

## Roll Stability Early Warning System Based on Tilt Sensor

<https://doi.org/10.3991/ijoe.v13i09.7586>

Jingmei Zhang

Beijing Jiaotong University, Beijing, China

Hebei University of Science and Technology, Shijiazhuang, China

zhjingmei@126.com

**Abstract**—In view of the over-speed phenomenon of heavy haul vehicles at high speed, the estimation of the effective range of the dynamic stability and inclination angle of the truck was carried out a rollover stability alarm system based on liquid pendulum angle sensor and virtual instrument software was developed. The working principle and data processing module of tilt sensor are discussed, through the data lines to output analog voltage signal transmitted to the vehicle electronic control unit. A control command is sent by the electronic control unit and sent to the driver via an alarm device, which enables the driver to control the speed in time, and so it reduces the risk of a rollover accident. The results show that the warning system is of good accuracy. The early warning system preventing malignant road traffic accidents has important social significance and actual application value for a safe vehicle.

**Keywords**—Heavy vehicle, tilt sensor, warning system, roll angle

### 1 Introduction

In the transportation industry, the heavy use of heavy vehicles has improved the transportation efficiency and produced huge economic benefits, but the ensuing security problems have become increasingly prominent. Rollover yearly caused a large number of casualties and property losses, which is the main safety problem of heavy vehicles. The investigation into accidents caused by automobile shows that a serious accident occurred in the number of vehicle rollover vehicle accounted for about 1/3 of the total number of vehicle traffic accident. Thus, the transportation safety problem of operating vehicle has become one of the key problems to be solved urgently.

The causes of rollover accidents are manifold, and mainly attributed to subjective and objective causes. The objective reason refers to the heavy vehicle when turning hard to avoid some technical factors. The rollover is caused by the shift of the center of gravity, and the driving operation is difficult to control. For example, when the steering emergency brake when rollover occurs, the brake balance and weight distribution around the state, linear driving vehicle brake after the body state is still in the same line direction. Once the brakes are out of balance (partial braking), or uneven

weight distribution, or even turn into a little, the heavy vehicle will have a pronounced tendency to roll under heavy braking.

Vehicle safety monitoring and warning technology in many countries as a basic research is put a lot of effort. A series of researches have been carried out on the development of vehicle monitoring and warning device. Developed countries also carry out a number of major projects in vehicle safety. Such as the US VII project and the CVHAS project, Japan's ASV, smart way and AHS projects, the European e safety program and so on the vehicle monitoring and warning device is one of the key research projects. After years of research, the multi vehicle safety auxiliary driving device developed by developed countries has gradually entered the practical process [1].

Study on the safety of road transport and the transport of dangerous goods in China started late, technology level is relatively backward. Roll stability control system of Ford automobile company is one of the mature products [2] [3], which uses sensors to monitor car roll dynamics. It uses a controller to allocate braking power to reduce the lateral tire force when the car rollover trend [4]. BOSCH (Bosch)'s proprietary electronic body stabilizing system is configured mainly in the high-end car and less in heavy vehicles.

An early warning system of roll stability for vehicle is developed against the rollover accident. A tilt sensor is arranged on the longitudinal symmetrical surface of the frame of the vehicle. The tilt change signal is out-put to the ECU system, and before or after driving and braking forces around the wheel are controlled by ECU. And the driver is warned to lower the speed. The lateral stability of the vehicle is improved to the maximum. Eventually reduce the possibility of car rollover.

## **2 Roll monitoring and warning system**

The overall structure of the vehicle roll monitoring and warning system of this study include three parts: roll information acquisition unit, information processing unit and Information output equipment. The roll information acquisition unit is mainly composed of a signal generator, tilt sensor and data conversion module; the information output device comprises an alarm buzzer and an alarm indicator lamp as shown in Figure 1.

## **3 Tilt sensor**

### **3.1 Working principle**

The theoretical basis of the tilt angle sensor is Newton's second law; its core is the "liquid pendulum" type inertial device.

The conductive liquid is put into a glass shell, three mutually parallel and equal spacing of the platinum electrode are inserted in the conductive liquid. The platinum electrode is connected with the exterior as shown in figure 2.a). The depth of conduc-

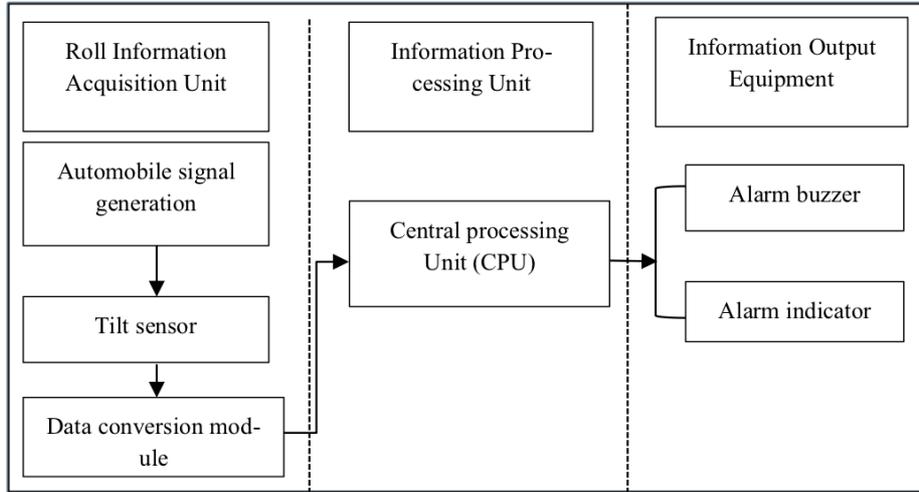


Fig. 1. Block diagram of roll warning system

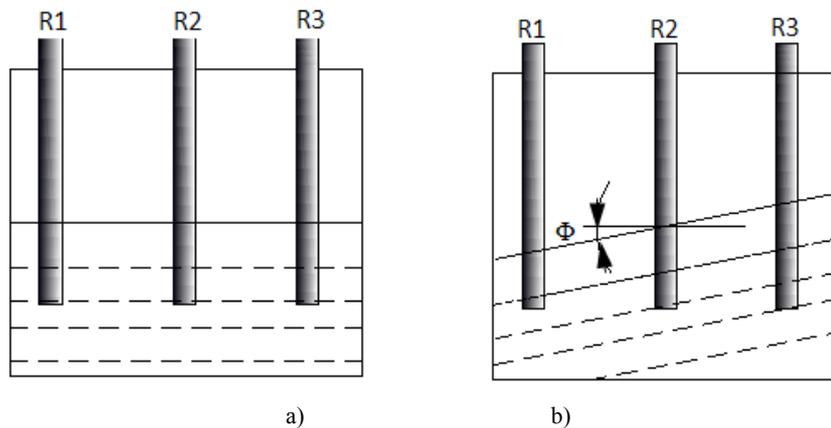


Fig. 2. Schematic diagram of sensor

tive liquid is same for three electrode inserted when the liquid is level. If an equal amplitude AC voltage is applied between the two electrodes, an ion current is formed between the electrodes. Between the two electrodes of the liquid equivalent of two resistors R1 and R3. When the liquid is horizontal,  $r_1$  equals  $r_3$ . The conductive liquid between the electrodes is not equal when the glass shell is tilted. The depth of the three electrodes immersed in the liquid also varies, but the immersion depth of the intermediate electrode remains almost the same. As shown in Fig 2. b). The left electrode dipped deeper and the conductivity decreases, the number of conductive ions decreases and the resistance R1 increases. In contrast, the conductive liquid increases and the number of conductive ions increases, while the resistance R3 decreases, i.e.  $R_1 > R_3$ , on the other hand, if the tilt is in the opposite direction,  $R_1 < R_3$ .

Conductive liquid adopts a novel conductive additive for LIB—a new high performance lithium ion conductive agent, it can increase the capacity, lower the IR, improve the rate, cycling life, high & low temperature performance and safety performance.

### 3.2 Data conversion module

The sensor charge is tilted due to the tilting of the vehicle, which result in a change in the liquid resistance. So the change of angle is changed into linear resistance. The analog voltage output is output through the circuit. Fig. 3 is the circuit for sensor data conversion module. The circuit is composed of two parts: the square wave signal generator and the indicating circuit. A square wave signal generator based on NE555 chip as the core. In the third feet square of NE555 the wave signal is output. After the C terminal is connected with the capacitance to be measured, the square wave signal is repeatedly charged and discharged with the measuring capacitor. If the time constant of the charge discharge circuit is much smaller than the period of the square wave signal, the average value of the charging current or discharge current is directly proportional to C. The charge discharge current of the capacitor is rectified by D1 to be the average voltage of charging, and it is shown by potentiometer, therefor the potentiometer indications that reflect the vehicle roll angle size.

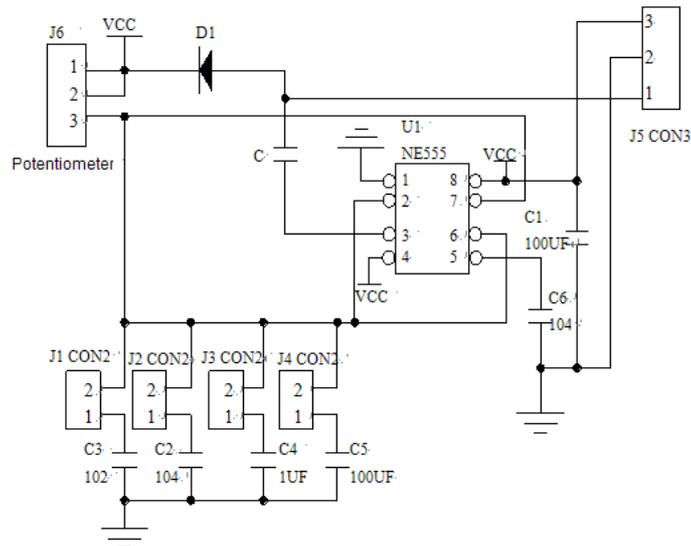


Fig. 3. Data conversion module of tilt sensor

The electronic tilt sensor is a high performance, and low cost angle measuring device. It combines advanced electronic technology to convert angular changes into linear resistance changes, and the analog voltage output is output through the circuit. So it is of high reliability, low power consumption and light weight structure.

#### 4 Experimental data processing and error analysis

The output voltage of the sensor by simulation, the relationship between the output voltage and the dip angle is experimentally measured, as shown in Fig. 4. Curve fitting using least square method according to actual measured output voltage. A linear fitting curve is obtained:

$$V = 0.025\phi + 0.45 \quad (1)$$

It can be seen that the results are very close by comparing the two curves, and the linear mean error is only 0.012%.

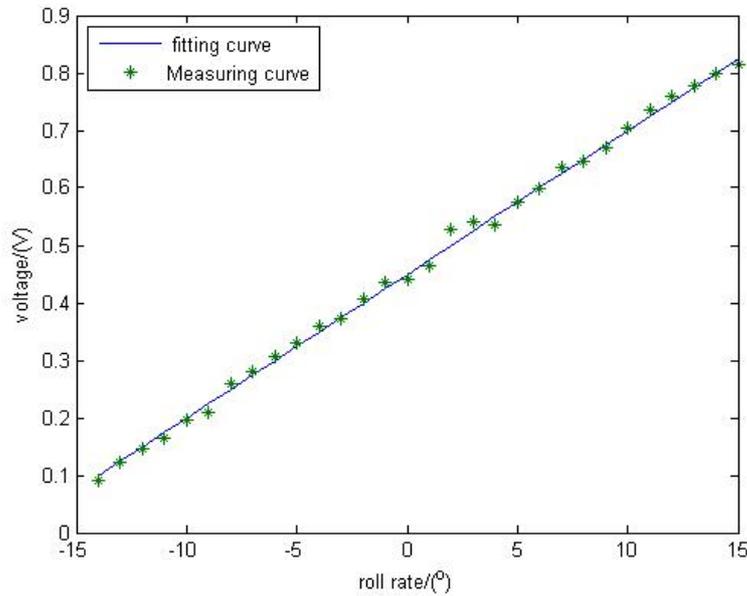


Fig. 4. Fitting curve and measuring curve

With a tilt angle of 3 degrees change rate, each tests 5 times, the average  $V_m$  is taken as the measuring value of the voltage. According to Eq. (1), the voltage fitting value of the same dip angle  $V_f$  is obtained. The fitting error and the standard deviation of measured value and fitted value are calculated.

Fitting error:

$$\alpha = (V_f - V_m)/V_m \quad (2)$$

Standard deviation:

$$\sigma = \sqrt{\frac{\sum_{i=1}^n (V_f - V_m)^2}{n}} \quad (3)$$

The results are shown in Table 1.

The average value of fitting error is 0.014%, the average value of the standard deviation of the fitting is 0.04% according to Table 1. In the range of side inclination from  $-15^\circ$  to  $15^\circ$ , the measurement accuracy for roll sensor is  $0.05^\circ$  and the sensitivity is 0.02V per  $1^\circ$ .

**Table 1.** Data and errors

Roll angle( $^\circ$ )	Determination of value ( $V_m$ )	Fitting value ( $V_f$ )	Error of fitting( $\alpha/\%$ )	Standard deviation of fitting( $\sigma/\%$ )
15	.100	.099	-.010	.01
12	.175	.165	-.060	.04
9	.250	.258	.032	.06
6	.325	.330	.015	.05
3	.400	.407	.018	.02
0	.450	.460	.022	.05
-3	.525	.541	.030	.05
-6	.600	.600	.000	.04
-9	.675	.671	-.006	.07
-12	.750	.759	.012	.02
-15	.825	.815	-.012	.03

## 5 Selection of the tilt sensor mounting position

### 5.1 Analysis of factors affecting rollover

The load is mainly concentrated in the carriage for heavy duty vehicles. The vehicle carriage rolls firstly at most of the time. Then the cab does that along with it. Taking the three axle 25 ton heavy haul vehicle as an example, the rollover factors are analyzed. Fig.5 is a schematic diagram of the roll of the vehicles.  $F_{sy}$  is the centrifugal force.  $\phi$  is the roll angle.  $v$  is the speed.

Through dynamic analysis, the internal and external tire reaction force can be obtained when the shafts are rolling as Eq. (4):

$$F'_{zil(r)} = F_{zil(r)} + \Delta F_{zil(r)} + F_{id(r)} \quad (4)$$

Where,  $F_{zil(r)}$  is the vertical reaction force of the left (right) tire of the front, middle, and rear axle. The dynamic load of the inner tire produced by roll can be expressed as:

$$\Delta F_{zil} = (F_{si}h_i + T_i + F_{vi}h_{vi})/B_i \quad (5)$$

According Eq. (5),  $\Delta F_{zil}$  is related with the centrifugal force  $F_{sy}$ , roll center height  $h_{vi}$ , moment resulting from sides way  $T_i$  and wheel-base  $B_i$ . When the vehicle is in the process it runs at a state change speed. Therefore, the speed of the car affects the size of the centrifugal force. The vehicle will run out of control under the influence of side

force or torque when the tire lateral force  $F'_{zil(r)}$  exceeds the pavement anti support force. The driver is difficult to control and rollover occurs. As a result, the main factor is the speed of rollover is too high if the vehicle is broken or turned on a smooth road surface.

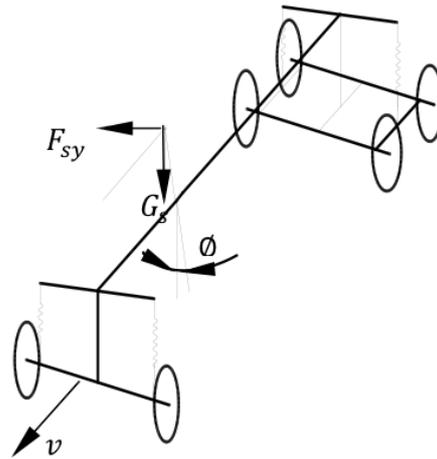


Fig. 5. Roll diagram

### 1.1 Sensor position determination

The heavy duty vehicle with non-independent balance suspension, the camber of the car body and the leaf spring of the balance suspension also appear lateral deviation when the vehicle rolls, and frame offset. The force diagram of the heavy vehicle is shown in Fig. 6.

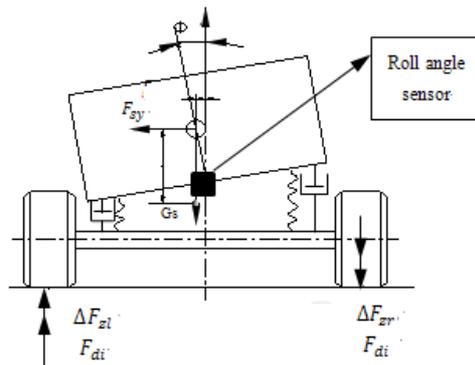


Fig. 6. Tilt sensor position

The tilt sensor is installed on the position of the left and right symmetrical shafts at the bottom of the frame, and accurately senses the change of inclination.

## 6 Information processing unit modify ECU and information output device

The voltage data from the voltage angle sensor is sent to the information processing unit ECU (Electronic Control Unit) through the data transmission system. Through modify ECU program [5] [6] that is to modified algorithm and store them in containers. The signal from the input device by the controller and converted to the signal processing to generate the corresponding instruction, and transferred out by the output transmission equipment. The modified part of the ECU program flow chart is shown in Fig 7.

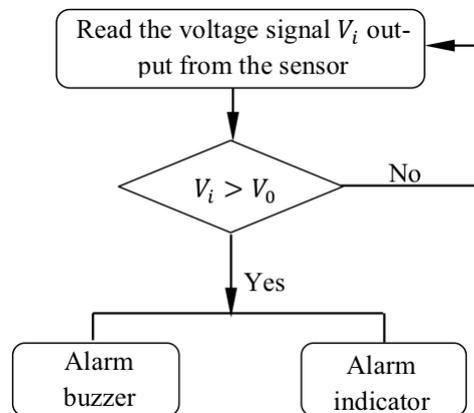


Fig. 7. Flow chart of refitted part of ECU program

The information output equipment mainly includes the alarm buzzer and the warning indicator light. ECU determines whether the value is greater than  $V_0$  when the output voltage of the tilt sensor is transmitted to the ECU by the data line. According to the different load of the car ahead of time to determine the car tilt limit angle [v],  $V_0$  is the maximum value of the permitted dip angle, it can be set to  $V_0=0.5[V]$  because it takes a certain amount of time to get the alarm for the driver. When the value read is greater than  $V_0$ , ECU sends out control instructions and transmits instructions to alarm buzzer and alarm light, or so ECU continue reading voltage values.

## 7 Conclusion

A rollover stability early warning system based on liquid pendulum angle sensor is proposed for heavy haul vehicle and the hardware and software architecture of the system is designed. The installation position of the sensor is determined. The sensor is installed on the position of the left and right symmetrical shafts at the bottom of the frame. By refitting ECU, ECU can issue an early warning order when the vehicle appears rollover in the course of running, and inform the driver in time to decrease the

speed in order to minimize the possibility of rollover and reduce the probability of reaching an accident. The roll stability early warning system is of great significance to reduce the rollover accident probability of heavy haul vehicles, but further experimental analysis is needed.

## 8 References

- [1] A Sathyanarayana , P Boyraz , JHL Hansen. Information fusion for robust ‘context and driver aware active vehicle safety systems. *Information Fusion*, 2011, 12 (4):293-303. <https://doi.org/10.1016/j.inffus.2010.06.004>
- [2] LI Xu, H ERIC TSENG. Robust Model-Based Fault Detection for a Roll Stability Control System. *IEEE Trans Control Systems Technology*, 2007, 15(3): 519-528. <https://doi.org/10.1109/TCST.2006.890287>
- [3] J Lu, D Filev, L Johnson. Real-time Tire Imbalance Detection Using ABS Wheel Speed Sensors, *Sae International Journal of Materials & Manufacturing* 2011, 4 (1):1036-1047. <https://doi.org/10.4271/2011-01-0981>
- [4] W Kim, K Yi, J Lee. An optimal traction, braking, and steering coordination strategy for stability and manoeuvrability of a six-wheel drive and six-wheel steer vehicle. *Proceedings of the Institution of Mechanical Engineers Part D Journal of Automobile Engineering*, 2012, 226 (1):3-22. <https://doi.org/10.1177/0954407011416055>
- [5] Ernesto Gutiérrez González, Jesús Alvarez Flórez, Sebastián Arab. Development of the management strategies of the ECU for an internal combustion engine. *Mechanical Systems and Signal Processing*. 2008, Vol.22 (6), pp.1356-1373. <https://doi.org/10.1016/j.ymsp.2007.11.030>
- [6] XJ Fang , JY Du , MQ Jia , YN Yuan , X Wu. Development of ECU calibration system for electronic controlled engine based on LabVIEW. *International Conference on Electric Information & Control Engineering*. 2011:4930-4933. <https://doi.org/10.1109/ICEICE.2011.5776866>

## 9 Author

**Jingmei Zhang** is with the School of Mechanical, Electric and Control Engineering, Beijing Jiaotong University, Beijing, China and the School of Mechanical Engineering, Hebei University of Science and Technology, Shijiazhuang, China (e-mail: zhjingmei@126.com).

Article submitted 13 August 2017. Published as resubmitted by the author 17 September 2017.