simulations and CAD drawings. The student has also begun a shop course taught at the Physics Students' machine shop. This course will allow him to have free access of the Physics Students machine shop for machining and assembling the next two segments.

We have developed an ambitious timeline for progress in this project. This timeline calls for completing the construction and assembly of a total of three segments by the end of the Winter term. With three assembled segments it will be possible to conduct the first major feasibility test, namely that of the three-legged gait. This test will also give us key insights into the critical power issue.

Infrastructure

Multi-controller interface board (MCIB)

We have implemented the Random Firing Algorithm (RFA) explained in Section 6.1.3 above on the MCIB. In order to make the MCIB fire the sonars in a pseudo-random manner, one new schedule was added to the firmware. This schedule is composed of four full schedules generated randomly that are called in the same way as the ones used by the Structured Firing Algorithm (SFA). In this way, only the two HC11 microcontrollers that act as slaves had to be reprogrammed.

Linux conversion

We resolved a notorious problem in our ongoing conversion from DOS to Linux based onboard computing environments. This problem had to do with the difficulty of obtaining millisecond or better timing resolution. We identified a function called GetTimeOfDay. The output of this function has two parts, one in seconds and the other in microseconds with real microsecond resolution. The other timing functions also return values in microseconds, but only with 10 ms resolution. Now we can accurately measure the cycle time of our mobile robot onboard control software, which is less than 20 ms when doing obstacle avoidance.

ClodBuster

We have worked on the turn radii calculations for the Clod Buster, which uses an uncommon 4-wheel steering mechanism (or “double Ackerman steering”). In a preliminary attempt at testing computer generated paths for this steering mechanism we have calculated some turn radii with respect to steering angles. We have also calculated the encoder counts for the inner radius and outer radius wheels for one complete turn as a function of turning radius.

Vision for Navigation and Mapping

Improvements were made to the signal processing software of our structured light data acquisition sensor. We extended the well-known sub-pixel stripe localization method of Trobina from one dimension to two dimensions, and developed new estimation procedures that are robust to undecidable and dropped pixels. A partial software implementation, excluding processing of dropped pixels, has been developed and tested. This work will be incorporated as stage one of a two stage procedure, where stripe contours are generated in the first stage, and then adjusted to a consistent state using geometric analysis in the second stage. We have begun the written documentation of this procedure for future publication.

In addition, we have updated our documentation of the multiview registration algorithm for final publication in IEEE International Conference on Robotics and Automation 2001.

Radiation Detection and Imaging

To investigate “Industrial Gamma Ray Imaging”, the question of whether an anti-mask is necessary for improving the existing hybrid camera was carefully studied in the past month. The hybrid camera uses both Electronic Collimation (EC) and Mechanical Collimation (MC) to cover a large gamma ray energy range. A coded mask is selected for the mechanical collimator since it can provide a large field of view and high efficiency for low energy gamma rays. It can also provide these features at medium energy range when combined with electronic collimation.

Recent research showed that the artifact occurring in near field situation can be eliminated by introducing an anti-mask. The coded mask was initially designed for astronomy research and it has ideal imaging properties in far field situations. A far-field condition means that the source is so far away from a detector that any gamma rays emitted from a single point source are seen as essentially parallel. When this condition is not satisfied, artifacts occur. The artifacts can be canceled by adding a coded mask image to an anti-mask image, the same technique as used when the non-uniform background must be canceled in far field cases. Since the hybrid camera is designed for industrial applications, a far field situation is not always guaranteed. One can expect that introducing an anti-mask could eliminate both the near-field artifacts and far-field non-uniform background.

However, the near-field artifact is still not the major factor in limiting the current hybrid camera's angular resolution. The recent experiment in the lab had a source distance of 160 cm and detector area of 5 cm x5cm. The divergence of the gamma rays translates into a maximum deviation of 1.8 degrees for gamma rays emitted from the point source. Comparing this with the 6 degree angular resolution of the camera, and considering that fact that this 1.8 degree is added with other factors in quadrature, this divergence is not considered the major factor limiting the angular resolution. It will be considered as a further improvement later when the major problem – detectors with finer intrinsic spatial resolution – is solved.

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

Our papers:

1. Chung, H., Ojeda, L., and Borenstein, J., 2001, "Sensor fusion for Mobile Robot Dead-reckoning with a Precision-calibrated Fiber Optic Gyroscope;"

2. Shoval, S. and Borenstein, J., 2001, "Using Coded Signals to Benefit from Ultrasonic Sensor Crosstalk in Mobile Robot Obstacle Avoidance"

3. Sharp, G., Lee, S. W., and Wehe, D. K., "Toward Multiview Registration in Frame Space,"

were accepted for presentation at the *2001 IEEE International Conference on Robotics and Automation*, Seoul, Korea, May 21-26.

Also, Sharp, G., Lee, S. W., and Wehe, D. K., *ICP Registration using Invariant Features*, was accepted for publication in IEEE Transactions Pattern Analysis and Machine Intelligence.

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.

No milestones were due this month.

/pm