A Rationale for the use of Optical Mice Chips for Economic and Accurate Vehicle Tracking

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Abstract—Accurate vehicle localization is a frequent requirement of tracking applications. Unfortunately cost is often the limiting factor in the selection of tolerable error limits. This paper provides a rationale for using optical navigation chips out of optical computer mice for economic and accurate vehicle tracking. Supporting evidence is provided in the form of a comparative analysis of several tracking technologies. The technologies analyzed include varieties of GPS, accelerometers, laser rangefinders, and optical mouse sensors. The comparative analysis presented in this paper uses a model based on cost, accuracy, speed, and range.

Index Terms—Position, Tracking, Localization, Accelerometers, GPS, Rangefinder

I. INTRODUCTION

Many research and commercial applications require accurate tracking of moving vehicles, localization of assets, or combinations of both. Available technologies include several Global Position System (GPS) varieties such as the extremely accurate Differential GPS (DGPS); as well as a wide variety of others. One constraint of these systems, besides cost, is that the error frequently goes up in proportion to vehicle velocity. Unfortunately the high cost of commercial solutions is often the limiting factor in the selection of tolerable error limits. This paper will provide a rationale for using optical mice chips for vehicle tracking by exploring several technologies that are readily available for purchase. These technologies will be evaluated based on cost, accuracy, speed, and range – and some recommendations will be made for suitable applications based on their performance in these areas.

The comparative analysis presented in this paper is a preliminary step in a project for the Alabama Department of Transportation [1]. While the analysis in this paper is concerned with appropriate applications for the technologies analyzed, the goal of the funded project is the tracking of a moving truck, with 10 cm accuracy, along a test section of road not exceeding 330 m, and including a bridge; while staying below a $1000 price limit. Some of the illustrations in this paper will depict a truck moving on such a test section.

II. PROBLEM FORMULATION

A comparative analysis will be performed of existing technologies. These technologies will be evaluated based on a selection model consisting of cost, accuracy, speed, and range. From the results of this comparative analysis, a case will be made for the use of optical mice chips as an economical alternative that does not sacrifice accuracy.

III. THE EVALUATION MODEL

In order to have an analytical comparison across multiple technologies a standard model must be used. The criteria of most interest to this project are cost, accuracy, speed, and range. These are the components of the evaluation model. These components were chosen because tracking requirements usually specify minimum values for one or more of these.

Based on the previously mentioned funded project, all of the technologies are evaluated against a total cost of $1000. Similarly, 10 cm accuracy is desired, at a maximum speed of 100 km/hr, and over a 330m test section.

IV. TECHNOLOGIES

This comparative analysis will focus on the most promising technologies for the funded project. Although GPS itself is not considered a realistic candidate, although GPS is included in this analysis because of its ubiquity in tracking applications and as background information for the GPS-based varieties that are presented as candidates.

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A. GPS

GPS is an obvious first choice for any outdoor localization problem because of its global coverage, availability, proven track record, and the number of existing tracking applications. In applications requiring high accuracy, however, GPS does not present an ideal solution.

GPS uses a constellation of 29 geosynchronous satellites to triangulate positions, each satellite transmits multiple identification and timing signals of varying accuracy. A GPS receiver requires signal from a minimum of 4 satellites to correctly calculate the receiver’s 3-dimensional global position – position is calculated by comparing the timing in the received signals.

Because GPS relies on satellite reception, GPS based technologies are highly susceptible to obstructions [2]. Given clear weather conditions and minimal horizon obstruction, however, the current maximum accuracy of most consumer units will approach 6-7 meters of accuracy. Since the lane width for most roads in the US are approximately 4 m [3], the error radius is large enough so as to prevent the user from even verifying the vehicle’s position is within the bounds of a standard US lane as shown in Fig. 1. This solution is also well below the 1 m minimum required accuracy. To increase accuracy, corrections must be used. Differential GPS (DGPS) receives corrections signals from local, terrestrial repeaters or through proprietary communication satellite channels from global correction services. While sub 1m accuracy is offered by several companies it is well over the $1000 goal with some units costing $40000.

B. Range Finders

Ultrasound and laser rangefinders can have accuracies better than 1 mm (and low cost) in a single dimension if a suitable surface can be used to reflect the measurement signal. Rangefinders would be a suitable solution for lateral positioning since simple, reflective barriers could be placed along side test roads. However getting longitudinal positioning would require additional work. In order to receive accurate longitudinal measurements (too far for ultrasonic use, therefore lasers must be used), a reflective surface (such as another vehicle) must be placed across the far end of the test stretch. In the case of highway speeds, (100 km/hr), such an obstacle would present significant safety considerations.

C. Accelerometers

Accelerometers are widely available as well as inexpensive and are available with either analog or digital outputs. A pair of accelerometers mounted on a vehicle to continuously measure lateral and longitudinal acceleration should provide a simple dataset from which to calculate xy positions by using the double integral of acceleration as shown in (1) [4].

\[ x(t) = \int \int a(t) dt dt \]  \hspace{1cm} (1)

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. Unfortunately, the external calibration method may limit absolute accuracy of the system. Another shortfall that is a consequence of their self-containment, accelerometers are subject to cumulative error. Any measurement error quickly accumulates between external calibrations. For this reason, accelerometers are widely used in combination with GPS systems to provide estimated tracking during momentary satellite signal loss.

D. Optical Mouse Sensors

Optical Navigation Technology is the current mainstay of the optical computer mouse field. Devices like the ADNS-2610 from Avago (formerly Agilent) [5] provide image capture and advanced image processing capabilities on a single chip. In the mouse application, these devices use LED lighting and a very short focal length lens to produce a suitable image. Due to height and space constraints, a piece lens is commonly used to focus the LED light onto the desktop, while the image is simultaneously provided to the sensor. These devices provide several functions accessible through a standard interface protocol. Through the interface raw pixel grayscale values can be retrieved to “see what the mouse sees.” Of interest to this paper, and the standard application of these devices, are the tracking capabilities. These devices compare sequential images to determine the amount of movement in discrete x and y directions. While the exact algorithms are protected secrets, it is generally assumed that some form of autocorrelation is used.

This processing occurs very fast, some image sensors provide around 6000 fps to the onboard image processor. Given the small sample size (~1 mm2) however, results in max speeds around 40 inches/sec (~7km/hr). While 7km/hr itself is not nearly fast enough, the key lies in the sample size. By replacing the extremely short focal length lens of a standard computer mouse with a much longer focal length lens (10mm) the maximum speed can be increased to
acceptable levels. The next paragraph explains the method for doing this.

An optical mouse chip is built to take measurements in pixels. Converting pixels to inches or cm requires knowledge of the focal length of the lens in use, the height from the lens to the moving surface (the ground), and the resolution of the device. The conversion uses a scalar – the Relative Factor (RF) – by which the device units may be scaled into real world units. The following two equations both describe RF. Equation (2) may be used to calculate RF, while (3) may be used to scale device units (labeled measured_distance) into real world units (actual_distance).

$$RF = \frac{\text{focal\_length}}{\text{height}}$$  \hspace{1cm} (2)

$$RF = \frac{\text{measured\_distance}}{\text{actual\_distance}}$$  \hspace{1cm} (3)

From these equations, the conclusion can be drawn that accurate height measurement plays a critical role in the accuracy of the optical mouse system. In computer mice the height is set by the manufacturer mechanically, but in a moving vehicle the height is continuously varying because of the uneven road conditions and the suspension system of the vehicle itself.

V. ANALYSIS RESULTS

Several of the analyzed technologies were available in the laboratory for testing. These technologies were tested by rapidly developing a test application and any necessary hardware. National Instruments' LabView software and Microsoft Visual Basic were used for rapid development of the test applications. In some cases the only hardware required was a standard serial port. For one test a digital acquisition module was purchased from National Instruments, while another test required some electrical rework.

A. Analog Accelerometer

One of the technologies available for evaluation was a LF series analog accelerometer from Crossbow. The LF series accelerometer has a range from -1 to +1g.

These accelerometers provide an analog, linear voltage/g response [6]. In order to capture the analog data for analysis on a PC in LabView, a USB digital acquisition (DAQ) unit was purchased, specifically a National Instruments USB-6215. The USB-6215 was selected because it provides more than enough channels, and integrates with the LabView software package very well. In LabView, a GUI was quickly constructed to graphically and numerically display the measured data, Fig. 2. Besides providing rapid GUI development, LabView provides a simple, graphical method for performing data capture and analysis.

Analysis of the Crossbow accelerometer found performance to be moderate. At rest a constant noise was present with a magnitude of 0.01g’s, shown in Fig. 4.

Using (4) 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
When dealing with slow accelerations as might often occur in normal driving circumstances, 0.01g becomes significant. From these results it seems that the Crossbow LF series accelerometers are not accurate beyond 0.05g’s and are only suitable for applications with frequent external calibrations.

B. Serial Accelerometer

An alternative to the Crossbow accelerometers is the SerAccel v5 serial tri-axis accelerometer produced by Spark Fun Electronics. 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].

Unlike the Crossbow accelerometers, the LabView package can acquire acceleration data directly from the SerAccel serial accelerometer through direct COM port access rather than requiring an external DAQ.

The GUI designed for the serial accelerometer is shown in Fig. 5. The major concern of this implementation is correctly parsing the string containing the accelerations. As such, this GUI does not display the scrolling graph of the Crossbow’s GUI, but instead has several text fields where the user can verify correct extraction of each of the directional accelerations.

The parsing mechanism is shown in Fig. 6.

In Fig., only the X output is connected for simplicity. Essentially, data is read in 29 byte segments, and divided into three pairs of strings and numbers. The strings are discarded while the numbers are output to the GUI.

The serial accelerometer test results were noisier than the Crossbow accelerometer. While the Crossbow showed small and “constant” deviation, the serial accelerometer was more random. Below is a sampling of data output from the serial accelerometer.

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

The largest fluctuation is in the thousandths position, however the more significant error is the fluctuation of the hundredths position. By using a rolling average of 10 samples the error can be reduced to +/- 0.01g. Unfortunately, accelerometer error is cumulative over time and can be described by (5) [8].

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

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. 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 many applications.

C. Laser Rangefinder

A Laser Rangefinder was also available for evaluation. Like the SerAccel, it used a RS-232 interface to provide
distance measurements. Unfortunately the particular rangefinder available had a published accuracy of 1 yard (~1 m), but it was evaluated anyway. LabView was used again, and a very simple GUI was constructed to display the distance measurements (and provide COM port selection), Fig. 7.

Like the SerAccel, LabView was required to parse an incoming ASCII stream to extract the measurements, as shown in Fig. 8.

As was expected from the published specifications, the Laser Rangefinder was incapable of measuring with sub-meter accuracy and had very poor repeatability for any measurements under 50 cm. While the range of 800 yards (~730 m) is impressive and useful for some applications, less than ideal accuracy limits its usefulness to this project – along with previously mentioned limitations of the technology.

D. Standard GPS

Although standard GPS was ruled out early on, National Instruments provided a LabView package to interface a NMEA compatible GPS unit. As was expected, standard GPS was far below 1 meter of accuracy. There was also some significant time lag in measured speed after acceleration or deceleration.

E. Optical Mouse Chip

Unlike the other technologies, LabView was not used to test the ADNS-3060 optical mouse chip. Based on previous work available online, it was decided instead to build a GUI using Microsoft Visual Basic. Initially a computer mouse was modified for direct interface to an ADNS-1610. More recently, however, a prototype has been purpose built for evaluation. This prototype was built using an ADNS-3060 with a 10mm focal length lens; and was interfaced to a PC through the parallel port. The GUI, shown in Fig. 9, provides controls to power up/down and reset the ADNS-3060, to switch between raw image capture and motion capture, and the ability to switch between resolutions. The GUI also provides a readout of status registers on the ADNS-3060 to verify correct operation.

The ADNS-3060 was mounted inside a prototype housing and tested both inside and outdoors (attached to a vehicle), Fig. 10.

Agreeing with the preliminary calculations, height played a critical role in the accuracy of the prototype during early tests. In order to verify the height was the cause, the vehicle was driven forward and then backward to the same spot. Theoretically the effects due to varying height should cancel out as the vehicle returned to the same spot using the same path. The prototype showed very high accuracy (~12.7 mm over 30.5 m) in this test case indicating that the varying height is indeed a significant issue for this design.

Fig. 11 below shows the last 35 measurements from an indoor test. The indoor test was conducted by mounting the prototype to a rigid cart with extra lighting. From Fig. 11 it is possible to see that while the sensor tracks very closely to the actual distance, there is a slight trend diverging from the actual. Measurements were taken in 30.48 cm (12 inches)
increments over a total distance of 22.25m (73 feet). The average error for that test was 1.07% with a standard deviation of 0.27%.

Fig. 11. Measured inches and actual inches plotted against actual feet.

VI. CONCLUSION

This paper has presented a comparative analysis of vehicle tracking in two ways. First, an introduction and theory of operation was provided along with an analysis based on published specifications and prices for each technology. Based on this analysis and available literature, strengths and weaknesses were suggested for each technology along with some recommended applications. Second, this paper presented a laboratory analysis of several of the technologies. This laboratory analysis included software and hardware interface design, and testing. The results of both analyses have been summarized below in Table I.

All of the analyzed technologies would be suitable for vehicle tracking of varying levels of accuracy. Of the tested technologies, the optical mouse chip is the only one that shows any promise of delivering sub meter accuracy within the desired price range. Although the accelerometers would most likely be unsuitable for direct position calculation by themselves, combining either with another system to remove the cumulative effect of the error is the most probable solution. It also believed that higher grade accelerometers from Crossbow technologies will not be as sensitive to noise, although realistically the data will still have to be corrected for errors.

Table I provides a centralized comparative analysis of the examined technologies. While each of the technologies was evaluated against the model individually, it is the author’s hope that the presentation of Table I aids the reader in comparing the technologies side by side.

While testing of the first optical mouse – based prototype revealed several weaknesses, the research team at UAB is already testing an updated prototype with new features to overcome these problems. The new features include an integrated rangefinder to accurately and continuously measure height as well as a medium range wireless radio to transmit data in near realtime.

<table>
<thead>
<tr>
<th>Table I – A Side by Side Comparative Analysis</th>
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<tr>
<td>Technology</td>
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REFERENCES

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