AUTOMATIC HEADLAMP SWITCHING SYSTEM USING ACCELEROMETERS

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Abstract: This paper presents a two-sensor method to enhance the nighttime driving safety. It consists of two accelerometers and an array of auxiliary swiveling headlamps. An alpha beta filter is proposed to stabilize the readings of the accelerometers. With the kinematics of a turning car, the cars turning path is predicted based on the steering angle measured by the accelerometers so that the relevant auxiliary swiveling headlamps will be switched on accordingly. In this paper, we will study the performance of the alpha beta filter. Test results demonstrate that our angular measurement method is an efficient way for proper road illumination along curved paths.

1 INTRODUCTION

Improving nighttime illumination is a crucial step for traffic safety (Plainis et al., 2006). Although the development of headlamp system has drawn much attention recently, many issues remain unsolved. The direction of headlamps should be able to change according to curved paths to enhance drivers visibility. When a car starts to make a turn, the focus of the driver should be on a curved path. In addition to the front direction, the headlamps should be able to illuminate along the curved road before the cars turning to ensure that there is no obstacle along the path. BMW also utilizes this kind of technology called adaptive headlights (Adaptive Headlights); the direction of headlamps is determined by the internally measured front wheel direction. In this paper, the relationship between the steering wheel angle and the moving direction of a car is studied, so that the moving direction can be measured by vehicles other than BMW. The cars moving path is then predicted by a simple car model. The direction of the headlamps is determined.

The major contribution of our work is to design a method for determining the illuminating direction without the knowledge of path history and digital map data. Since the method does not depend on the path history and digital map data, the system can respond immediately even if the drivers do not follow the path history or the digital map data is not up-to-date. It is also more robust when compared with traditional approaches because the data used to determine the illuminating direction is collected inside the car but not from the road scenes or Global Positioning System (GPS) signals which are unstable and easily affected by environment. Moreover, the system can predict and illuminate the cars turning path to provide enough time for the driver to react and prevent accidents. It emphasizes on a simple but robust approach to improve curved path visibility in real-time.

2 RELATED WORKS

Predictive advanced front lighting system (P-AFS) (Ibrahim, 2005) is proposed to determine the path that a vehicle is most likely to drive. The path is determined by using the current position of the vehicle, a digital map and the current vehicle data such as speed. After analyzing those data, the headlight beam direction is found. The headlamps will be swiveled accordingly to keep the kink point of the beam in the center of the road. Clearly, the performance of the P-AFS depends on the digital map and GPS signals. If the digital map is not up-to-date

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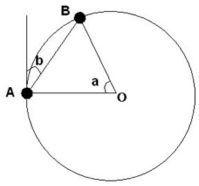


Figure 1: The circular motion of a turning car.

or the GPS signal is not stable, the performance of the P-AFS will be affected.

(Morishita et al., 2007) investigate the drivers preferences for headlight swivel angles on the test track at the DENSO Abashiri Test Center in Hokkaido. The preferences are then used to estimate the optimal swivel angles by multiple-regression model. Also, this study shows that the headlight swivel should be predictive. This approach is based on path history to determine the optimal swivel angles. The system wont work if the driver does not follow the path history or the path history is not available. Also, to locate the position of the car, a reliable navigation system is needed.

3 KINEMATICS OF A TURNING CAR

A simple car can be considered as a rigid boy. Adopting the symbols from (LaValle, 2006), the angular velocity of the car is

$$\dot{\theta} = \frac{u_s}{L} \tan u_\phi \tag{1}$$

When the car is turning around a corner, it performs circular motion. In Figure 1, if the car is turning from point A to B in the period of time t, the angle between point A and B at the center O is

$$a = \dot{\theta} t \tag{2}$$

Assume the angles of the two front wheels are the same. The ratio between the angle of the front wheels and the angle of the steering wheel is fixed in most vehicles. If the ratio is r and the angle of the steering wheel is u_α, the angle between the tangent at point A and the line joining point A and B is

$$b = \frac{u_s t}{2L} \tan(u_\alpha r) \tag{3}$$

4 HEADLAMP DIRECTION PREDICTION

As discussed in section 3, the position of the car on a curved path can be predicted by Equation (3). The point A and B in Figure 1 correspond to the current and predicted positions of the car on a curved road. The predicted position is a place where the driver should pay most attention to. It should be as close to the car as possible so that any unexpected incident near the car can be discovered, reacted and avoided. The distance between the current and predicted positions turns out to be the car stopping distance. If the driver uses time t_R to react and the car undergoes constant deceleration (d) along the curved path to avoid accident, the predicted direction of headlamp is

$$b = \frac{u_s \left(t_R + \frac{u_s}{d}\right)}{2L} \tan(u_\alpha r) \tag{4}$$

Typically, the deceleration rate is $3.4 m/sec^2$ and human reaction time is 2.5 seconds (Transportation Research Institue, 1997). The general speed limits in build-up areas are around 40-60km/h (Legislative Council Panel On Transport, 1999). Based on the car configuration, the possible range of headlamp directions can be calculated by Equation (4). Then, an array of headlamps, in which each headlamp has a continuous illuminating angle, can be installed in the car. Each headlamp can be switched on according to the instantaneous speed u_s and the steering wheel angle u_α of the car.

The instantaneous speed can be easily obtained from the speedometer of the car. To measure the steering wheel angle of the car, two accelerometers are used to provide an accurate and stable angle.

4.1 Steering Wheel Angle Measurement

To measure the angle of the steering wheel, a two-axis accelerometer (A1) is attached to the center of the steering wheel with the x-y plane parallel to the steering wheel plane. Another two-axis accelerometer (A2) is installed such that one axis is parallel to the line of intersection of the ground plane and the steering wheel plane.

Initially, the X-axis and Y-axis of the accelerometer A1 are placed horizontally and vertically on the steering wheel surface respectively. The horizontal acceleration A_h of the car is measured by A2. If the X-axis and Y-axis acceleration rates measured by A1 are A_x and A_y respectively, the steering wheel angle u_α is

$$u_\alpha = \arctan\left(\frac{A_x}{A_y}\right) - \arcsin\left(\frac{A_h}{\sqrt{A_x^2 + A_y^2}}\right) \tag{5}$$

4.2 Steering Wheel Angle Stabilization

To stabilize the sensor readings measured by A1 and A2, a running average algorithm with T data points is

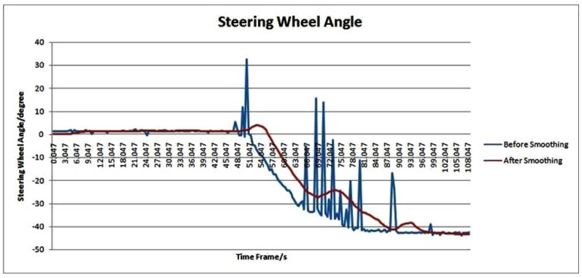


Figure 2: Sensor readings from A1 are stabilized by the running average algorithm.

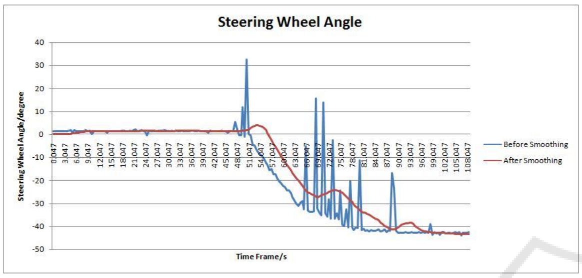


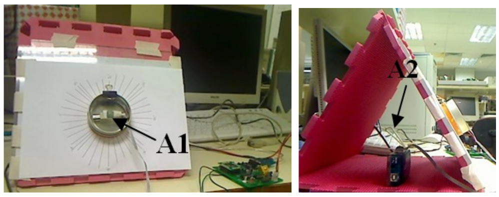
Figure 3: Steering wheel angle after smoothing using alpha beta filter.

adopted. The running average of a sensor reading A(i) at time i is calculated by Equation (6). Subsequently, the rotational acceleration of the steering wheel generated by the driver which is treated as a short-term fluctuation is removed by applying the alpha beta filter (Penoyer, 1993) on the steering wheel angle. The alpha beta filter is employed because it is fast in computation and requires only the previous state for estimating the next state. As described in Figure 2, the sensor readings from A1 are stabilized by the running average algorithm. Figure 3 shows the steering wheel angle which is smoothed by the alpha beta filter.

$$A(i) = \frac{1}{T} \sum_{k=i-T+1}^{i} A(k) \tag{6}$$

5 EXPERIMENTS

In the proposed approach, the predicted direction of headlamps is calculated by Equation (4). In Equation (4), there are typical values for all the variables except the steering wheel angle. So, the accuracy of the direction mainly depends on the steering wheel angle. To test the accuracy of the measured steering wheel angle, several experiments were conducted in a simulated car environment.



(a) Front view (b) Side view

Figure 4: Experiment setup.

5.1 Experiment Setup

A circular disc was affixed on an inclined plane at an inclination angle of 60°. Two accelerometers (ADXL322) were attached to the center of the disc and the ground plane respectively. The experiment setup was shown in Figure 4.

There were two sets of experiments. In the first set, the system was tested under 4 different angles ($-45°$, $-90°$, 45°, 90°). In each test, the disc was rotated from 0° to a specific angle five times. During the test, the plane was vibrated manually to simulate the car vibration on a rough and curved road. In the second set, the disc was first rotated to one of the 4 different angles ($-45°$, $-90°$, 45°, 90°). The plane was then vibrated manually to test the stability of a fixed steering wheel angle.

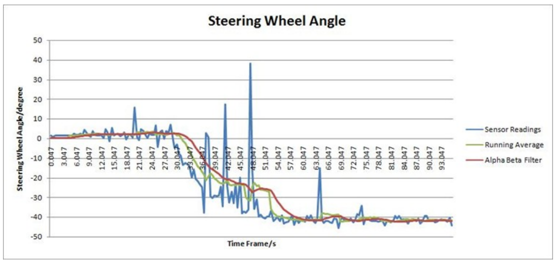
The best results were achieved when the parameter T in Equation (6) was set to 10. The parameters alpha and beta in the alpha beta filter were set to 0.2 and 0.01 respectively.

5.2 Evaluation Results

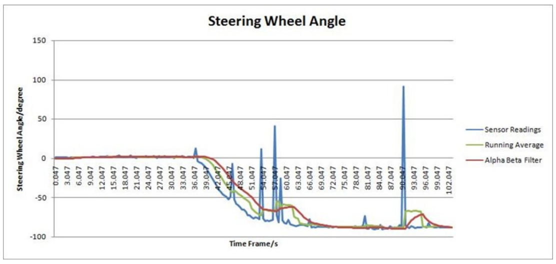
The angular transitions of one trial in each test are shown in Figure 5. Among the tests, our system can successfully remove the noise and fluctuations from the sensor readings. Table 1 shows the root mean square deviations (RMSD) at specific angles while vibrating. The results are reliable and robust to car vibration on uneven and curved roads. There is a real time demonstration available at http://www.cse.cuhk.edu.hk/~kcchan/stabilization.avi

6 CONCLUSIONS AND FUTURE WORK

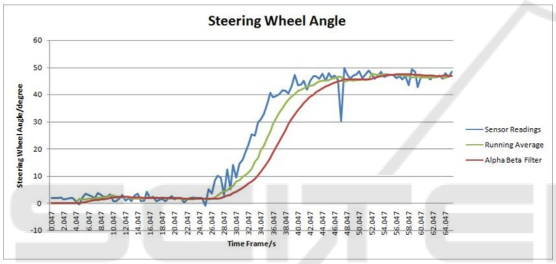
We have presented a novel method to determine the headlamp movement direction when the car is turning. Without using any path history or digital map data, the directions of headlamps on curved paths are predicted based on the steering wheel angles. Two accelerometers are coordinated to measure the steering



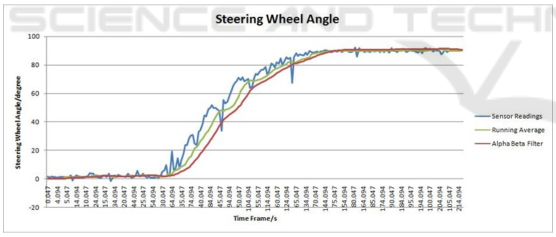
(a) The first trial rotating from 0° to −45°



(b) The first trial rotating from 0° to −90°



(c) The first trial rotating from 0° to 45°



(d) The first trial rotating from 0° to 90°

Figure 5: The angular transitions of one trial under specific angles.

wheel angles. The sensor readings can successfully be stabilized using the running average algorithm and alpha beta filter. The evaluation results under a simulated environment are promising. In the future, the system will be implemented on a vehicle to evaluate the illumination effectiveness under corners with different radii. The simple turning car model can be improved later for better modeling of car turning.

Table 1: The root mean square deviations (RMSD) at specific angles.

	−45°	−90°	45°	90°	Overall
No. of Samples	214	229	226	257	926
RMSD (degree)	4.66	4.50	1.51	1.07	3.30

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