Location Tracking of Test Vehicles Using Accelerometers

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Abstract: - This paper proposes a cost effective solution to localized mobile positioning with high accuracy requirements when high grade GPS is cost excessive or unavailable. Specifically this solution is targeted for accurate position determination of test vehicles on a known stretch of bridge.

Key-Words: Position, Tracking, Localization, Accelerometers, Vehicle, GPS, Rangefinder

1 Introduction

The Alabama Department of Transportation (ALDOT) must continuously evaluate the condition of local bridges in order to keep the maximum load ratings as high as is safely possible. The testing of these bridges involves the driving of special, heavy, test trucks over the bridge at various speeds while monitoring strain gauges placed at critical locations on the bridge. Analysis of the strain data can be correlated (through time) to the longitudinal and lateral (x and y) position of the truck on the bridge to provide detailed information about the current condition of the load bearing structures in question. Currently the x-y position is estimated by an observer using calibration lines painted on the bridge as an ALDOT worker directs the truck driver to follow the lines. While this method provides a reasonable estimate of position for the low speed (about 5 mph) test, it cannot be used on the high speed test which is performed at 50 mph. Also, the initial setup of the current method requires the measurement and painting of tracking lines on the bridge.

This paper considers several proposed methods for xy position tracking, with a more in-depth discussion of the method currently being researched. As a design requirement, all of the methods must be cost effective, use off-the-shelf components, and provide for portability and easy setup and take down [1].

2 Problem Formulation

The problem consists of tracking the xy position of a single truck moving at up to 50 mph across a bridge. The xy position must be measured for the entire time the truck is on the bridge with a desired minimum accuracy of 2 inches as shown in Figure 1. (Because this project's requirements are in English measurement units, all subsequent measurements will be in English units.)

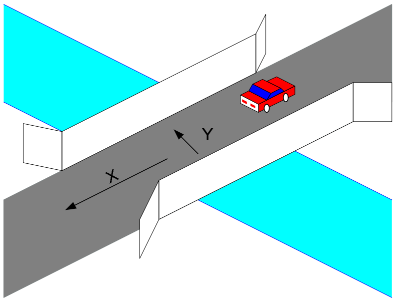

Fig. 1: Truck relative to x and y position

2.1 Proposed Solutions

Several solutions to tracking x and y have been proposed. A discussion of each solution is presented below.

2.1.1 GPS

Global Positioning System (GPS) is an obvious first choice for any outdoor positioning 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 30 ft for non-military applications [2]. 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 12 ft without correction for atmospheric conditions, and approximately 9 ft with corrections. Since the lane width for most roads in the US are approximately 12 ft [3], 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 Figure 2. The GPS is therefore well below the 2in. minimum required accuracy. Although greater accuracy can be achieved through techniques such as Differential GPS, the equipment costs and setup time can be excessive.

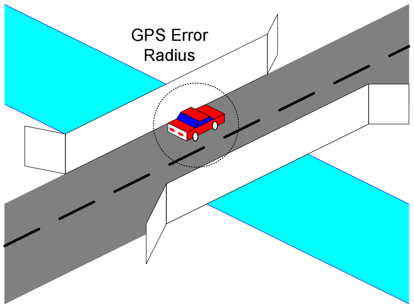

Fig. 2: Accuracy window of GPS

2.1.2 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 side of the bridge could be used to provide a suitable built-in reflection surface. 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 must be placed across the far end of the bridge, as shown in Figure 3. In the case of the high-speed test (50 mph) 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 refection surface.

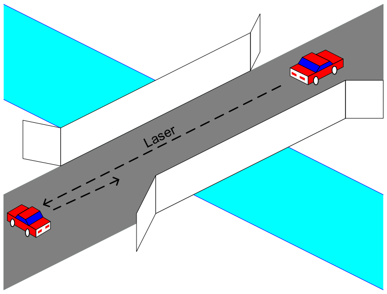

Fig. 3: Range finder with reflection surface

2.1.3 Accelerometers

Accelerometers are widely available and 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 the xy positions by using the double integral of acceleration as shown in Equation 1 [4].

$$x(t) = \iint a(t)dtdt \qquad (1)$$

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. In the high speed test, the driver begins the run approximately one (1) mile before the bridge in order to reach sufficient speed making it necessary to measure accelerations the entire time (even off the bridge) 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 Figure 4.

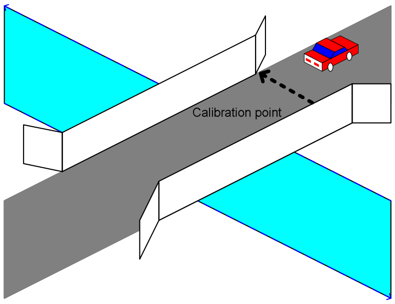

Fig. 1: Using a laser start signal

3 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 1) retrieving meaningful acceleration data, 2) calculating the xy position, 3) calibrating the xy position and 4) transmitting the data to the data acquisition for the test equipment.

3.1 Retrieving Meaningful Data

Assuming a maximum acceleration of 0 to 60 mph in 5 seconds the acceleration can be calculated as shown in Equation 2.

$$60MPH * \frac{1.47\,fps}{MPH} * \frac{1}{5\sec} = 17.64\frac{feet}{\sec^2}$$
$$17.64\frac{feet}{\sec^2} * \frac{1g}{32.2\frac{feet}{\sec^2}} = 0.56g \qquad (2)$$

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 0-0.56g incorporates significant margins. The 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 60mph and a steering correction of 10 degrees is applied, the acceleration can be calculated as shown in Figure 5 and Equation 3.

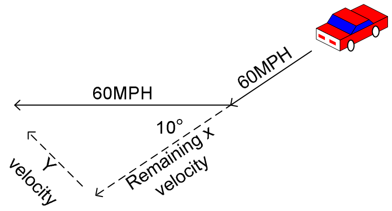

Fig. 2: Steering correction accelerations

$$\sin(10) = \frac{y}{60MPH} \qquad (3)$$
$$y = 10.42MPH = 15.3\,fps$$

Since the acceleration is instantaneous, the y velocity magnitude becomes the y acceleration magnitude.

$$\frac{15.3\,fps - 0\,fps}{\sec} = 15.3\frac{feet}{\sec^2}$$
$$15.3\frac{feet}{\sec^2} * \frac{1g}{32.2\frac{feet}{\sec^2}} = 0.48g \qquad (4)$$

Taking into consideration the bounds calculated for x and y accelerations, a reasonable range of 0 to 0.5g can be established for accelerometers.

Currently this project is evaluating LF series accelerometers by CrossBow Technologies, as shown in Figure 6, which has a range from -1 to +1g. These accelerometers provide an analog, linear voltage/g response [5]. An alternative to the CrossBow accelerometers is the SerAccel v5 serial tri-axis accelerometer produced by Spark Fun Electronics as shown in Figure 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 [6].

Fig. 3: Crossbow Accelerometer

Fig. 4: Spark Fun Accelerometer

The project is currently investigating the LabView software by National Instruments to perform data acquisition and calculations. National Instruments provides various digital acquisition (DAQs) modules for analog signal acquisition. The use of this software package can acquire acceleration data directly from the SerAccel serial accelerometer, while the use of a DAQ would allow acquisition of the CrossBow analog acceleration data.

3.2 Calculating position

Acceleration is the 2nd derivative of position or, more relevantly, position is the 2nd integral of acceleration (Equation 1 repeated). 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.

3.3 Calibrating the position

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 may be over one (1) mile 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 Figure 8. A laser would be projected across a calibration point on the bridge, most likely close to the beginning as shown in Figure 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.

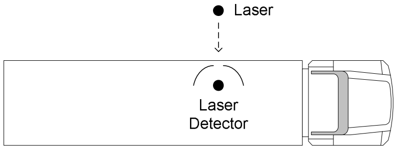

Fig. 5: Calibrating system

3.4 Transmitting the data

ALDOT requires real-time data to their collection point. LabView provides several means for storing and transmitting data. With full TCP/IP networking access as well as Serial (RS-232), Bluetooth, and IR-DA support there are several means for transmitting data directly from the software to a remote system. One difficulty with this requirement is the subsequent requirement for a communications system that can transmit the data while the truck is mobile and possible further than one mile away.

4 Conclusion

The problem of developing a localized mobile positioning with high accuracy requirements for load testing on bridges has been described. The possible alternatives, including GPS, have been discussed. A proposed solution has been presented which uses accelerometers to capture acceleration data and then integrates to get the position has been proposed. The design includes the analysis for the accelerometer specifications and the calibration of relative to fixed positions.

The presented approach does present several problems. As described in [7], using raw accelerometer data to derive position is subject to cumulative error. Although methods exist to correct this error, [7] and [8], they have not been thoroughly evaluated yet, and involved external sources for error corrections.

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