PTS MONTHLY CHECKLIST

Submitted by: *University of Michigan* Report Month: July 2000
Submitted to: *US DOE/Albuquerque Operations Office*
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.

UM is fusing path-planning software and vision data into the current obstacle avoidance algorithms. The use of magnetic field measurements for position information is being investigated as well. The initial prototype module of a novel vehicle formed from fused deposition modeling was received and design changes already incorporated into the next prototype. The radiation imaging work has involved renovation of the CSPD-2 camera and improvements to the Hybrid Imager.

☐ **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.**

☐ 6. TECHNICAL STATUS:
This is likely to be the longest section of the narrative and describes the technical accomplish-

ments 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 Integration of D* algorithm for path planning and vision

As a complement to UM’s earlier developed reflexive obstacle avoidance system, we have now completed the integration of the D* (pronounced: “De-Star)”–based path planning algorithm with our on-board control software. We also integrated a simulation program, designed to test the D* algorithm and measure its execution time. Execution time is critical in a dynamic planner (i.e., a planner designed to run in real time while the robot is moving). We tested the algorithm with a map of 100 x 50 states (cells). Planning the initial path from one corner of the map to the opposite corner took about 200 ms on a 233 MHz Pentium PC running under MS-DOS for a simple (one obstacle) environment. The dynamic replanning after adding a second obstacle took about 205 ms. Both times are acceptable, but will be larger for more complex environments, and are much too large for the available portion of the onboard control cycle (10 ms).

Since we decided on having the D* run on the main control computer (i.e., not adding a second on-board computer), we will probably incorporate a simple heuristic to determine if the planned path is blocked, and in that case invoke the D* algorithm to perform *static* replanning of the entire path while the robot is stopped.

6.1.2 Integration of computer vision

UM is currently integrating computer vision and path planning with UM’s existing obstacle avoidance software. As a sample application module we implemented a tracking feature for the video system, which tries to have the camera point straight forward regardless of the platform’s motion and orientation, within the limitations of the video system’s pan/tilt unit.

6.2 Position Estimation

Detection of the True Earth’s Magnetic Field Using a Three-Axis Magnetometer

In order to use the earth’s magnetic field as an absolute orientation reference it is only necessary to consider the phase difference between the X- and Y-components of the magnetic field. However this approach does not detect magnetic anomalies in the environment, caused by electromagnetic interferences. UM is currently developing novel methods for using a three-axis magnetometer to detect magnetic anomalies.

To explain UM’s approach we observe that in the absence of magnetic anomalies, the earth’s magnetic field is quite constant within any given area (say, a radius of 1 km). If a three-axis magnetometer is placed horizontally (i.e., so that its z-axis is normal to the earth’s surface), then the measured Z-component of the earth’s magnetic field is very small and constant. In addition, the absolute magnitude, A, of the earth's magnetic field can be calculated using only the X- and Y-component of the magnetometer readings. We now hypothesize that these two observations can be used as criteria for determining whether the readings of the magnetometer are truly those of the earth’s magnetic field and not influenced by magnetic anomalies caused by the environment.
In order to verify this hypothesis we collected data from several locations within a radius of 1 km outside of the laboratory. The experimental data confirms that the magnitude of the earth’s magnetic field was indeed nearly constant in all the locations.

Using the collected baseline data we calibrated the magnetometers and performed several outdoor and indoor experiments with the magnetometer mounted on a mobile robot. Computing the magnitude of the earth's magnetic field as $A = \sqrt{X^2 + Y^2}$ and observing the Z-component as measured by the magnetometer, we were able to successfully identify several locations that were free of magnetic interference. For this experiment we used the heading angle provided by the onboard gyroscope as a reference.

So far we have investigated only the two-dimensional case (i.e., with a tilt angle of zero). However, the described technique can also be used if the robot is tilted. In that case it is necessary to measure the tilt of the robot with an additional sensors. In our case we can provide this information using our on-board tilt information system, which is based on gyroscopes and accelerometers, as reported on earlier.

6.3 Novel mobility concepts

OmniPede

UM continued to work on the prototype of the OmniPede. We received the first major part manufactured by the fused deposition manufacturing (FDM) machine (recall that the FDM process produces three-dimensional parts of complex geometry in a single run from a plastic-like material). As we had expected we found some of the design features that had to be changed in order to accommodate this unique manufacturing process. One of the larger changes needed was that we had to redesign the single, extremely complex part as two separate parts. This redesign almost completely eliminates overhanging features and will drastically reduce the time required to remove what the FDM documentation calls “support structure.” A support structure is material that needs to be added underneath overhanging features in order to support them during the manufacturing process. The removal of this support structure is a very time consuming task. This change will also improve the surface quality of the part. Another large change is that bearings cannot be made from the FDM material. Rather, we will use nylon sleeves that will be glued in place using a fixture.

We were pleased to see that the strength of the FDM parts will not be a problem as we had feared. We are now confident that we can improve the strength of the structure by redesigning the geometry of the part, if needed.

Most of the off-the-shelf parts that we had ordered have come in. These are higher quality pneumatic tubes and fittings from different companies and various drive components. We tested the pneumatic parts and verified that they are in fact much higher quality. UM is also conducting a preliminary patent search to investigate patentability of the OmniPede. In the course of this search we found some prior art in the form of mobility devices developed for endoscopy. One of these research efforts is ongoing at Cal Tech. We found that not only are our ideas different, but the approach used in the OmniPede may be more effective and simpler.

6.4 Vision for Navigation and Mapping

We have been conducting a more thorough experimental analysis of previous feature-based registration research in preparation for the final archival version of the article. The experiments are conducted over four test sets and 100 initial conditions, using three shape invariant features and thirteen different feature weighting values. The experiment is partially finished, and will require about eighteen days to complete.

Also, we are preparing for a large scale map-building experiment using real range and reflectance data. We will mount our structured light sensor on top of a mobile platform and capture range data from different positions within the indoor environment of our lab, register and fuse the data. Major unresolved issues include improving the signal processing and calibration of the structured light system.

6.5 Radiation Detection and Imaging

In the area of radiation imaging, the CSPD2 has been restored to a functional condition. Images have been acquired using the camera, but display unrealistic artifacts. Since this is the imager that has proven useful in E M applications, we are upgrading it to ensure it is ready for operational field trials.

The hybrid camera remains under study. With the significant gains already reported from more accurate system representation, we are looking at the limiting factors in spatial resolution. Our approach will be to tackle successively each factor in order of priority until the resolution is optimal.

In the area of detector development, we are awaiting two sets of customized readouts. One set has the advantage of sparse readout, enabling us to read out just those channels having interesting signals. The second set, obtained from a different supplier, offers the advantage of timing information on each signal. Once these electronics arrive, we shall begin intensive testing. We are also awaiting the delivery of two specialized detectors that will be mated to the electronics.

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

The paper Borenstein, J., 2000, “The OmniMate: A Guidewire-free AGV for Highly Flexible Automation” was presented at the 2000 Japan-USA Symposium on Flexible Automation, Ann Arbor, MI., July 23 – 26, 2000.

The paper Hong Y., Borenstein, J., and Wehe D.K, 2000, “Sonar Based Obstacle Avoidance System for Large, Non-point, Omni-direction Mobile Robots” has been accepted for presentation at the Spectrum 2000 International Conference on Nuclear and Hazardous Waste Management, Chattanooga, TN, Sept. 24-28, 2000.

The UM Mobile Robotics Lab conducted an Open House in conjunction with the 2000 Japan USA Symposium on Flexible Automation that took place in Ann Arbor, MI, July 23 – 26, 2000. Over 100 international researchers attended the Open House.

UM researchers traveled to LLNL and met with researchers having joint interests in position-sensing radiation detectors for imaging applications during 7/26-28/00.

UM presented two papers at the SPIE meeting in San Diego, CA on 7/31-8/4/00.

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.

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