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Improving the Response of a Rollover Sensor Placed in a Car under Performance Tests by Using a RLS Lattice Algorithm

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Abstract: In this paper, a sensor to measure the rollover angle of a car under performance tests is presented. Basically, the sensor consists of a dual-axis accelerometer, analog-electronic instrumentation stages, a data acquisition system and an adaptive filter based on a recursive least-squares (RLS) lattice algorithm. In short, the adaptive filter is used to improve the performance of the rollover sensor by carrying out an optimal prediction of the relevant signal coming from the sensor, which is buried in a broad-band noise background where we have little knowledge of the noise characteristics. The experimental results are satisfactory and show a significant improvement in the signal-to-noise ratio at the system output.

Keywords: dual-axis accelerometer; rollover angle; RLS lattice algorithm; adaptive noise canceller; uncertainty

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1. Introduction

Unfortunately, the highest fatality rates per year in car accident statistics are attributed to rollover crashes [1]. In fact, this type of crash accounts for about 40% of passenger vehicle fatalities. This is why today's cars are designed with the highest priority placed on passenger safety.

On the question of what the causes for this kind of crash are. It has been shown that tall, narrow vehicles with high center of gravity are bound to roll over if they are involved in single-vehicle crashes. In addition, excessive speed, alcohol consumption, poor roads and environmental factors, among others, are all contributory factors to rollover crashes.

Therefore, with this scenario in mind, no one would dispute the need to improve the design of the sensors used for industrial measurements [2-22]. This is why in the last decades researchers from all

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around the world have been working hard to invent intelligent devices consisting of not only sensors, but also advanced materials [23] and microprocessors, among other devices, that incorporate a certain amount of intelligence to the sensors themselves, transforming them into better prepared measuring systems [24-47].

Nevertheless, the process of improving the performance of sensors is not an easy task. Actually, we have to deal with disturbances and/or interferences whose characteristics we have little or no prior knowledge of, and we have to use efficient methods of estimation, prediction and control in order to get clear information about the physical magnitude or process that we want to measure or control [38-47].

In short, this paper shows the improvement of the real-time response of a sensor to measure the rollover angle of a car under performance tests. Furthermore, this system can be easily integrated into technologies that aim to improve the comfort and safety of the passengers in most of today's cars. Electronic stability control, variable ride-height suspension and rollover airbag systems are examples of the above mentioned technologies.

1. Accelerometers

2.1. Principles

In the industrial world, the most common design of sensors to measure acceleration is the accelerometer design based on a combination of Newton's law of mass acceleration and Hooke's law of spring action.

Figure 1 shows the basic spring-mass system accelerometer. Such a mass is connected to the base by a spring that is in its unextended state and exerts no force on the mass. In addition, the mass is free to slide on the base [20].

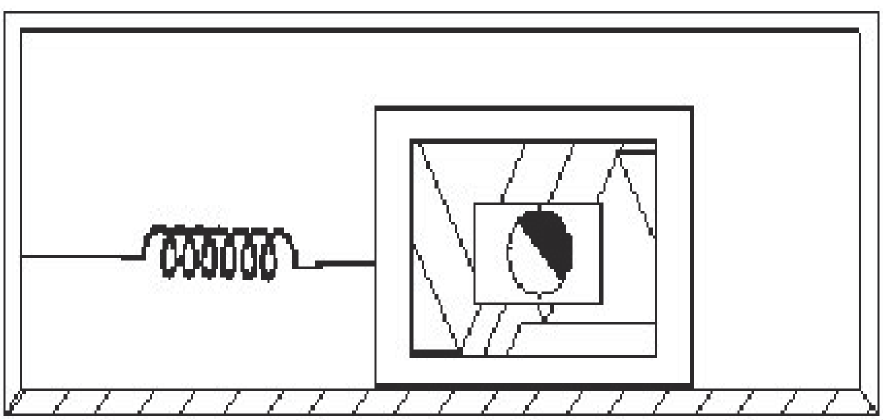

Figure 1. Basic spring-mass system accelerometer.

According to Johnson [20], if the seismic mass m, is undergoing an acceleration a, then there must be a force F acting on the mass and given by $F = m \cdot a$. In addition, the spring of spring constant k is

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extended (or stretched) from its equilibrium position for a distance Δx, with a force F_2 (opposite to F_1) acting on the spring and given by $F_2 = k \cdot \Delta x$. This condition is described by equating Newton's and Hooke's laws. Thus, the measurement of acceleration is reduced to a measurement of spring extension (linear displacement):

$$a = \frac{k}{m}\Delta x \quad (1)$$

The spring-mass principle applies to many common accelerometer designs, but most designs differ from each other in how they carry out the measurement of the displacement of the spring.

In analyzing the time domain performance of the spring-mass system and carrying out the impulse response analysis, it can be seen that such a system exhibits oscillations at a natural frequency with damping:

$$f_{osc} = f_N \sqrt{1-\zeta^2} \quad (2)$$

$$f_N = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \quad (3)$$

where f_{osc} is the frequency of oscillation, f_N is the natural frequency and ζ is the dimensionless damping ratio.

At this point, it is important to point out that the greater the friction associated with the seismic mass and the base, the sooner the mass settles to equilibrium. That is to say, as the friction increases, the damping becomes greater and the response will reach zero sooner. In addition, if the spring-mass system is underdamped, the mass will swing back and forth with decreasing amplitude. In this case, the frequency of oscillation is given by Eq. (2). However, if the friction tends to zero (lossless case), the seismic mass will oscillate at some characteristic natural frequency (see Eq. (3)).

2.1 Types of accelerometers and the selection of the sensor

There is a wide variety of accelerometers that could be used in various applications depending on the requirements of range, natural frequency, damping, temperature, size, weight, hysteresis, low noise, and so on. Piezoelectric accelerometers, piezoresistive accelerometers, variable capacitance accelerometers, linear variable differential transformers (LVDT), variable reluctance accelerometers, potentiometric accelerometers, gyroscopes used for sensing acceleration, strain gauges accelerometers, among others, are some of the numerous accelerometers.

In this paper, we are interested in measuring steady-state accelerations. That is to say, we are interested in a measure of acceleration that may vary in time but that is nonperiodic [20]. In this application, the frequency at which the acceleration changes is low (< 50 Hz).

Generally speaking, the accelerometers should have the following characteristics:

1) Adequate range to cover expected acceleration magnitudes.
2) A natural frequency higher than twice the frequency at which the measured acceleration changes.

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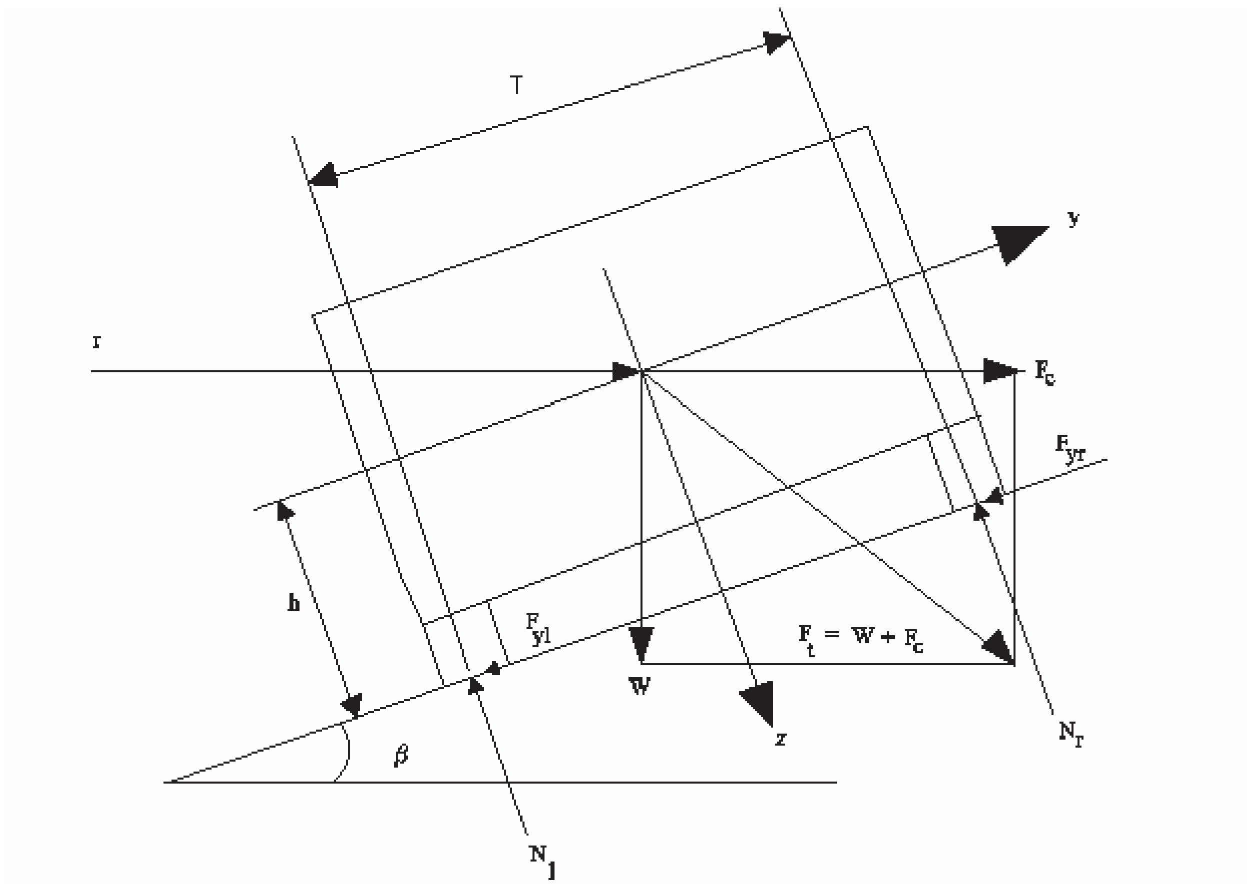
Therefore, taking into consideration the above statements, in this paper the Analog Devices dual-axis accelerometer ADXL202 was used. Such a sensor is a low cost, low power, complete 2-axis accelerometer with a measurement range of $\pm$ 2g and sensitivity 312 mV/g, where g is the gravitational acceleration (9.81m/s2). Also, this sensor can measure both dynamic acceleration (e.g., vibration) and static acceleration (e.g., gravity). Furthermore, the bandwidth of such an accelerometer may be set from 0.01 Hz to 5 kHz, and the typical noise floor is $500\,\mu g/\sqrt{Hz}$ allowing signals below 5 mg to be resolved for bandwidths below 60 Hz.

2. Rollover sensor system and mathematical modeling

In order to obtain an approximation of the model of the system, it is usually assumed that the movement of the car's center of gravity can be discarded [48, 49]. That is to say, it is assumed that the car has a stiff suspension. Thus, the movement of the car's center of gravity owing to the flexibility of the suspension is disregarded.

Figure 2 shows the mechanical model of the system. In such a figure the car is seen from the front. Furthermore, experience tells us that the influence that the movement of the car's center of gravity exerts on the measure of both the acceleration of the car in the y direction and the acceleration of the car in the z direction (see Fig. 2) can be discarded.



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In Fig. 2 a dual-axis accelerometer is situated at the car's center of gravity with one of its axes sensing the acceleration in the y direction and the other in the z direction. Also, T represents the track width, r is the radius of the curvature of the path of motion, F_c is the centrifugal force, h is the height of the car's center of gravity, and F_{yl} and F_{yr} are friction forces that prevent the car from sliding off of the road. In addition, W represents the weight of the car, β is the degree of inclination of the curve in the road, N_l is the normal force between the left front tire and the ground, and N_r is the normal force between the right front tire and the ground. Furthermore, the total forces in the y and z axis are

$$F_y = ma_y = F_c \cos\beta - W\sin\beta \tag{4}$$

$$F_z = ma_z = W\cos\beta + F_c \sin\beta \tag{5}$$

$$F_c = m\frac{v^2}{r} \tag{6}$$

$$W = mg \tag{7}$$

where F_y is the total force in the y axis, F_z is the total force in the z axis, v is the longitudinal speed of the car, m is the mass of the car, g is the gravitational acceleration, a_y is the acceleration in the y direction and a_z is the acceleration in the z direction.

Therefore, analyzing the mechanical model shown in Fig. 2, it can be said that the car is bound to roll over if the vector indicating the force F_t strikes the ground at any point lying to the right of the center of the front right wheel. What is more, it can also be said that Eq. (4) and Eq. (5) are the orthogonal projections of F_t on the y and z axis, respectively; and that the car will roll over if

$$\frac{F_y}{F_z} = \frac{T}{2h} \tag{8}$$

Also, as it can be seen from Eq. (4) and Eq. (5) that

$$\frac{F_y}{F_z} = \frac{a_y}{a_z}$$

Eq. (8) can also be given by

$$\frac{a_y}{a_z} = \frac{T}{2h}$$

The rollover angle is

$$\gamma = \tan^{-1}\left(\frac{T}{2h}\right) \tag{9}$$

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