An Inertial/Vehicular-Based Driver Situation Monitoring System in Vehicle Driving Assistance

C. W. Hsu, M. K. Ko, C. H. Chen, L. Y. Ke and C. F. Hung

***Abstract*—Many accidents were happened because of habitual working overtime or tired spirit. This paper presents a methodology of remote warning for driver situation system using inertial and vehicular data. The development system integrates vehicular data and inertial information with embedded system into a research platform using IXP processor in linux system. To sense driver action, the steering angle sensor is adopted via controller area network. An inertial measurement unit is installed on a demonstrated vehicle, and the lateral acceleration is trigger and captured with attitude projection in this study. The processing method comprises of construction of driver model based on autoregressive exogenous method, quaternion and kalman filter using driving data. Driving data with s-cure and lane change motion using demonstrated vehicle was test in highway and express way. From inertial data and vehicular information, this paper provided a warning detection algorithm with learning parameters to do remote warning. The proposed system is carried out with theoretical application and hardware integration, and furthermore the result shows driver monitoring approach applicability.**

I. INTRODUCTION

ACCORDING to statistics data of National Highway Transportation Safety Administration (NHTSA) [1],[2], the majority accidents are result from driver himself/herself who has low attention in driving. The inattentive driving may be caused by many factors, including drivers talking on cell phones (30 percent increased risk of danger), dial phone (3 times increased risk of danger), asleep (4 times increased risk of danger), pick up moving objects (nine times increased risk of danger) and other acts. To effectively reduce the inattentive driving caused the accident and ensure safety, many design and related products have been proposed, such as lane departure warning system (LDW), forward collision warning system (FCW) by image processing methods to determine the lanes and the departure possibility relative to lanes in front of camera capture information. When vehicle deviates under threshold value, system will remind driver through the warning light or buzzer.

In addition to lane departure warning system, there are also other ways to monitor driver to determine whether drivers concentrate on driving. Such as fatigue detector from Attention Technology [3], it produces bright and dark in pupil reaction. The pupil image is processed to detect the location and determine driver's state according to eye closure of PERCLOS (PERCentage of eyelid COLSure). However, its prices is too expensive, and only at night. Too solve the drawback of LED budget; Australia Seeing Machines use two cameras and develop FaceLAB to capture characteristics of head, moreover they analyze the behavior of the driver's state by eye tracking and blink under the eye gaze direction [4]. However, the subjects must be corrected before the test program. In addition, FaceLab is a set of personal computer operating platform for the research and analysis system and it can't be directly installed in all types of vehicles.

We have presents image-based driver monitoring system using single camera in ARTC research. The derived algorithm from AdaBoost method is applied by detecting the driver's face to determine whether the driver concentrate on driving and focus on the front direction [5]. Eventually, the system determines warning level and alert by logic rules of driver's state. The concept has been achieved at low cost DSP platform, and it is easier to apply in a variety of different types of vehicles compared to DD850 or FaceLab products. In addition, regardless of day or night, all-weather monitoring of this system can achieve the function.

The proposed system uses an embedded system to operate as a driver situation monitoring system (DSM) and to manipulate vehicular and inertial sensors instead of camera-based system. Unlike the above methods, this paper presents a new method to judge by detecting vehicle motion to determine whether the driver concentrate on driving without directional light signal. A hybrid method is adopted and the collected data are processed with suitable method filter.

II. DRIVER SITUATION MONITORING SYSTEM

A data fusion of DSM platform is built of three mainly components, including platform unit, on-board diagnostic (OBD) unit and inertial measurement unit (IMU) in demonstrated vehicle. The architecture of the proposed

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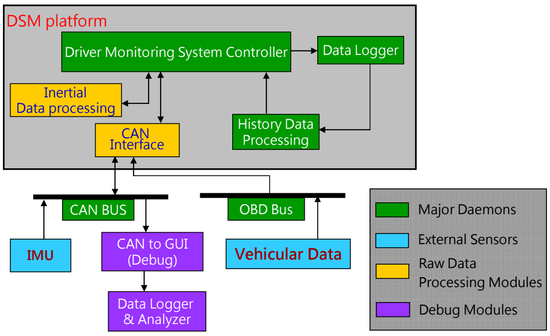

Fig. 1. The architecture of driver situation monitoring system.

system is shown in Fig. 1 below. The DSM strategy is completed by means of data fusion using OBD data variation and IMU information in vehicle motion to define a warning level. Fig. 1 shows the external sensors which is connected to different bus, such controller area network (CAN) bus [6] and OBD bus [7]. The fabricated circuit board has two local networks. The CAN bus is designed and built in self-defined protocol, but the vehicular data acquisition from OBD bus should refer motor standard. One network is used to transmit scheduled data, and the other function utilizes this interface to get required data from vehicular network. All of network information is processed and logged into platform unit. Hence, the delicate timing scheme is well-done before system operation. In research process, the debugger interface is used to display warning or interested data. This paper will present and focus how to design, integrate and analysis DSM information, as in [8], [9], [10].

A. *The Proposed System Architecture*

The system technology proposed a system configuration using embedded system to operate as a control system to manipulate OBD unit, IMU unit and platform operation for driving monitoring function. A IXP processor is the mainly adopted controller, where the embedded kernel to access data input and output is programmed. To fulfill the proposed DSM application, IMU data as well as vehicular data are processed in specific logic, digital formats and sent through can bus in controlled intervals. The data packet is formed up in IXP processor from the peripheral sensors as well as GPS. Each data packet is collected and logged to CF card within each cycle of data surveillance. Meanwhile, the processor is activated by embedded linux system.

To fulfill the proposed vehicle monitoring application, steering angle data as well as inertial data are processed in specific logic, digital formats and sent through CAN bus in controlled intervals. Each data packet is less than 8 bytes using standard ID (11 bit); moreover, the refresh time of packets is about 20ms. The CAN transceiver is the interface between the CAN protocol controller and the physical transmission line and it is one of the key factors influencing the capability of network system. It is fully compatible with the “ISO 11898”.


Fig. 2. IMU circuit board which is installed in trunk.

B. *Inertial Measurement Unit*

An IMU is a closed system that is used to detect altitude, location, and motion. It normally uses a combination of accelerometers and gyroscopes to track the vehicle motion in attitude and location. The IMU is capable to transmit inertia data from core to IXP, where the interface is full duplex UART2. In order to output vehicle spatial states, it is accomplished by integrating an output set of sensors, such as gyros and accelerometers. Gyros measure angular rate with reference to inertial space, and accelerometers measure linear acceleration with respect to vehicle’s frame. The IMU utilizes a tri-axis accelerometer and three one-axis gyroscopes as inertial measurement components. The accelerometer is measured for X-Y-Z axis; while the gyros are assigned to X-Y-Z axis correspondingly. The IMU plays a full inertial function for vehicle in real time, as shown in Fig. 2. The IMU is packed into a box which is located in trunk, and furthermore inertial sensor should be set in right direction. The IMU provide precise attitude to project 3-axes acceleration onto y-axis acceleration. The third part of Fig. 2 is GPS antenna whose module outputs vehicle heading.

The ADXRS614 operates on the principle of a resonator gyroscope. The output signal of ADXRS614 is a voltage proportional to angular rate about the axis normal to the top surface of the package. With the increase of the rotation rate, the output voltage leaves the neutral point [ADXRS614 Datasheet, Analog Devices Products Inc., UK, web: http://www.analog.com/]. An external capacitor is used to set the bandwidth. Use external capacitors in combination with on-chip resistors to create two low-pass filters to limit the bandwidth of the ADXRS614’s rate response. ADXL330 is made by the principle of resonant accelerometers. It can measure both dynamic acceleration (e.g., vibration) and static acceleration (e.g., gravity). The outputs are analog voltages proportional to acceleration [ADXL330 Datasheet, Analog Devices Products Inc., UK, Rev. A., 2003. Available on web: http://www.analog.com/]. This sensor is capable of measuring both positive and negative accelerations to at least ±3 g. Because the signal measure from the accelerometer is analog, it may be disturbed by external noise. According to specifications, the external capacitor can be chosen to determine the bandwidth of the accelerometer, e.g., 0.47μF capacitor for 20 Hz is used in this paper.

C. *On-Board Diagnostic system II Unit*

The amount of electronic devices in vehicles is connected and diagnosed by CAN bus. In DSM platform, data is transmitted or received by CAN bus. CAN is a serial, asynchronous, multi-master communication protocol for connecting electronic control modules, sensors and actuators in automotive and industrial applications. CAN-based system is based on the broadcast communication mechanism which is achieved by using a message oriented transmission protocol. The bit rate of CAN bus is up to 1 Mbps and is possibly operated at network lengths below 40 meter. In this study, the data rate is 500 kbps and its sampling point is held in 75%. Each unit is implemented, and the ECU is embedded CAN controller and it adopts NXP TJA1040 as the transceiver. CAN transceiver is the interface between the controller and the physical transmission line and it is one of the key factors influencing the capability of network system.

Vehicular information usually is packet with scheduled timing in OBD II connector after 1995, and the demonstrated vehicle provides many kinds of signals, such as ESP information, ABS signals, and brake states and so on. This paper adopts steering angle and directional light signals to detect driver behavior. The OBD II connector usually locates near brake/throttle under steering, and the connector is D-type and 16 pins with CAN interface. In Fig. 3, the left part is DSM platform and left is the OBD II connector which is used to capture vehicular information.

III. PRINCIPLE OF SYSTEM ALGORITHM

In driver situation monitoring system, the key parameters compose of on-line steering angle and y-axis acceleration. The first parameter, steering angle, is directly captured from OBD bus. In addition, the state will be processed and discussed by Kalman filter and differential signals. Owing to inertial sensor misalignment and scale factor uncertainty, we also derived a vehicular calibration method to calibrate parameters using autoregressive exogenous method. The inertial measurement sensors are three orthogonal angular rates and three orthogonal accelerations, and moreover the orthogonal direction is shown the hardware fabrication in Fig. 2. The calibrated acceleration and angle rate will be compensated with each other. Quaternion method is adopted in acceleration projection, as in [11], [12].

A. *Signal processing – discrete kalman filter with ARX model*

Filtering is desirable in many situations, and a good filtering algorithm can remove the noise from electromagnetic signals while retaining the useful information. In this study, it uses autoregressive exogenous model to simply the process of inertial signal. The processing flow chart is described in Fig. 4. The first procedure is used to guess initial ($\hat{X}_0^-$) and observation covariance values (P_0^-) of inertial sensor; moreover the kalman gain (K_k) is estimated.

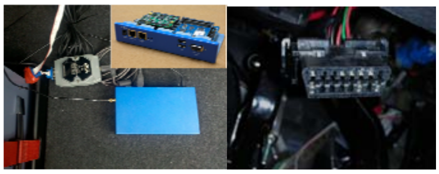

Fig. 3. System platform and OBD II connector.

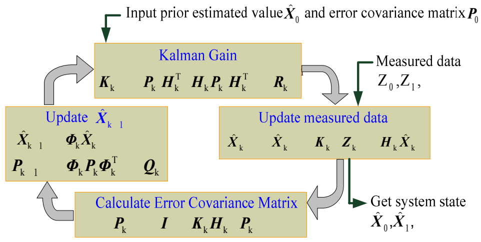

Fig. 4. The flow chart of discrete kalman filter.

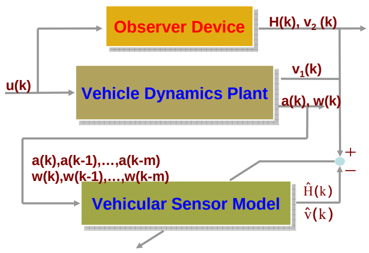

Fig. 5. Inertial sensors calibration method.

The second procedure utilizes measured data to get system true state (Q_k), and this value is the filtering value of torque sensor. The third step will use K_k and P_k to update newer P_k. At the fourth procedure, it will estimate system state and observation covariance value using system error covariance value (Q_k). These initial values will decide system performance in this paper, and these values will be trained with many cases and scenarios. To meet a high performance, $\hat{X}_k$ state is processed via autoregressive exogenous model, and the model is presented using linear polynomial equation.

B. *Sensor correction - inertial sensors calibration method*

The vehicle sensing components consist of accelerometer and gyros, and furthermore they are used to perform the attitude computations in strapdown. These errors are associated with gyros and accelerometer that typically include static biases, drifts, scale factor and random noise. To solve this kind of shortcoming, inertial sensors calibration method is applied in this paper, as shown in Fig. 5.

The vehicle plant is demonstrated vehicle, and the output is captured from IMU. In calibrated operation, this paper corrects gyro and accelerometer parameters. Taking gyro procedure as example, the observer device used GPS to get vehicle heading. Refer to (1) and (2), system controller integrated angle rate and compared with heading. This method uses second-order minimal energy and gradient method to get error variation in (3). The relation can be derived to discrete form in (4).

$$\hat{H}[k] = \int (\hat{p}_n w^n + \hat{p}_{n-1} w^{n-1} + \ldots + \hat{p}_0) dt \qquad (1)$$

$$e_H[k] = H[k] - H[k-m],\quad e_{\hat{H}}[k] = \hat{H}[k] \tag{2}$$

$$J = \frac{1}{2}(e_H[k] - e_{\hat{H}}[k])^2 \tag{3}$$

$$\begin{bmatrix} \hat{p}_n[k] \\ \hat{p}_{n-1}[k] \\ \vdots \\ \hat{p}_0[k] \end{bmatrix} = \begin{bmatrix} \hat{p}_n[k] \\ \hat{p}_{n-1}[k] \\ \vdots \\ \hat{p}_0[k] \end{bmatrix} + \lambda \cdot (e_H[k] - e_{\hat{H}}[k]) \cdot \begin{bmatrix} w^n[k] \\ w^{n-1}[k] \\ \vdots \\ 1 \end{bmatrix} \tag{4}$$

C. Acceleration projection –attitude calculation via quaternion method

Euler angles are the values which present the attitude of the vehicle. The attitudes of the vehicle mean the angles between body axes with navigation axes. There are three Euler angles φ, θ and ψ used to show the relative angles along x, y and z axis. The definition of Euler angles is shown in Fig. 6. The Direct Cosine Metrics (DCM) is used to transfer information from one coordinate system into another coordinate system. It is carried out as a sequence of three successive rotations about different axes. The DCM mentioned earlier is limited since the solution become indeterminate when $q = 90^{\circ}$. The quaternion method is used to overcome this problem. The concept of the quaternion is based on the idea that a transformation from one coordinate frame to another can be effected by a single rotation angle δ and an orientation unit λ defined with respect to the reference frame in Fig. 7.

In the quaternion transformation, the orientation is written as a vector which contains four elements with the magnitude of the rotation. The preceding about body-to-navigation DCM can be expressed through quaternion elements as (5). The q_i (i=0, 1-3) are calculated from kinematic equation in (6), and it can be substituted with the quaternion elements which is shown in (7). Refer to (7), vehicle attitude can be integrated and updated to get Euler angles.

$$C_b^n = \begin{bmatrix} q_0^2+q_1^2+q_2^2+q_3^2 & 2(q_1q_2-q_0q_3) & 2(q_1q_3-q_0q_2) \\ 2(q_1q_2+q_0q_3) & q_0^2-q_1^2+q_2^2-q_3^2 & 2(q_2q_3-q_0q_1) \\ 2(q_1q_3-q_0q_2) & 2(q_2q_3-q_0q_1) & q_0^2-q_1^2-q_2^2+q_3^2 \end{bmatrix} \tag{5}$$

$$q = \begin{bmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{bmatrix} = \begin{bmatrix} \frac{1}{2}\sqrt{1+C^n_{b_{11}}+C^n_{b_{22}}+C^n_{b_{33}}} \\ \frac{1}{4q_0}(C^n_{b_{32}}-C^n_{b_{23}}) \\ \frac{1}{4q_0}(C^n_{b_{13}}-C^n_{b_{31}}) \\ \frac{1}{4q_0}(C^n_{b_{21}}-C^n_{b_{12}}) \end{bmatrix} \tag{6}$$

$$\begin{bmatrix} \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \\ \dot{q}_0 \end{bmatrix} = \frac{1}{2} \begin{bmatrix} 0 & r & -q & p \\ -r & 0 & p & q \\ q & -p & 0 & r \\ -p & -q & -r & 0 \end{bmatrix} \begin{bmatrix} q_1 \\ q_2 \\ q_3 \\ q_0 \end{bmatrix} \tag{7}$$

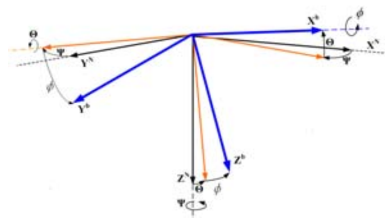

Fig. 6. Definition of Euler angles.

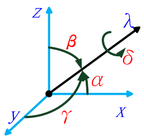

Fig. 7. Quaternion coordinate.

IV. SYSTEM IMPLEMENTATION AND TESTS

After IMU had been set well in demonstrated vehicle, a driver drove in different speed to test straight moving and turn availability. The straight driving test is used to adjust accelerometer parameters refer to GPS speed. The output data would be processed using integration. Owing to integration error, the result should be calibrated and delicate processed well. Fig. 8(a) used a one-axis acceleration to get speed and the result is compared with GPS speed. The parameters was learned and calibrated by parameters learning and error cancelation. Hence, the speed error is under 5kph and the measured data will close to true condition. In the similar way, the gyro integrated angular rate into heading comparing with GPS course w.r.t North direction in Fig. 8(b).

The proposed system is integrated until unit tests and interface tests have been finished. In DSM operation, the background acceleration should be known and measured in Fig. 9(a). The position of test field is located between Taichung and Changhua, as shown in Fig. 9(b). The result showed that the road condition would not affect vehicle driving dynamics by kalman filtering method. This processing procedure should be done to filter background noise.

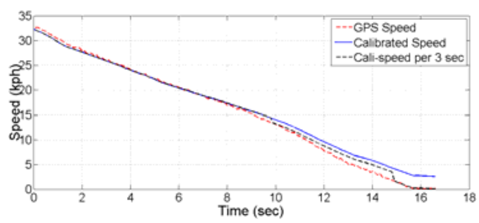

Fig. 8(a). Acceleration calibration test.

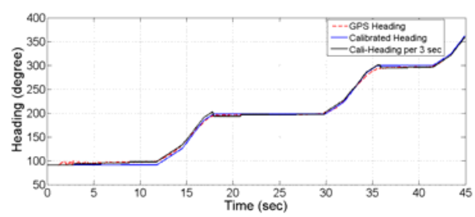

Fig. 8(b). Gyro calibration test.

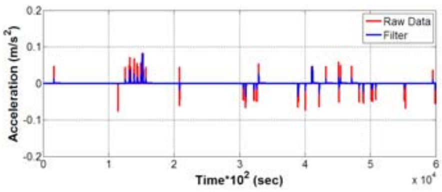

Fig. 9(a). Background acceleration.


Fig. 9(b). Test field in highway.

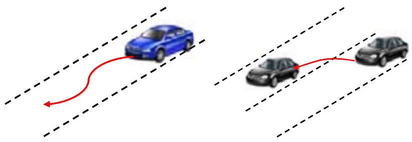
Fig. 9(c). S-cure and lane change motion.

There are two test scenarios, including s-cure motion in same lane and do lanes change. The test vehicle was derived and collected data from Taichung to Changhua. In Fig. 9(a), the acceleration is well-processed and the statically level of warning data is over 0.1 m/s^2. All of the filtering result showed inattention condition, and the DSM can alert driver suing buzzer when filtering value is over threshold, such as Fig. 10(a)&(b). Comparing with both of conditions, the acceleration of s-cure motion is smaller than lane change because of kalman filter. Hence, steering angle variation is another consideration for inattention judgment.

The s-curve motion and lane motion is showed in Fig. 9(c). After finishing s-curve and lane change experiment, Fig. 11(a)&(b) showed steering angle variation, and the angle relative to operation time is discussed in this paper. In Fig. 10, the s-cure motion has accumulative acceleration immediately. However, the steering angle variation is continuously smaller than normal condition. When vehicle did lane change motion, the steering angle variation is bigger than normal condition. The experiment also used different driver to verify system method, and the CF card plays the role of data log. The storage data would collect driver driving mode, and the DSM controller did model learning and decided threshold value of acceleration and steering angle variation. This paper is well-scheduled inattention scenarios to verify system method ability and analysis dangerous condition.

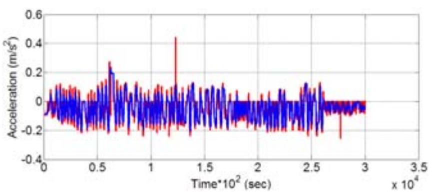

Fig. 10(a). Acceleration of s-cure motion.

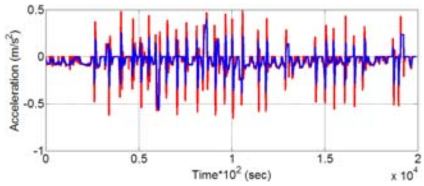

Fig. 10(b). Acceleration of lane change motion.

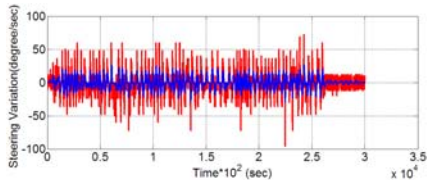

Fig. 11(a). Steering angle variation of s-cure motion.

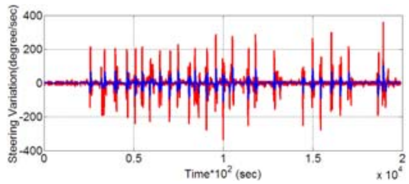

Fig. 11(b). Steering angle variation of lane change motion.

V. CONCLUSION

In this paper, the capability of driver situation monitoring system using sensor fusion is applied and verified. The proposed system designed and implemented an integrated technology using microcontroller to accomplish motion measurement by adding inertial sensor through data processing. By inattention and dangerous testing, the implementation presented the capability of the sensing information into situation monitoring applications. The kalman filter and sensor calibrated algorithm is effectively developed and embedded into DSM controller and processed in accordance with threshold value after learning driver driving parameters.

The verification tests have proven that the advantages of inertial sensor and steering angle integration. The proposed system can assist drivers to have a predicted active safety with driving awareness capability. The advantage of driver situation monitoring system has presented with exact awareness of self-driving spirit, and the demonstration provides a feasible solution to enhance driving safety.

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