A Method for Relative Position Tracking of Vehicles Using Optical Navigation Technology

JOSHUA D. JACKSON, DALE W. CALLAHAN, JON MARSTRANDER
Department of Electrical and Computer Engineering
University of Alabama at Birmingham
Birmingham, AL 35294
USA

PERCY F. WANG
Department of Mechanical Engineering
University of Alabama at Birmingham
Birmingham, AL 35294
USA

Abstract: - This paper proposes a new and unique as well as cost effective solution for applications which require high accuracy relative tracking and for which GPS solutions are cost excessive or inappropriate.

Key-Words: Position, Tracking, Localization, Optical Navigation, Vehicle, GPS

1 Introduction

The goal of an ongoing research project funded by the Alabama Department of Transportation (ALDOT), is to develop an accurate yet economical vehicle tracking system. Unlike some applications, this tracking system need only provide position data with respect to the starting point (relative tracking) instead of systems that provide position data in terms of global coordinates (absolute tracking). This paper will discuss the use of Optical Navigation Technologies as the tracking mechanism. Optical Navigation Technology is most prevalent in optical computer mice. The system discussed is designed to the meet the project requirements [1]. This paper is an extension of previous investigations into available technologies [2], [3].

2 Problem Formulation

The problem consists of tracking the xy position of a single truck moving at up to 60 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. Figure 1 shows the truck relative to the bridge's x and y positions. (Because this project's requirements are in English measurement units, all subsequent measurements will be in English units.)

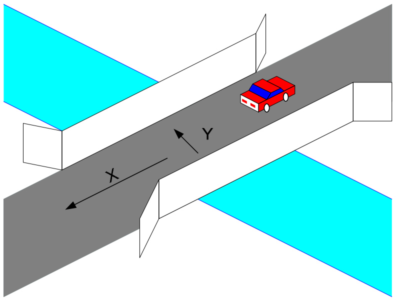

Fig. 1: Truck relative to x and y position

2.1 Proposed Solutions

As discussed in [2] and [3], several solutions to this problem have been proposed, including GPS. Because of the widespread use of GPS this paper will briefly address the drawbacks of using GPS, however the central focus will be on the application of Optical Navigation Technology to this problem. Other technologies considered in [2],[3] included inertial navigation using accelerometers, laser systems, and ultrasonic range finders.

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 [4]. 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 [5], 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. This solution is 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.

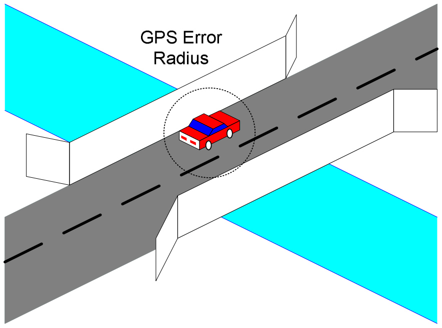

Fig. 2: Accuracy window of GPS

2.1.2 Optical Navigation Technology

Optical Navigation Technology is the current mainstay of the optical computer mouse field. Devices like the ADNS-2610 from Avago (formerly Agilent) [6] 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 one piece lens is commonly used to focus the LED light onto the desktop, while the image is simultaneously provided to the sensor, Figure 3.

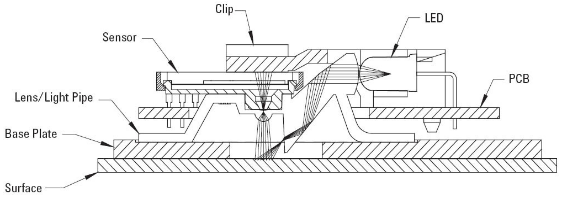

Fig. 3: A typical optical mouse setup (Courtesy of Avago Technologies [6])

These devices provide several functions which are 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 project, 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 kept secret, 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, resulting in max speeds around 80 inches/sec (~7km/hr). While this may not seem very fast, the small sample size (~1/4 inch^2) must be taken into account.

Like the pixel values, the magnitudes and directions of the movement are read through the standard interface. The device accumulates motion between reads in onboard registers which are cleared when read.

2.2 Relative vs. Absolute Tracking

This paper discusses a design for a relative tracking solution. It is important to distinguish this from an absolute tracking solution. Absolute tracking systems provide data in the form of geographical coordinates. One example would be a GPS receiver. The output is a stream of longitudes and latitudes. Relative tracking systems on the other hand, provide coordinates with respect to an arbitrary point. This might be the starting point of the measurement; or it might be the midpoint between radio emitters (for triangulation systems).

3 Proposed Application

The discussion of the proposed application of Optical Navigation Technology to vehicle tracking will be divided into several sections: 1) proposed design, 2) extracting real world units, 3) operating characteristics and the problem environment, 4) calibrating the xy position and 5) transmitting the data.

3.1 Proposed Design

As shown in Figure 4, the proposed application will consist of a layout somewhat different from the typical mouse layout shown in Figure 3. While the chip will continue to be used in a "look down" configuration, a new lens will be used to allow the chip to process images of the road surface from a much greater height.

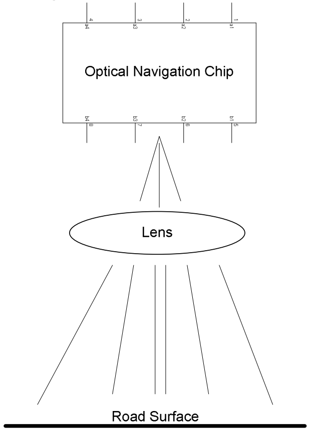

Fig. 4: Proposed Layout

This layout would consist of a PCB with the optical navigation chip and supporting circuitry combined with a lens of longer focal length (than used in computer mice). The focal length would have to be suitably long to focus an image of the road surface onto the optical navigation chip's image aperture from a typical truck's bumper height (20-40 inches). This increase in height along with a new lens results in a larger sample area, increasing the maximum speed capabilities of the proposed device.

3.2 Extracting Real World Units

Similar to the application of real world units to aerial photographs, the motion units of the optical navigation chip must be converted to real world units. This can be accomplished using the same equations used in aerial photography. The equations rely on an accurate knowledge of the actual height from the lens to the surface and the distance in device units as well as in real world units. To make some of the calculations it is also required to know the resolution of the device's image sensor. The ADNS-3060 supports two modes, 400cpi and 800 cpi (counts/inch) [7]. This example will consider 800cpi with a 10mm focal length lens, and a height of 22 inches where device units are in counts.

The following two equations describe RF, the Relative Factor, note that they must be in the same units in order for RF to be unit-less.

$$RF = \frac{focal\_length}{height} \quad (1)$$

$$RF = \frac{picture\_distance}{actual\_distance} \quad (2)$$

First the RF is calculated using the known focal length and height applied to Equation 1.

$$RF = \frac{0.393700787}{22} = 0.0178955$$

By normalizing to 1 inch actual distance, a calibration factor can be calculated by which device units (counts) can be converted into inches (for a height of 22inches only).

$$1inch * RF * 800\,{}^{counts}\!/_{inch} = 14.316$$

The result of this calculation is that all future measurements in counts from a height of 22 inches can be converted to inches through simple division by 14.316. Similarly, 1 inch of actual motion corresponds to 14.316 device units.

3.3 Operating Characteristics and the Problem Environment

Along with budget and availability constraints, any proposed solution must be robust enough to survive in the target environment. In this case the environment is an outdoor and mobile one. The end solution will be mounted to a moving test vehicle and must survive outdoor temperatures as well as vehicle vibration. As solid state devices, there are no moving parts to come loose or fall off. Already designed to withstand daily use in a desktop computing environment, these devices present a robust solution platform.

Another concern is the performance limitations of the optical navigation chips. An ADNS-3060 has a published maximum speed capability of 40 inches/sec [7], or 2.7mph which is a far cry from the 60mph goal. As stated previously, however, the proposed design greatly increases the image sample size, thereby increasing the maximum speed capabilities. Using the same equations as in 3.2, it is possible to solve for the maximum speed.

$$40\,{}^{inches}\!/_{\sec} * 800\,{}^{counts}\!/_{inch} = 32000\,{}^{counts}\!/_{\sec}$$

$$60mph = 1056\,{}^{inches}\!/_{\sec}$$

$$1056\,{}^{inches}\!/_{\sec} * RF * 800\,{}^{counts}\!/_{inch} \approx 15200\,{}^{counts}\!/_{\sec}$$

The first calculation is to convert the published maximum speed to device units, or counts/sec. This is important because the published speed is in inches/sec and assumes the layout in Figure 3. The next calculations take 60mph and convert it to device units, or counts, using the RF from 3.2 which assumes a height of 22 inches. One conclusion that can be made from these calculations is that as the height increases that maximum speed will increase.

Another concern in the problem environment is lighting. The typical mouse setup (as in Figure 3) includes an internal light source. The proposed layout makes no allowance for an internal light source. In fact this design simply counts on the Sun being the primary light source. This places a limitation on the use of the design. For nighttime uses, lighting will have to be provided.

3.3 Calibrating the position

As stated earlier, this solution provides position relative to the starting point. It is necessary, therefore, to provide a means to relate the starting position to a known point in the test area. This is not an issue when the vehicle can be started from the same location repeatedly. However in high speed environments it is possible that test vehicles will require space outside the area to build up speed before entering the test area.

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.

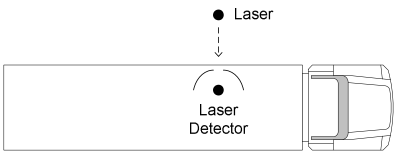

Fig. 3: Calibrating system

3.4 Transmitting the data

Different applications will have different requirements for handling the tracking data. For the ALDOT project currently being researched, they require an analog signal at a stationary command vehicle near the test site. In this case equipment must be selected with appropriate transmission ranges to maintain communications during tests as well as additional equipment purchased or designed to convert the position data to an analog signal.

4 Conclusion

Some preliminary work shows promise. The key is to develop a suitable lens system to correctly focus the image and ambient light onto the image sensor correctly. Early prototype work shows promising image quality and tracking accuracy. Future work will involve testing a prototype outdoors on a moving vehicle as well as extensive error testing.

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