Abstract- Accurate vehicle localization is frequently a requirement of tracking applications. Cost, however, often becomes a limiting factor rather than tolerable error in applications requiring better than 1 meter of accuracy. In this paper methods are proposed to provide accurate vehicle localization using off the shelf components, with the goal being accuracy down to 4cm at 80km/hr. The technologies proposed include the use of regular GPS, laser and ultrasonic rangefinders, optical mouse sensors, and accelerometers. Methods will also be discussed for calculating position from accelerometer data with a discussion of current results and future plans for combining GPS and accelerometer data.

Index Terms- Position, Tracking, Localization, Accelerometers, Vehicle, GPS, Rangefinder

I INTRODUCTION

Many research and industrial applications require accurate localization and/or tracking of moving vehicles. Available technologies include differential GPS (DGPS) which compare satellite measurements to measurements from local, terrestrial stations to correct for atmospheric errors; and complex Doppler-based signal analysis. One constraint of these systems, besides cost, is that the error frequently goes up proportionally to vehicle velocity as well as distance from the local station. While this constraint can eliminate some technologies for certain applications, it often results in even higher costs for applications requiring a high degree of accuracy at speed.

Unfortunately the high cost of commercial solutions is often the limiting factor in the selection of tolerable error limits. It should be possible, however, to use available off-the-shelf components to build a more cost effective system with suitably high accuracy. This paper will explore several technologies that are readily available for purchase. The technologies mentioned are currently being tested in an ongoing research project with a goal of 4cm accuracy at 80km/hr [1][2].

II PROBLEM FORMULATION

The problem under current consideration is tracking a moving vehicle on a limited and known stretch of roadway. This implies that it is possible to place sensors in the area to aide in the localization and tracking of the vehicle. The problem consists of vehicular movement in the x and y directions, Fig. 1, ignoring motion in the z direction. Position must be measured at regular intervals, at a frequency of approximately 10Hz or higher.

III AVAILABLE TECHNOLOGIES

Several localization technologies have been proposed, with GPS being an obvious choice for consideration. A discussion of each technology is presented below.

A. GPS

Global Positioning System (GPS) is an obvious first choice for any outdoor localization problem. In applications requiring high accuracy, however, GPS does not always present the ideal solution. GPS was originally designed with an inherent error of at least 10m for non-military applications [3]. Although the error inducing system was turned off by the US government in 2000, GPS is still accepted to have an error of at least 4m without correction for atmospheric conditions, and approximately 3m with corrections. Since the lane width for most roads in the US are approximately 4m [4], the error radius is large enough so as to prevent us from even verifying the truck’s position is within the bounds of a standard lane as shown in Fig. 2. This solution is well below the 4cm minimum required accuracy. Although greater accuracy can be achieved through techniques such as Differential GPS, with some companies advertising sub-1m accuracy, the equipment costs and setup time can be excessive.

This project is being funded with a grant from the Alabama Department of Transportation as project # 930-671
B. Range Finders

Ultrasound and laser rangefinders can be extremely accurate in a single dimension if a suitable surface can be used to reflect the measurement signal. Rangefinders would be a suitable solution for the y position since the simple, reflective barriers could be placed along side the test road. However getting the x position would require additional work. In order to receive accurate measurements in the x direction (significantly far enough to require a laser), a reflective surface, such as another vehicle, must be placed across the far end of the test stretch, as shown in Fig. 3. In the case of a high-speed test (80 km/hr), such an obstacle would have to be moved out of the way at the last moment to prevent a collision between the test vehicle and the reflecting surface.

C. Accelerometers

Accelerometers are widely available as well as inexpensive and can be purchased to provide either analog or digital outputs. A pair of accelerometers mounted on the truck to continuously measure acceleration in the x and y directions should provide a simple dataset from which to calculate xy positions by using the double integral of acceleration as shown in (1) [5].

\[ x(t) = \int \int a(t) dt \]  

A shortfall of this approach is the requirement that the position be calibrated externally by using a known position to correlate the relative position to the actual position. In a high-speed test the driver would start the run almost 1.6km away from the end of the test stretch in order to reach sufficient speed. In this situation it is necessary to measure accelerations the entire time (even outside of the region of interest) in order to have access to the most current velocities. The x position could be calibrated using a laser start marker across the road at a known point before the bridge or on the bridge, as shown in Fig. 4.

D. Optical Mouse Sensors

The sensors used in optical mice are a marvel of modern technology. In a single, small chip a high speed, low resolution, grayscale image sensor captures images at up to 6kHz while an on-chip DSP compares successive images to determine the magnitude of change in both the x and y directions. Mass production of these chips has allowed the cost of these chips to fall below $10. Although this paper focuses on the investigation of accelerometers as a solution, optical mouse sensors will be investigated in the future, including the requirements for a lens train that would enable such a sensor to work around 0.5m from the moving surface.

IV PROBLEM SOLUTION

Although there is ongoing research into the use of rangefinders, this paper will deal primarily with the accelerometer solution which consists of several discrete problems including A) retrieving meaningful acceleration data, B) calculating the xy position, C) calibrating the xy position.

A. Retrieving Meaningful Data

Assuming a maximum acceleration of 0 to 96km/hr in 5 seconds the acceleration can be calculated as shown in (2).

\[ \frac{96 \text{ km}}{\text{hr}} \times \frac{1000 \text{ m}}{1 \text{ km}} \times \frac{1 \text{ hr}}{3600 \text{ sec}} \times \frac{1}{5 \text{ sec}} = 5.3 \frac{m}{\text{sec}^2} \]

\[ 5.3 \frac{m}{\text{sec}^2} \times \frac{1 \text{ g}}{9.8 \frac{m}{\text{sec}^2}} = 0.54 \text{ g} \]  

This result establishes the top of the measurement range for x direction acceleration. Since the problem deals with a large, heavily-loaded truck it can safely be assumed that a range of 0-0.54g incorporates significant margins. Y direction accelerations are more difficult to anticipate. Accelerations in the y direction represent steering corrections and are directly related to the x velocity at the time the correction is applied. Assuming the test truck is moving in a straight line at 96km/hr and a steering correction of 10 degrees is applied, the acceleration can be calculated as shown in Fig. 5 and (3).
Since the acceleration is instantaneous, the y velocity magnitude becomes the y acceleration magnitude.

\[
\sin(10^\circ) = \frac{y}{96 \text{ km/hr}} \quad (3)
\]

\[
y = 16.7 \text{ km/hr} = 4.6 \frac{m}{\text{sec}}
\]

(4)

Taking into consideration the bounds calculated for x and y accelerations, a reasonable requirement can be established for accelerometers with minimum ranges from 0 to 0.5g.

With sensor requirements calculated, it becomes necessary to evaluate available accelerometers for cost and performance. Currently this project is evaluating LF series accelerometers by CrossBow Technologies, as shown in Fig. 6, which has a range from -1 to +1g.

These accelerometers provide an analog, linear voltage/g response [6]. An alternative to the CrossBow accelerometers is the SerAccel v5 serial tri-axis accelerometer produced by Spark Fun Electronics as shown in Fig. 7. Although based on the MMA7260Q tri-axis accelerometer by Freescale Semiconductor, which is similar in design to the CrossBow sensors, the SerAccel package performs A/D conversions on-board and outputs digital measurements via a standard RS-232 interface. The SerAccel is configurable for measurements in the following ranges: +/- 1.5, 2, 4, 6g [7].

B. Calculating position

As stated previously, acceleration is the 2nd derivative of position or, more relevantly, position is the 2nd integral of acceleration (1) [4]. LabView provides a means for integrating a series of discrete measurements with a known sampling time. Utilizing this capability, it is possible to directly and continuously calculate position from the accelerometer data.

C. Calibrating the position

As mentioned previously, calculating the position from acceleration data exclusively produces a position relatively to the starting position. In the case of the high speed test, the starting position could be over 1.6km from the bridge to allow sufficient distance to gain speed. It is necessary to provide a means to relate the starting position to a known point on the bridge. The proposed solution consists of two sensors, a laser detector with narrow reception in the horizontal (only a thin vertical slit in an opaque covering) and an ultrasonic range finder. Both sensors would be mounted on one side of the truck as shown in Fig. 8. A laser would be projected across a calibration point on the bridge, most likely close to the beginning as shown in Fig. 4. When the truck passes the laser, the detector is triggered for a very short time and the ultrasonic range finder takes a distance measurement. At that instant the truck’s position in relation to the bridge is known and can be used to calibrate all previously calculated positions as well as future positions.

V. RESULTS AND DISCUSSION
Preliminary evaluation of the Spark Fun serial accelerometer brought up several issues. National Instruments LabView software was used to design an application that acquired the serial data and calculated the x velocity and the x position in real time, the GUI is shown in Fig. 9.

While testing this application it was discovered that the accelerometer data was very noisy. This resulted in somewhat random accelerations and, consequently severe position errors. As is visible from this sample of raw data output:

\[
\begin{align*}
X &= -0.049, Y = 0.037, Z = 1.019 \\
X &= -0.062, Y = 0.050, Z = 1.019 \\
X &= -0.059, Y = 0.033, Z = 1.030 \\
X &= -0.036, Y = 0.047, Z = 1.011
\end{align*}
\]

there is a large amount of error in the 100th position as well as significant error in the 100th position. Using the same methods as in (2), we can show that accelerating to 96km/hr over a period of 30sec (estimated for a large truck) results in a constant acceleration of 0.091g. Obviously any error in the 100th position is significant when dealing with such small accelerations. By using a rolling average of 10 samples the error can be reduced to +/- 0.01g.

Unfortunately, using the current process all error is cumulative over time and can be described by (5) [8].

\[
\text{Position Error} = \frac{1}{2} g \cdot \text{error} \cdot \text{Time}^2 \tag{5} \tag{8}
\]

With no means for correction the requirements for the accelerometers become very stringent, ideally accuracy to +/- 0.0001g.

Similar to the noise error, the serial accelerometer is also subject to an offset error (see the sample raw data above). This problem is made difficult by the fact that the offset is not constant, but changes with each test run. The current solution is to take a finite number of samples (using the rolling average method) to determine the offset, then subtract that offset from all subsequent measurements, referred to as “calibrated” measurements. As would be expected, the cumulative effect of the noise and the offset is that the calibrated measurements tend to stabilize at either +/- 0.01 instead of 0. These errors will most likely result in the serial accelerometer being designated as unfit for this application.

VI CONCLUSIONS AND FUTURE WORK

Although the serial accelerometer will most likely be unsuitable for direct position calculation by itself, combining it with another system to remove the cumulative effect of the error is the most probable solution. It also believed that the accelerometers from CrossBow technologies will not be as sensitive to noise, although realistically the data will still have to be corrected for errors. Regardless, the work shows a lot of promise with the primary costs being the LabView software and a PC or laptop computer to run it.

Future work will consist of investigating methods for fusing the accelerometer data with another source for error correction, or exploring alternative technologies such as the optical mouse sensors. Both [8] and [9] provide references to coupling a GPS signal to the system, and performing correction through the use of a Kalman filter. This approach emulates the methods used by some of the high end equipment, products which combine inertial sensors (such as accelerometers or gyro sensors) with DGPS through large (15 state) Kalman filters. Another approach being considered is to measure the x and y accelerations and use the ratio of x and y to determine the direction of the acceleration. While GPS position data is erroneous, the velocity data tends to be much more accurate. Tying the directional data from the accelerometers to the velocity data from the GPS could produce a more accurate position estimate.

REFERENCES

[1] D. W. Callahan, P. Wang, and J. A. Richardson, Location Tracking of Test Vehicles for Bridge Load Rating, ALDOT project# 930-671.