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Application note

SafeDriving: A mobile application for tractor rollover detection and emergency reporting

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ABSTRACT

This paper introduces a tractor rollover detection and emergency reporting software application, SafeDriving, developed for iOS-based mobile electronic devices (smartphones and tablet computers). The SafeDriving application uses a mathematical model to calculate the stability of a tractor using the physical parameters of the tractor and the data from the inbuilt sensors of the mobile electronic devices or the data from the external sensors attached to the tractor. When the SafeDriving application detects an accident, it sends automated email and phone messages with the GPS location, date, time and other critical information. The functions of the SafeDriving application were tested on a small-scale model tractor in laboratory conditions and on a 45 HP utility tractor in field conditions. The field-upset tests with the utility tractor were conducted for 10 times at 10.8 km/h and 21.6 km/h. During all of the tests, the application successfully monitored the vehicle stability and reported the accidents to the emergency contacts when a rollover accident happened.

1. Introduction

Tractor safety plays an important role in agricultural production (Springfeldt, 1996). Rollover accidents are the most severe and major safety problems for agricultural tractors. Tractor rollover accidents are responsible for approximately 50% of the fatal tractor crashes (HOSTA, 2004). Tractors are often operated on uneven terrains with varying slopes. Because all of the tractor rollover accidents can cause severe injuries to operators, Occupational Safety and Health Administration (OSHA) requires agricultural tractor manufacturers to install Roll Over Protective Structures (ROPS) since 1976 (OSHA, 2005). While the ROPS can reduce the severity of the rollover accidents to the operators, timely reporting of the accidents to rescue teams would minimize the impact of the accident to the operator. Mobile electronic devices being equipped with several sensors in addition to their internet, telephone and wireless communication capabilities (Wi-Fi and Bluetooth) are excellent tools for tracking, detection of rollovers and accident notification. iPhones and iPads are equipped with a 3-axis accelerometer, gyroscope, GPS sensor, digital compass, digital cameras and touch screens. We implemented the tractor rollover, detection, and emergency reporting application, SafeDriving, on iOS-based mobile electronic devices (Apple, Inc., Cupertino, CA).

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2. SafeDriving smartphone/tablet application

The SafeDriving application was developed using the iOS software development kit, XCode (Apple, Inc., Cupertino, CA). The SafeDriving application has two working modes as shown in Fig. 1. In mode 1, the application uses the sensors and the Wi-Fi or 3G/4G network functions of the mobile electronic device to monitor the tractor stability, display warnings, detect accidents and transmit emergency messages when an accident occurs. Mode 1 requires the users to mount the mobile device on the tractor to monitor the stability of the vehicle. In mode 2, the SafeDriving application receives the data streamed from a microcontroller-based standalone/backup system via Bluetooth to monitor the tractor stability, display feedback messages (warnings), detect accidents and transmit emergency messages when an accident occurs. Mode 2 does not require the users to mount the mobile device on the tractor. The mobile device can be in the operator's pocket or anywhere within the Bluetooth communication range of the external backup sensors installed on the tractor.

The flowchart for the SafeDriving application algorithm is shown in Fig. 2. The SafeDriving application utilizes the physical parameters of the tractor and the data from the internal sensors of the mobile device or the external backup system to conduct the signal processing and implementation of the mathematical model. SafeDriving algorithm uses a vehicle rollover model to calculate a rollover stability index value using the data from the sensors and the vehicle's physical parameters. Stability index is a metric used to represent how stable the tractor operation is. The

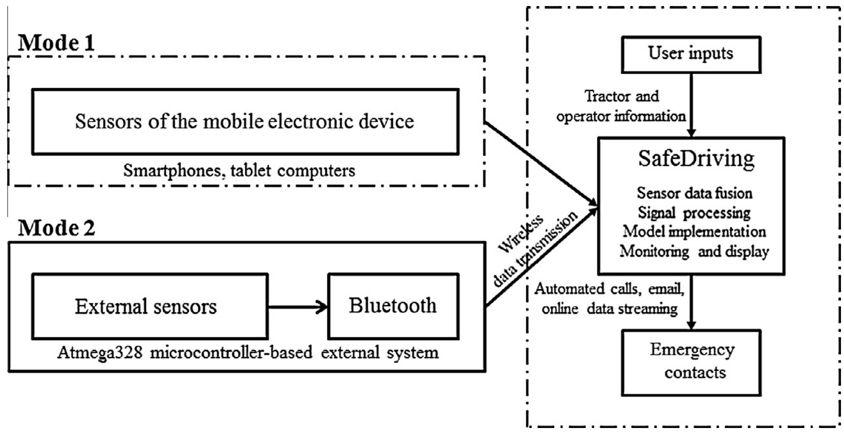

Fig. 1. Schematic diagram of the SafeDriving application.

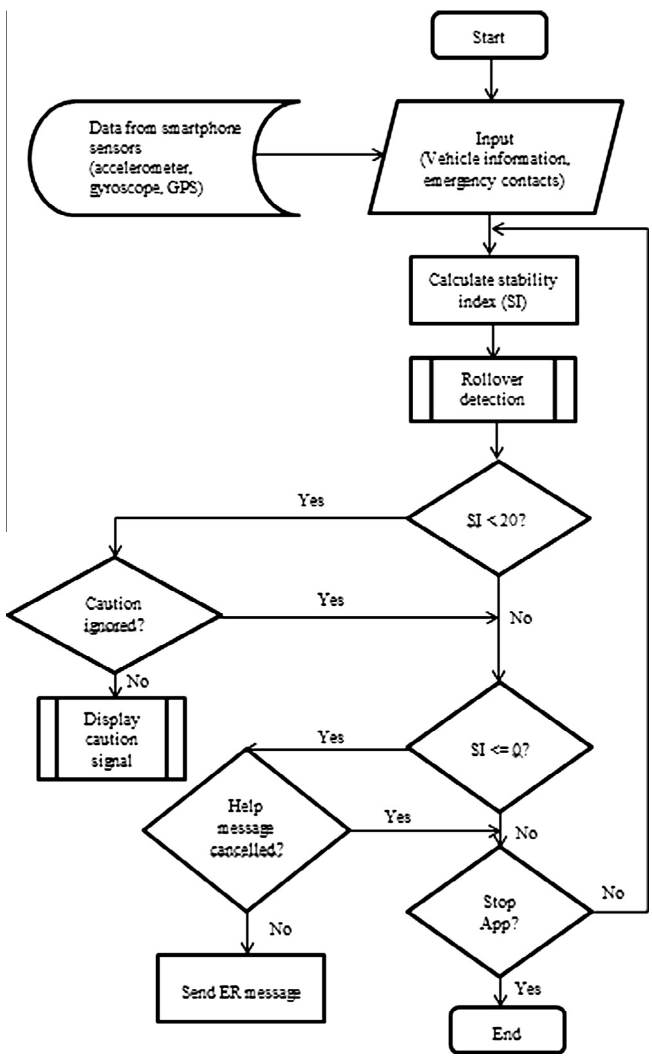

Fig. 2. Flowchart for the algorithm used in SafeDriving application.

deflections of tires and suspension of the vehicle, road conditions, and environmental factors were not considered in the model. However, the vehicle's lateral and longitudinal stabilities were used to calculate an overall stability index value. The overall stability index value is calculated by using the following equation:

$$SI_{overall}(t) = \left(1 - \sqrt{\left(\frac{\varphi}{\varphi_{cri}}\right)^2 + \left(\frac{\theta}{\theta_{cri}}\right)^2}\right) * \left[1 - \sqrt{\left(\frac{\dot{\varphi}}{\dot{\varphi}_{cri}}\right)^4 + \left(\frac{\dot{\theta}}{\dot{\theta}_{cri}}\right)^4}\right] \times 100 \quad (1)$$

where φ and θ are the roll angle and pitch angle of the vehicle and φ_{cri} and θ_{cri} are the critical roll angle and critical pitch angle, at which lateral or longitudinal overturning is about to happen; $\dot{\theta}$ is the pitch rate, $\dot{\theta}_{cri}$ is the critical pitch rate, $\dot{\varphi}$ is the actual roll rate, and $\dot{\varphi}_{cri}$ is the critical roll rate of the vehicle (Ertlmeier et al., 2012). The details of the derivation of the overall stability index value shown in Eq. (1) is provided in Koc and Liu (2013), Koc et al. (2012). When the stability index value drops below 20, a caution signal indicating "rollover hazard" appears on the phone screen. Stability index value of 0 indicates a rollover or accident condition. If an accident is detected (stability index = 0) and the operator did not stop the application, the SafeDriving application transmits an email message containing the date, time and GPS coordinates of the accident location automatically to the emergency contacts. An automated phone call is also made to the emergency contacts specified by the user. The GPS coordinates transmitted in the email message are from the GPS sensor of the smartphone. Most smartphones use assisted-GPS (A-GPS) to reduce the time for identifying locations. A-GPS uses the locations of the cell phone towers and Wi-Fi hotspot locations for this service. A-GPS increases the accuracy of the GPS coordinates and allows position estimations when GPS satellites are not visible to the cell phones. The emergency notification function of the application works only in areas where there is cell phone signal coverage.

The screenshots of the SafeDriving application are shown in Fig. 3. Fig. 3a shows the user data input interface. The user must fill the vehicle physical parameters, email addresses and the phone numbers of the emergency contacts. The stability status of the tractor is displayed in Fig. 3b. The stability index on the screen indicates how stable the tractor is being operated. A value of 100 indicates the most stable operation while a value of 0 indicates a rollover or accident condition. If the stability index value gets below a threshold (i.e. 20) indicating a high risk of rollover or overturning is approaching, a caution message is displayed to warn the operator (Fig. 3c). Because rollover accidents can happen in very short time, the caution message displayed to the operator may not provide enough reaction time to prevent an accident, however, this lead time would be long enough for triggering electromechanical intervention mechanisms used for automatically

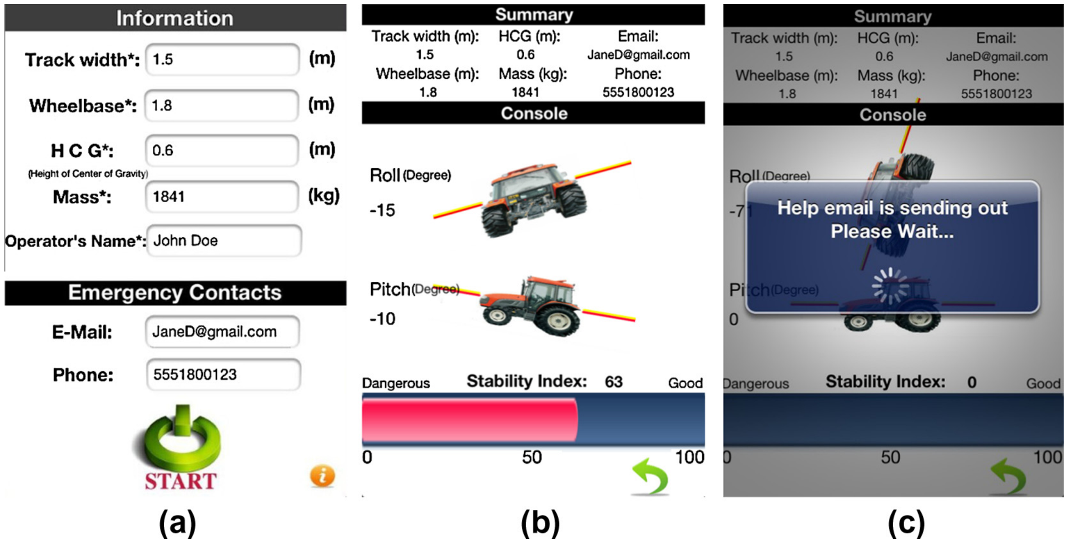

Fig. 3. (a) The user input screen, (b) real time vehicle stability monitoring screen, and (c) sending an email when accident is detected.

deployable rollover protective structures (ROPS) (Powers et al., 2001; Silleli et al., 2008).

3. SafeDriving evaluation

Conducting experiments with real tractors, sensors, computers and display units would be costly. Therefore, before testing the application on a utility tractor, a small-scale model vehicle was built and an iPhone 4S with the SafeDriving application was mounted. The track width of the model tractor was 21.6 cm, the height of the center of gravity was 10.7 cm, and the mass of the model tractor with the iPhone 4S was 1.3 kg. The roll and pitch angles, roll and pitch rates and the stability index values were calculated from the mathematical model. The iPhone's internal sensors made the measurements for the parameters of the mathematical model. The vehicle was operated on a test platform with rising slope in laboratory conditions. The measured and calculated data were transmitted to a personal computer via a user datagram protocol (UDP) in a LabView program for further analyses and reporting.

After testing the SafeDriving application on a small-scale vehicle in laboratory conditions, the application was tested on a John Deere 2040 tractor. The phone with the application was mounted on a frame built around the tractor hood. The track width of the John Deere 2040 was 1.6 m the height of the center of gravity was 0.6 m, wheelbase was 1.9 m and the mass of the tractor was 2467.3 kg. Field upset tests were conducted at the University of Missouri Bradford Research and Education Center (Columbia, MO). Field upset tests at 10.8 km/h and 21.6 km/h were conducted for 10 times. Changes of the roll angle, pitch angle and stability index values with time for one of the field upset tests at speeds of 10.8 km/h and 21.6 km/h are shown in Fig. 4. The experimental results showed that the roll angle and pitch angle increased as the slope was increasing and the stability index value decreased with an increasing slope. When the stability index value approached zero, the tractor rolled over and the roll angle and pitch angle began to change dramatically at this moment. The SafeDriving application successfully showed the warning messages on the screen when the stability index value was lower than 20. The SafeDriving application also sent out the email messages to the emergency contacts and called the emergency contacts' phone number automatically when the rollover accident was detected for all of the ten field upset tests.

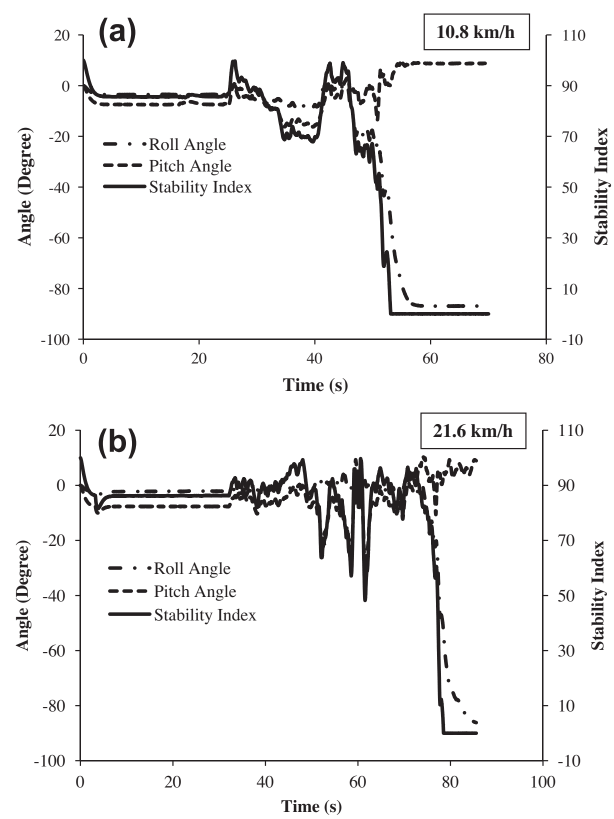

Fig. 4. Change of roll and pitch angles and stability index value with time at (a) 10.8 km/h and (b) 21.6 km/h.

4. Conclusions

The SafeDriving application illustrated how a mobile electronic device can be used to monitor the stability of a tractor. The experiments in laboratory and field conditions showed that the proposed method to predict/detect an accident and displayed caution messages when stability status of the vehicle was poor. The phone number of the emergency contact was called automatically. The accident coordinates with a location map, the date, time and other important information were sent to the emergency contacts with the email message. The SafeDriving application is suitable for various motorized vehicles and it can be used for safety training of new tractor operators in classrooms and laboratories. The on-going research activities on SafeDriving application will include developing a database so that the user can select the make and model of the tractor to enter the physical parameters of the tractor rather than entering them separately.

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