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Research

Vehicle Navigation and Localization Using Multiple Navigational Aids

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The purpose of this project was to test the feasibility of the integration of heterogeneous sensor systems at the implementation level, as well as to investigate the theoretical development of the algorithms to integrate the navigation information. The goal is a set of algorithms to handle failures in any particular sensor and adaptive adjustment of parameters and navigational fixes. Using real field data, we have demonstrated that different sensors can be integrated in a low cost system. We have also demonstrated that no single sensor can handle the arbitrary situation, but that multiple sensors yields redundancy and robustness unachievable by each sensor alone.

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VEHICLE NAVIGATION AND LOCALIZATION USING MULTIPLE NAVIGATION AIDS
FINAL REPORT.

Abstract

The purpose of this project was to test the feasibility of the integration of heterogeneous sensor systems at the implementation level, as well as to investigate the theoretical development of the algorithms to integrate the navigation information. The goal is a set of algorithms to handle failures in any particular sensor and adaptive adjustment of parameters and navigational fixes. Using real field data, we have demonstrated that different sensors can be integrated in a low cost system. We have also demonstrated that no single sensor can handle the arbitrary situation, but that multiple sensors yields redundancy and robustness unachievable by each sensor alone.

1. Background – The Global Positioning System

The fundamental question this research addresses is the various ways to answer the question "Where am I?". There are many possible applications for a system to answer this question. An obvious example are Tourists in an unknown city looking for particular destinations. Delivery vehicles seeking addresses in unusual parts of a city, or in outlying areas, could also use such a system to find their way to their destinations. City buses could keep track of their position in order to display their positions to riders waiting at bus stops or on the bus, or even to the driver to let him/her know whether the bus is on schedule. City managers could keep track of snowplows during snow emergencies with real-time information in order to better track the progess of snow clearing operations.

It is by now generally accepted that the Global Positioning System (GPS) is the primary method capable of answering this question under most circumstances. GPS receivers have become widespread and inexpensive, and their accuracy has been (and should continue) improving. But our research has shown that there are many circumstances where GPS may fail to provide an answer to this question ("a fix"). When this happens, alternative sensors must be used to obtain a navigation fix. There are many types of alternative sensors that could be used in this regard: odometry, gyroscopes, compasses, accelerometers, cameras, radio beacons, and/or ultrasonic and infrared sensors combined with a suitable database. In this research, we have developed an inexpensive sensor testbed which combines several of these sensors into a single unit. Figure 1 illustrates the performance of GPS in Minneapolis. This simple experiment showed how easy it is to lose the GPS signal due to buildings (in Downtown Minneapolis) or due to trees (along the Mississippi River). Other obstructions that can yield to loss of signal include tunnels or the radio noise around airports. Multipath effects in the presence of buildings yielded false position estimates, sometimes putting the vehicle off by as far as a whole city block. Differential Corrections would not be capable of handling many of these conditions unless a very thick infrastructure of GPS repeaters were installed so that multiple repeaters were visible from any location.

It is already recognized that supplementary information is often needed. One option is to use the odometry to estimate the current position during temporary loss of GPS signal. This is the approach taken on many commercial vehicle navigation systems currently available in rental cars in locations such as Orlando FL and San Jose CA. The supplementary system operates only when GPS is lost, but is unable to correct for

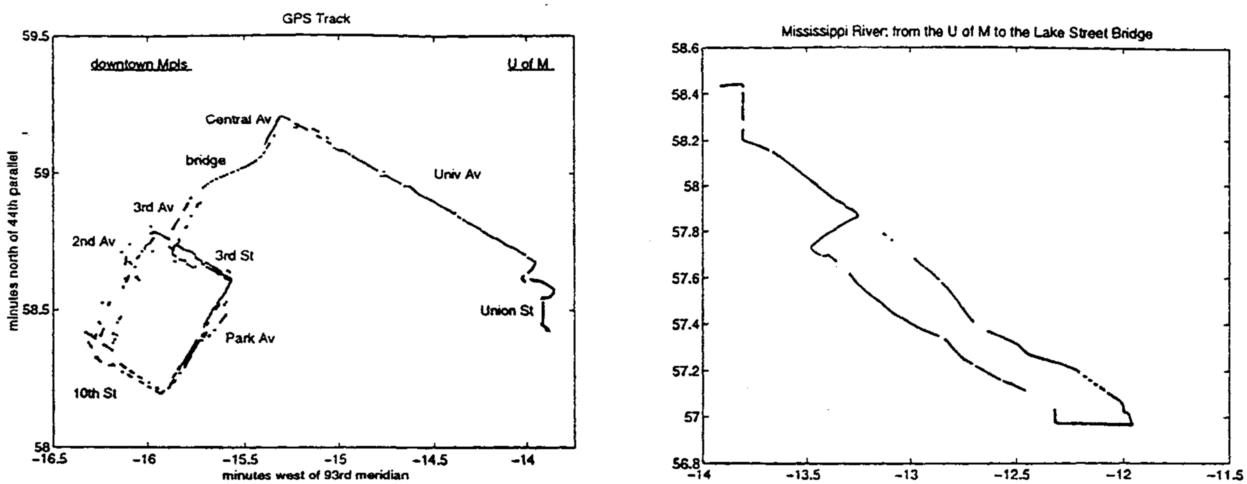

Figure 1: *Sample GPS Tracks: from Downtown Minneapolis to the University of Minnesota (left) and from the University along the Mississippi River to Lake Street (right).*

errors in heading. A second approach is to use the map database to correct the position: in this approach we would move the current position to the nearest road in the database. This approach could be easily confused by multipath effects, since it could end up putting us in the wrong city block.

2. A Sensor Testbed

We have developed and assembled a sensor testbed combining several sensors into a single integrated unit: GPS, odometry, gyroscope, and a vision system, using only off-the-shelf inexpensive hardware. In order to integrate the systems, we has to write the software to read the various sensors and integrate the results into a single software package.

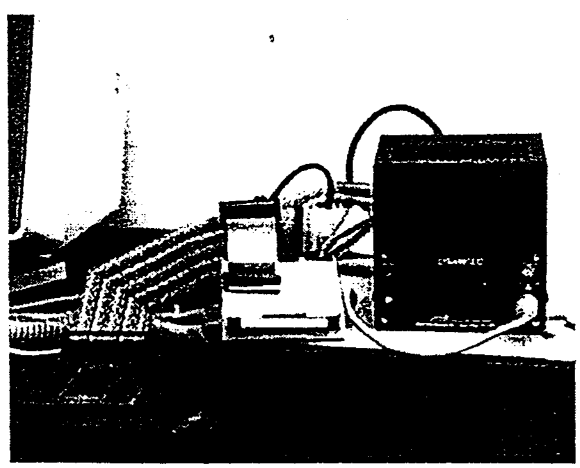

Figure 2: *The PC/104 main processor, with the A/D converter and floppy disk drive*

Our unit is built around a PC-104 standard 486 processor running standard DOS (Figure 2). The main processor unit includes

(a) a frame grabber board (to grab camera images),

(b) a communications board,

(c) a power supply board for operation with a 12 volt supply found in vehicles,

(d) a VGA monitor board, and

(e) an analog-to-digital (A/D) board (which also includes a D/A converter),

all with the cubical six-inch enclosure shown in figure 2. The external sensors atached to this system consist of the following:

(a) A Trimble GPS unit with the DGPS option connected through a serial port,

(b) A Murata GyroStar sensor, connected with the A/D board,

(c) A magnetic switch on the vehicle drive train to act as the odometer, connected through the A/D board, and

(d) a Panasonic NTSC monochrome video camera connected to the frame grabber.

3. Experimental Configurations and Results

Using our testbed, we performed experiments using two configurations: (a) odometry with vision, and (b) odometry and gyro with GPS. In the first configuration, we used vision as the primary sensor and odometry as the supplemental sensor. The vision system is capable of recognizing distinctive existing landmarks, such as bus stop signs or stop signs. When combined with a databse of sign locations, this system would yield current accurate location information with an accuracy on the order of a few inches. Our experiments indicate that it is easy to accuracy on the order of 1 to 2% of the distance to the landmark using a relatively low resolution camera.

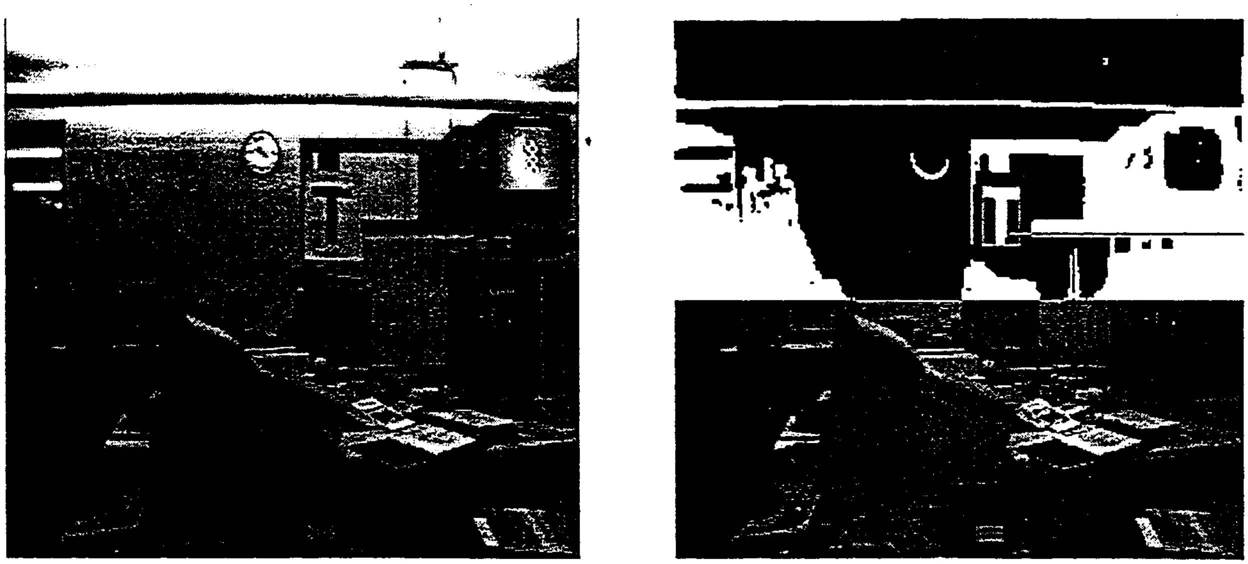

Figure 3: *The vision system recognizing "T"'s: the raw image (left) and the processed image (right).*

Figure 3 illustrates the performance of the vision system. It is capable of finding distinctive landmarks (in this case a "T" on a simple white sheet of paper) within a cluttered image. As the robot moves, the image is updated continuously. On the PC/104 486 processor running at 33MHz a new image can be processed and a landmark located at a rate of 2 or 3 per second.

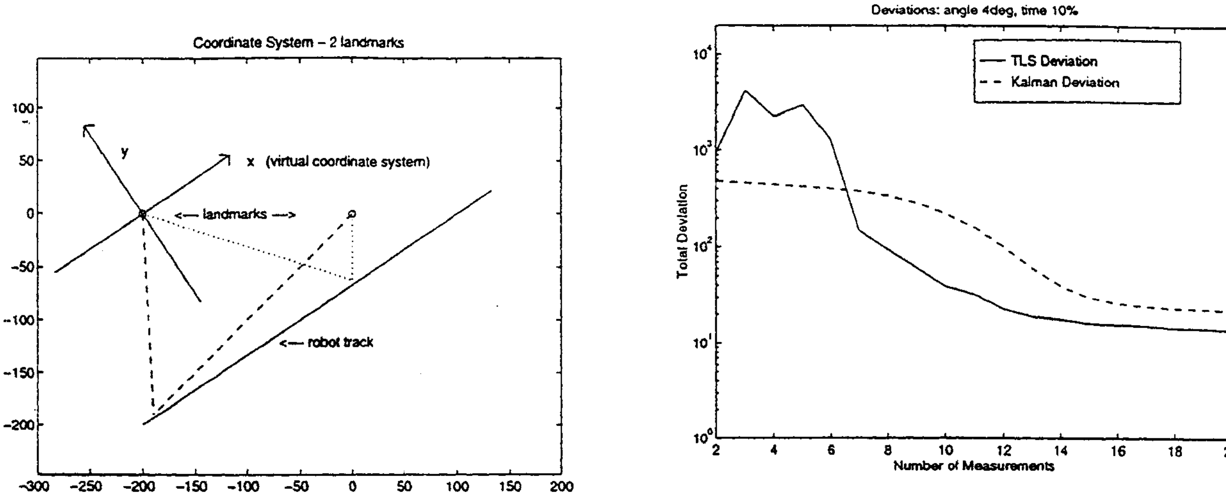

Figure 4: *Obtaining location from vision data: the geometric setup (left), typical performance results (right).*

The location of the landmark in the image (measured in pixels) is used by the geometric triangulation algorithm to compute the location of the vehicle. In order to account for noise and the low resolution of the camera image, a linear least squares formulation has been developed which show convergence superior to that of the Kalman filter. A virtual coordinate system is set up as shown in Figure 4 (left) centered at one landmark, but with the x-axis along the direction of vehicle motion. We then set up the equations to solve for positions of the vehicle and of the other landmark in this virtual coordinate system. This latter position is then used to map the virtual coordinate system to the true ground coordinate system. A typical convergence result, compared to the Kalman filter, is shown in Figure 4 (right). The Kalman filter requires an initial estimate of the position, whereas our method does not. But after approximately 7 to 8 readings, we can achieve an error at least half of that of the Kalman filter with no initial information. Achieving locations with only a few readings is critical since landmarks typically remain in the field of view of the camera for only a limited time. In our formulation, it is not necessary to both landmarks to be visible at the same time.

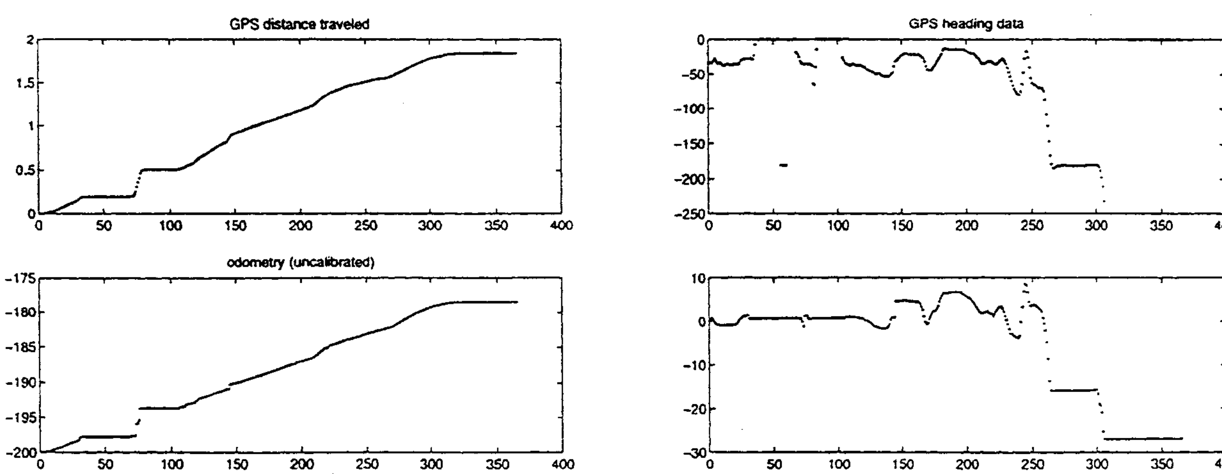

Figure 5: *GPS data compared with odometry (left) and gyroscopic sensor (right).*

In the second configuration, we combined odometry and a gyroscopic sensor with GPS in a vehicle. This method does not require an a-priori database of the environment, but does require installation of some minor devices to access the odometry information of the vehicle. This particular combination is an active area of research in the Robotics and Automation community. Our preliminary results (Figure 5) show that the data from the inexpensive odometry and gyroscopic sensors are consistent with that from the GPS, that the noise from the inexpensive sensors is minor, and that these sensors are sufficient for use in a dead-reckoning algorithm.

4. Conclusions

Given these results, several algorithms for sensor fusion suggest themselves.

(a) Use GPS except during GPS failure. This method would account for loss of signal, but would not account for multipath effects.

(b) Use GPS unless a large discrepancy is found between GPS and the other sensors. This is a method suggested by Borenstein (ICRA '96) for indoor navigation. During such discrepancies, use the alternative sensors: odometry and gyro.

(c) Use a weighted average of inertial data, GPS, and vision data. By using a Bayesian analysis of the accuracy from each sensor, this method will permit the continuous updating of the position estimate, together with accuracy estimates. The various thresholds for the conditional probabilities involved in a Bayesian analysis would have to computed by experimentation.

This research has shown that no one sensor, including GPS, is sufficient to obtain a navigation fix with a high degree of accuracy and robustness. A combination of sensors can be used to improve the performance of a vehicle navigation system. We have shown the feasibility of combining GPS, odometry, gyroscopic sensor information, and vision, into a single integrated unit. A choice of algorithms exist for the integration of the competing sensor information, often with very different accuracies, robustness, update rates, and partial availability. Our testbed has shown that any of a wide variety of algorithms can be used and tested in the field.