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Experimental Results from UM's Proprioceptive Position Estimation System Installed on CMU's ATRV

By

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1 OVERVIEW

During the last week of January 2003 University of Michigan (UM) Engineer Muks Raju installed a **Proprioceptive Position Estimation (PPE)** system developed at UM on an ATRV mobile robot at Carnegie Mellon University (CMU). The PPE System uses high-quality fiber-optic gyroscopes and the unique, UM-developed Fuzzy-Logic Expert Navigation (FLEXnav) software to provide unparalleled dead-reckoning accuracy for mobile robots. The PPE is housed in a custom-built aluminum case as shown in Figure 1. Figure 2 shows the PPE and its "brain," a Toshiba Libretto installed on CMU's ATRV platform.

In all the experiments described in this report a human operator used a joystick to drive the ATRV along a predetermined path. In all but experiment 2.1 and 2.2 the path was a closed path of 160 m total length. Upon return to the starting position we measured the discrepancy between the actual robot position and the position reported by our PPE. The resulting discrepancies are the position errors produced by the PPE. For each experiment we provide a plot that shows the *x*- and *y*-values of the final position error for each individual run. We also provide for each experiment as a set of values X_e, Y_e, and Ψ_e. These values represent the *average of absolute errors (AAE),* in *X*-and *Y*-direction and heading, respectively. For example, if for a certain experiment we performed *n* runs and measured position errors (x_1, y_1, φ_1), (x_2, y_2, φ_2)… (x_n, y_n, φ_n) at the end of each run, then, $X_e = \frac{1}{n}\sum_{i=1}^{n}|x_i|$, $Y_e = \frac{1}{n}\sum_{i=1}^{n}|y_i|$, and $\Psi_e = \frac{1}{n}\sum_{i=1}^{n}|\psi_i|$.

Figure 1: UM's Proprioceptive Position Estimation (PPE) system

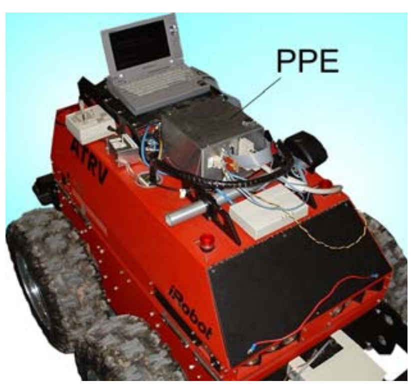


Figure 2: UM's PPE system installed on CMU's ATRV for testing.

Key Specifications of UM's PPE System:

Typical positioning error < 1.0% of total travel distance on rugged terrain	
Instrumentation: 3 precision-calibrated KVH fiber-optic gyros, 2 accelerometers	
Size:	~6.5"L x 6.6"W x 5.0"H
Weight:	~4.4 lbs
Power:	~28 Watt
Brain:	Toshiba Libretto CT100

2 EXPERIMENTAL RESULTS

2.1 Calibration Experiment

This experiment was used to calibrate the PPE linear scale factor, which depends on vehicle-specific odometry. For the Calibration Experiment the ATRV was steered along a straight line, for a distance of 15 meters, and at a speed of 300 mm/sec. The errors in these seven runs were averaged and used as calibration parameters in the PPE. The thus-calibrated scale factor, of course, yielded final position errors in Y-direction near zero for this experiment.

2.2 Snaking Path

For the two experiments described in this section the robot was moved from a starting point A to an ending point B located 15 meters ahead along a snaking path similar to the one shown in Figure 3. The results are shown in Figure 4.

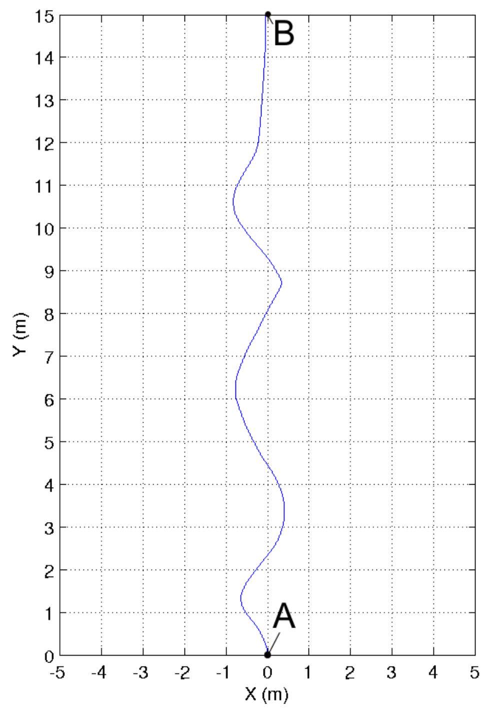


Figure 3: Typical trajectory for the Snaking Path Experiment.

2.2.1 Snaking path on smooth floor

In this experiment the robot followed the snaking path of Figure 3. The total traveled distance was about 17.5 m and the speed was 300 mm/sec. The terrain was a carpeted indoor floor. The AAEs were:
X_e = 136 mm, Y_e = 111 mm (green circles) and Ψ_e = 0.4°.

2.2.2 Snaking path on rough terrain

In this set of experiments the terrain was also carpeted indoor floor. However, rough terrain was simulated by driving the robot over large objects while still following the snaking path. We used an approximately 5”×5” aluminum rod and placed it under the wheels repeatedly (5-8 times per run) while the robot was moving. Some runs were performed at 300 mm/sec and some at 450 mm/sec. AAEs: X_e = 140 mm; Y_e = 85 mm; (red circles in Figure 4) and Ψ_e = 1.9° .

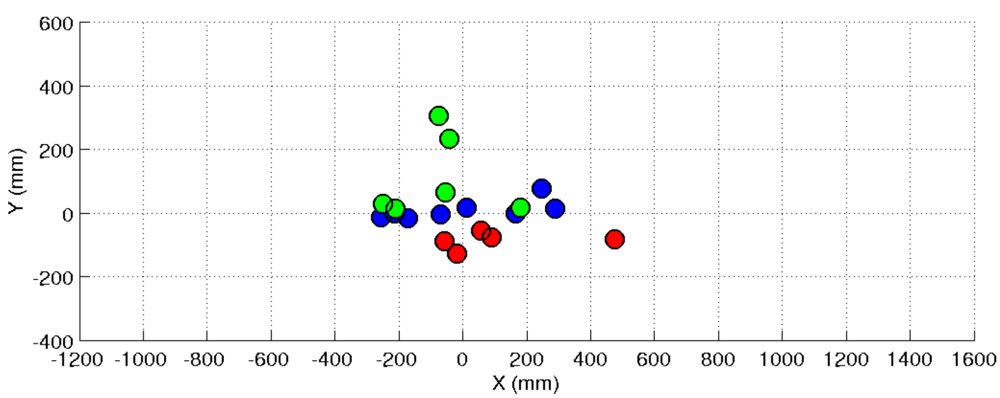


Figure 4: Final position errors for the snaking path experiment.

The **blue circles** are the results of the Calibration Experiment.

Note: This results plot and subsequent ones should be viewed in color

2.3 Closed-loop Path on Smooth Terrain

This group of experiments was performed on smooth horizontal terrain (carpet) with the robot following a rectangular path (see Figure 5). The total traveled distance was about 160 meters. The AAEs are listed below, colors refer to the circular marks in Figure 6.

2.3.1 Clockwise runs at 450 mm/sec

$X_e = 735$ mm, $Y_e = 213$ mm (blue circles), and $\Psi_e = 1.3°$

2.3.2 Counterclockwise runs at 300 mm/sec

$X_e = 254$ mm, $Y_e = 156$ mm (green circles), and $\Psi_e = 1.3°$

2.3.3 Clockwise runs at 850 mm/sec

$X_e = 931$ mm, $Y_e = 114$ mm (red circles), and $\Psi_e = 1.3°$

2.3.4 Counterclockwise runs at 850 mm/sec

$X_e = 657$ mm, $Y_e = 54$ mm (cyan circles), and $\Psi_e = 0.3°$

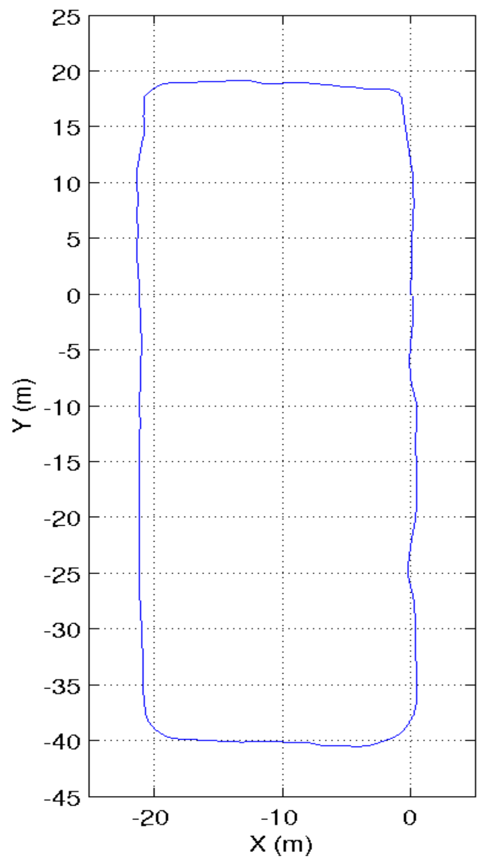


Figure 5: Near-rectangular path followed by the robot during the Closed- Loop Path Experiment on smooth terrain.

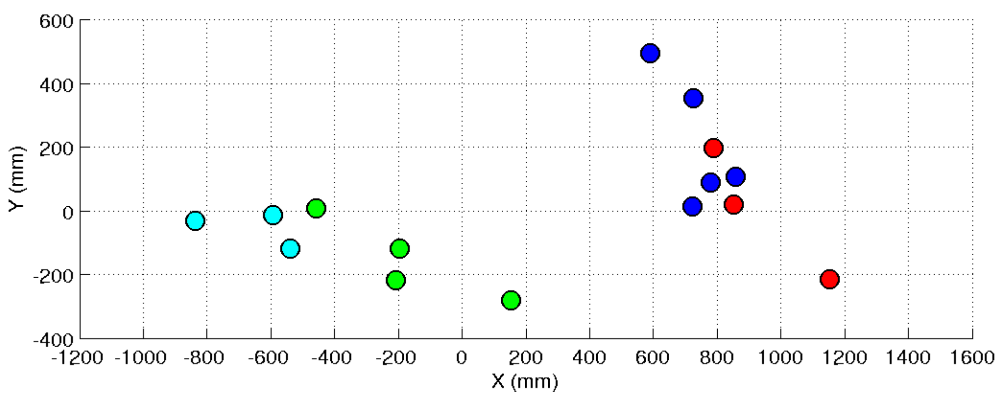


Figure 6: Final position errors for the Closed-loop Path Experiment on smooth terrain.

2.4 Closed-loop Path on Rugged Indoor Terrain

These experiments where performed under the same conditions as those of Section 2.3, but this time rugged terrain was simulated by driving the robot over large objects while still following the closed loop path. In some of the experiments we used an approximately 5”x5” aluminum rod and placed it under the wheels repeatedly (7-8 times per run) while the robot was moving. In other experiments we performed two of the four 90-degree turns on wooden ramps that were inclined about 20 degrees. Turning while on an incline can be shown to introduce large heading errors even with high precision gyros. This is therefore a good test for our system.

2.4.1 Clockwise runs at 450 mm/sec and 850 mm/sec with aluminum rod obstacles

X_e = 983 mm, Y_e = 90 mm (blue circles), and Ψ_e =1.1°

2.4.2 Counterclockwise runs at 450 mm/sec and 850 mm/sec with aluminum rod obstacles

X_e = 858 mm, Y_e = 290 mm (green circles), and Ψ_e = 1.9°

2.4.3 Clockwise runs at 850 mm/sec with 2 wooden ramps in 2 corners of the path

X_e = 586 mm, Y_e = 301 mm (red circles), and Ψ_e = 0.6°

2.4.4 Counterclockwise runs at 850 mm/sec with 2 wooden ramps in 2 corners of the path

X_e = 332 mm, Y_e = 185 mm (cyan circles), and Ψ_e = 1.7°

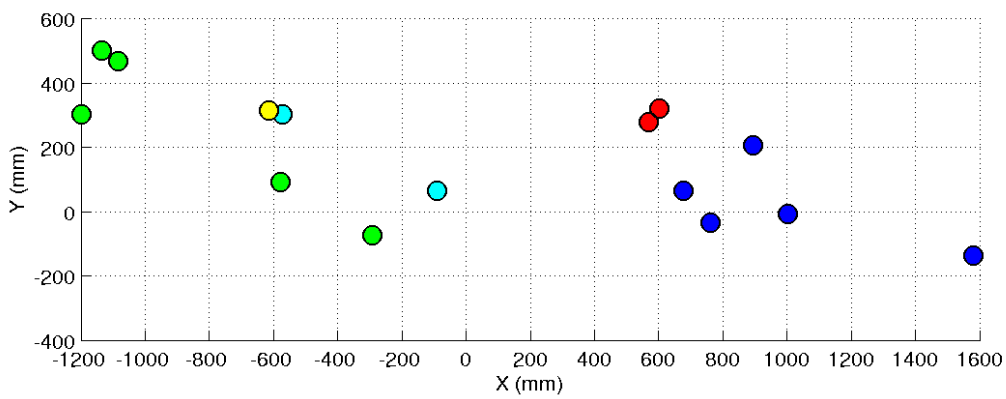


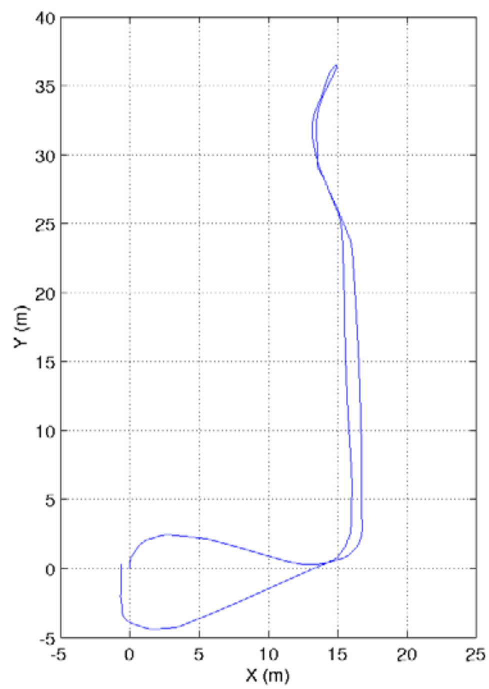
Figure 7: Final position errors for the Closed-loop Path Experiment on rugged terrain

2.5 Closed-loop Path on Outdoor 3-D Terrain

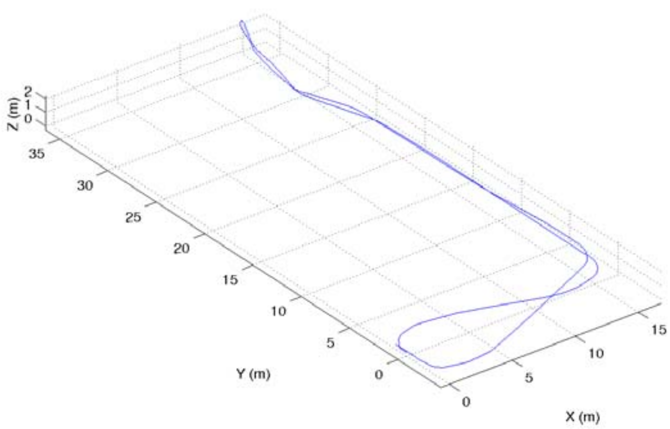
This particular experiment was significantly different from the experiments reported on in the proceeding sections. The experiment was conducted outdoors, mostly on paved walkways, but it included climbing up ***the stairs*** shown in Figure 8a and then driving down the ramp next to the stairs. The height difference was about 1.5 meters.

The return position error for this experiment was x_e = -609 mm, y_e = 310 mm, z_e = 620 mm, and Ψ_e = -1.0°. The single yellow dot in Figure 7 above indicates that position. Because of the severe cold on the day of experimentation we were able to conduct only this single outdoor experiment. Therefore x_e, y_e, z_e, and Ψ_e are the results of just one single run, and not AAEs, as shown for the other experiments in this report.

(a)



(b)



(c)

Figure 8: Trajectories and path details for the outdoor 3-D terrain experiment.

a. Photo of the stairs and ramp the robot drove up and down in the experiment.
b. 2-D trajectory plot
c. 3-D trajectory plot