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A Predictive Rollover Sensor

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ABSTRACT

A simple system composed of a single axis accelerometer or inclinometer, an inexpensive solid-state rate gyro and a micro-controller is explored as a predictive rollover sensor. Inclinometers or accelerometers alone cannot predict rollover due to the effects of lateral forces during turns. These forces cause such systems to over estimate the roll angle of the vehicle by a wide margin, resulting in false alarms and rendering them useless. Inexpensive solid-state rate gyros are likewise not up to the task because of large variations in the bias both under temperature and parametric variations. Using both of these sensors along with proprietary algorithms similar to those developed for the Archangel Air Data Attitude Heading Reference System (ADAHRS) for aviation, a successful predictive system can be constructed.

Using Fuzzy Logic Adaptive Signal Processing (FLASP) algorithms, the drift is removed from the gyro in real time without extensive calibrations or modeling and the effects of lateral forces are removed from the accelerometer/inclinometer. This results in a system possessing redundant and, therefore, highly reliable information concerning both the roll rate and angle of the vehicle. The efficacy of this method is clearly demonstrated by the flight proven Archangel ADAHRS used in aircraft.

In the system, the combination of the roll rate and angle are used to predict an impending rollover up to 500 ms in advance[1]. This information used in conjunction with an active yaw control system could be used to prevent the rollover. Failing prevention, the information could be used to deploy airbags to minimize passenger danger.

INTRODUCTION

Approximately 8.2 million Light Truck Vehicles, which include Sports Utility Vehicles (SUV) are produced yearly worldwide[2]. Currently, 120 models of SUV are offered for sale by 16 manufacturers under 28 brand names. All of these vehicles possess rollover problems. The Chevrolet/GMC Blazer has the worst record with over 55,000 rollovers last year[3]. New fatality figures show that 10,694 people died in rollovers last year and SUVs has the highest rate, by far, with 62% of all SUV deaths occurring in rollovers[4]. Countless lives can be saved with the introduction of rollover warning and prevention systems. Central to this effort is the development of early predictive rollover sensor systems.

The system presented here is composed of a single-axis piezoelectric angular rate sensor, a solid state accelerometer, analog signal conditioning circuits, power conditioning circuits and a micro-controller with CAN output. The accelerometer is mounted to sense lateral accelerations, while the gyro is mounted to sense roll rate. Mass production costs of the system are estimated to be under $15 (MEMS Gyro - $8, MEMS accelerometer - $5, PIC micro-controller - $2) while weight is estimated at 3 oz. The FLASP algorithms have been extended and modified to enable the use of extremely low-cost gyro chips such as the Tokin ceramic chips.

The micro-controller samples both the accelerometer and gyro outputs. Using these signals and the proprietary FLASP algorithms[5], the drift and drift variance due to temperature and random walk are removed from the gyroscopic measurement yielding a high fidelity roll rate signal. The roll rate is numerically integrated to form roll, which is corrected using the FLASP proprietary algorithms to remove any residual effects. The roll and roll rate signals are then fed into the predictive filter.

The output of typical low-cost gyro sensors is composed of signal (roll rate), noise, acceleration effects and thermally induced drift. Without extensive device characterizations, even the better devices cannot usually yield useful angular rate information. Very low cost devices do not even have repeatable thermal characteristics. Additionally, bias variations can exceed the maximum signal output by a factor of 2 or 3.

While other systems exist to detect rollover, they either use a triad of accelerometers and several gyroscopic sensors[6] or are not predictive[7] or use a wide variety of sensors including gyros, accelerometers and vehicle speed.[8] While one of these uses the same sensor set to predict rollover a higher grade of sensors is required. Additionally, extensive device characterizations are required in order to correct for the temperature induced drift and scale factor changes. In the present system, no sensor calibrations are performed on the gyro sensors. All corrections are performed in real time using the FLASP proprietary algorithms.

In the present work, all data were generated by a tractor-trailer simulation ArcSim.[9] These data were then used in the predictive algorithm developed in Matlab. A simple quadratic fit to the roll data, over a varying number of points, was performed. This fit was then extended over the same number of points to predict the roll from 5 to 20 sample periods in the future. This simple method is one that can be easily adapted to micro-controllers since the number of data points per fit is small.

RESULTS

Figure 1 shows the yaw rate of the vehicle during the maneuver while Figure 2 shows the lateral acceleration. It can be clearly seen from these two figures that lateral acceleration cannot be used by itself to determine the roll angle or when a rollover will occur. Lateral acceleration increases drastically during the non-banked turn at the beginning of the maneuver and likewise decreases later during the reactionary motion. In both cases, any roll angle determined by the inverse sine of lateral acceleration will grossly overestimate the roll angle. As a good example, the roll angle estimated from lateral acceleration at 0.5 seconds is 16.2°, while the actual roll angle is only 1°.

Figure 3 shows the actual roll angle for the maneuver along with the predicted roll angle using a five-point least-squares, fit to a quadratic and projecting ahead 5 samples. The projection is, therefore, made about 250 ms before the data. The actual point where a rollover is inevitable occurs at -40° (t = 2.95). This point is accurately predicted at t = 2.70.

Prediction error for the five-sample projection is shown in Figure 4. As can be seen in this figure, prediction error is bounded by approximately 1.5° until 3 seconds. At this time, the ArcSim program limited the roll angle to -45°, while the prediction continued to decrease. At the critical point of -40°, the prediction error is -1.0°. This error increases our estimated time to rollover by about 2 ms.

In all figures, “ * * * * ” indicates estimates while solid lines indicate ArcSim data.

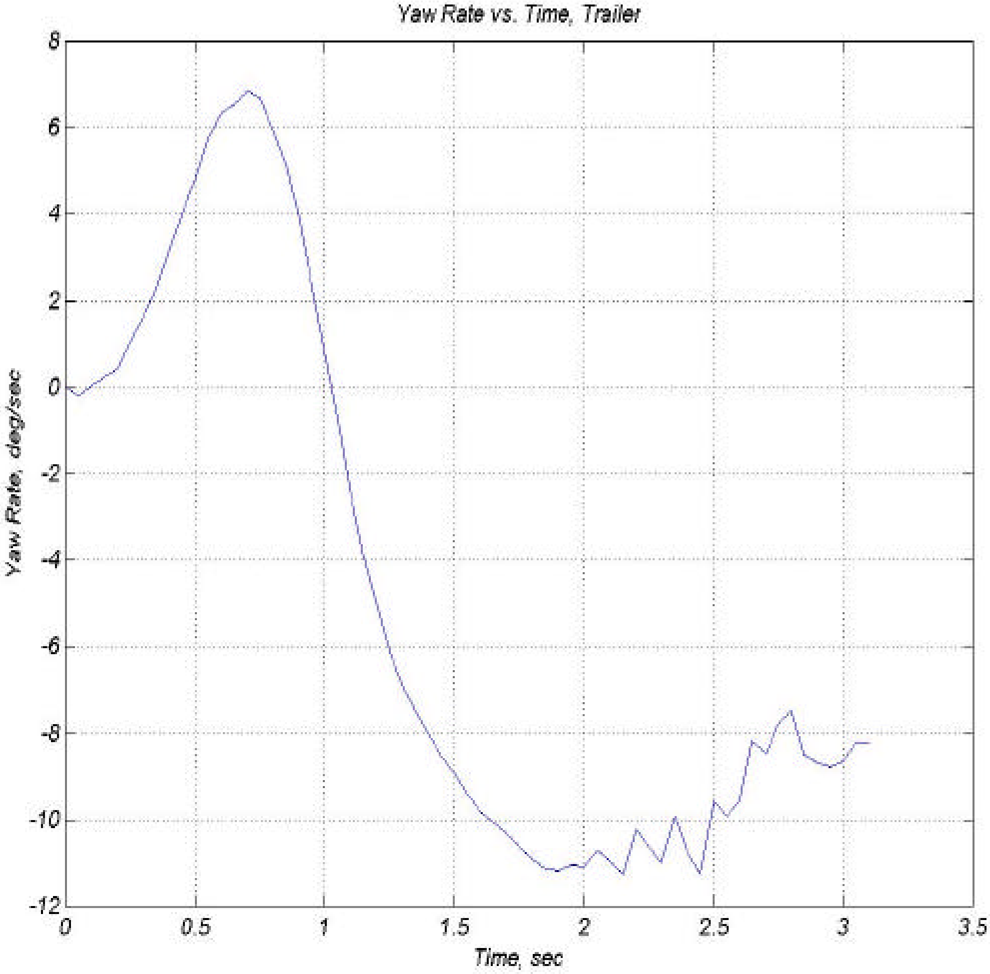

Figure 1: Yaw Rate (degree/s) vs. Time

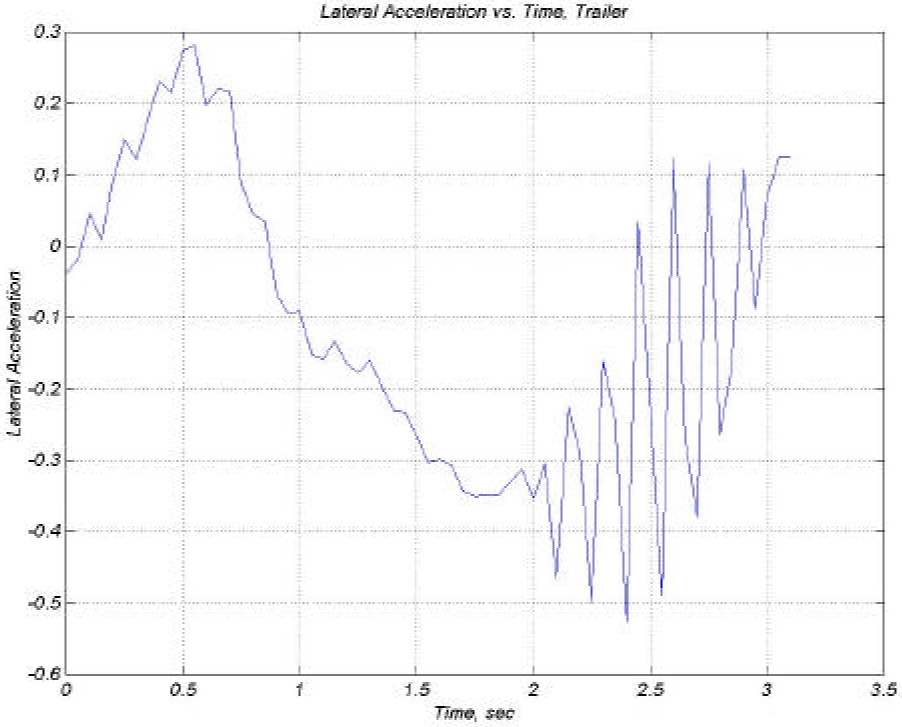

Figure 2 Lateral Acceleration (g)

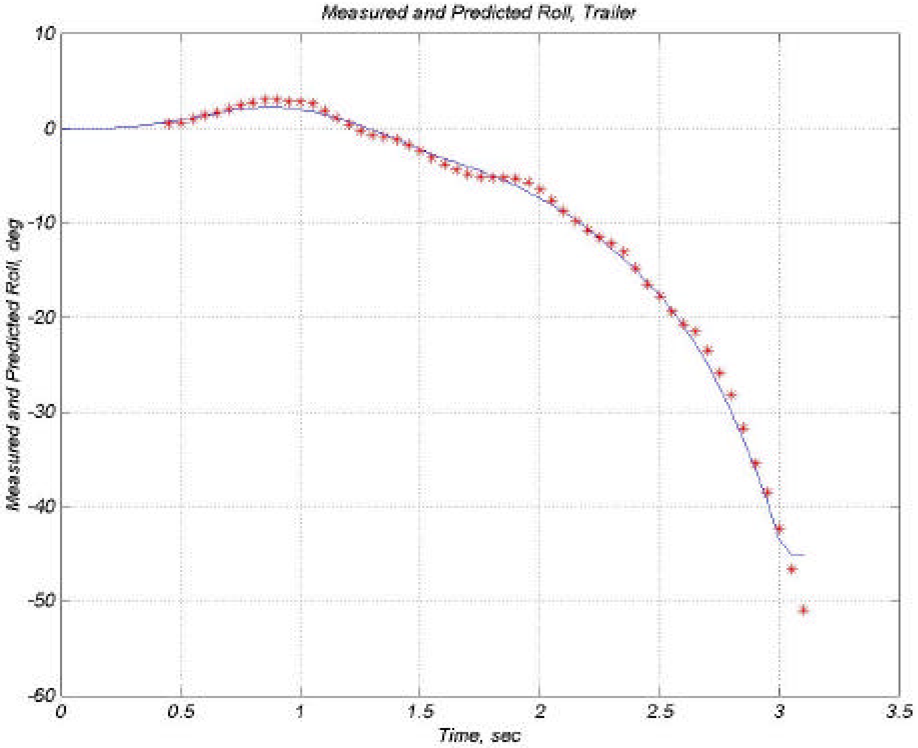

Figure 3: Roll Angle and Predicted Roll Angle Using 5 Samples

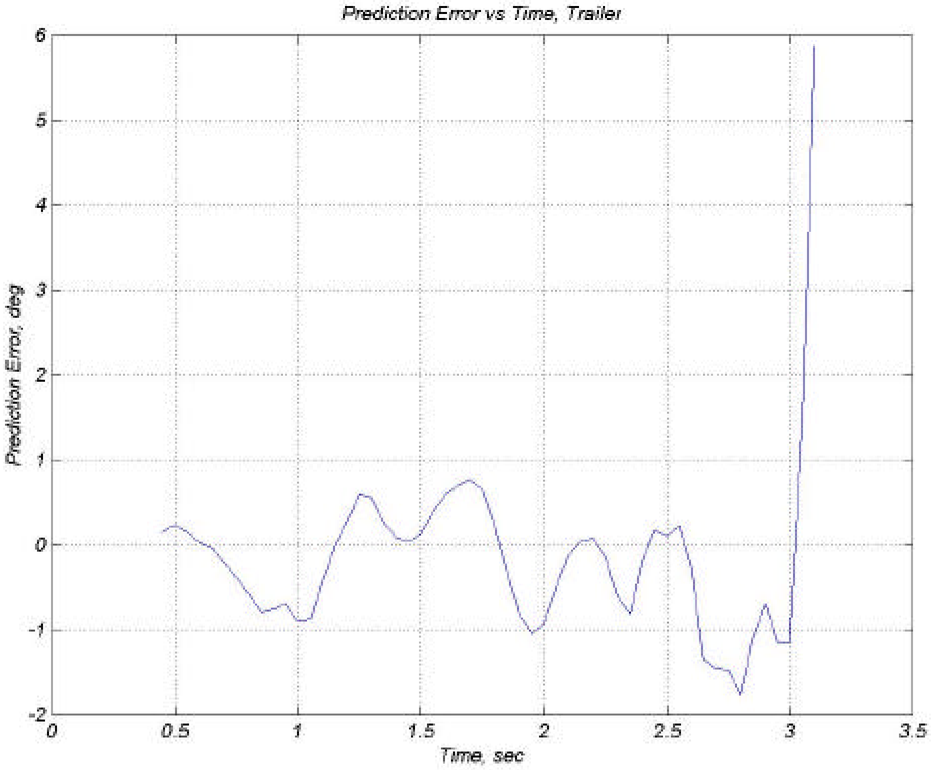

Figure 4: Roll Prediction Error Using 5 Samples

Figure 5 shows the actual roll angle for the maneuver along with the predicted roll angle using a ten-point least-squares, fit to a quadratic and projecting ahead 10 samples. The projection is, therefore, made about 500 ms before the data. The actual point where a rollover is inevitable occurs at -40° (t = 2.95). This point is accurately predicted at t = 2.55 seconds.

Prediction error for the ten-sample projection is shown in Figure 6. As can be seen in this figure, prediction error is bounded by approximately 2.5° until around 3 seconds. At this time, the ArcSim program limited the roll angle to -45°, while the prediction continued to decrease.

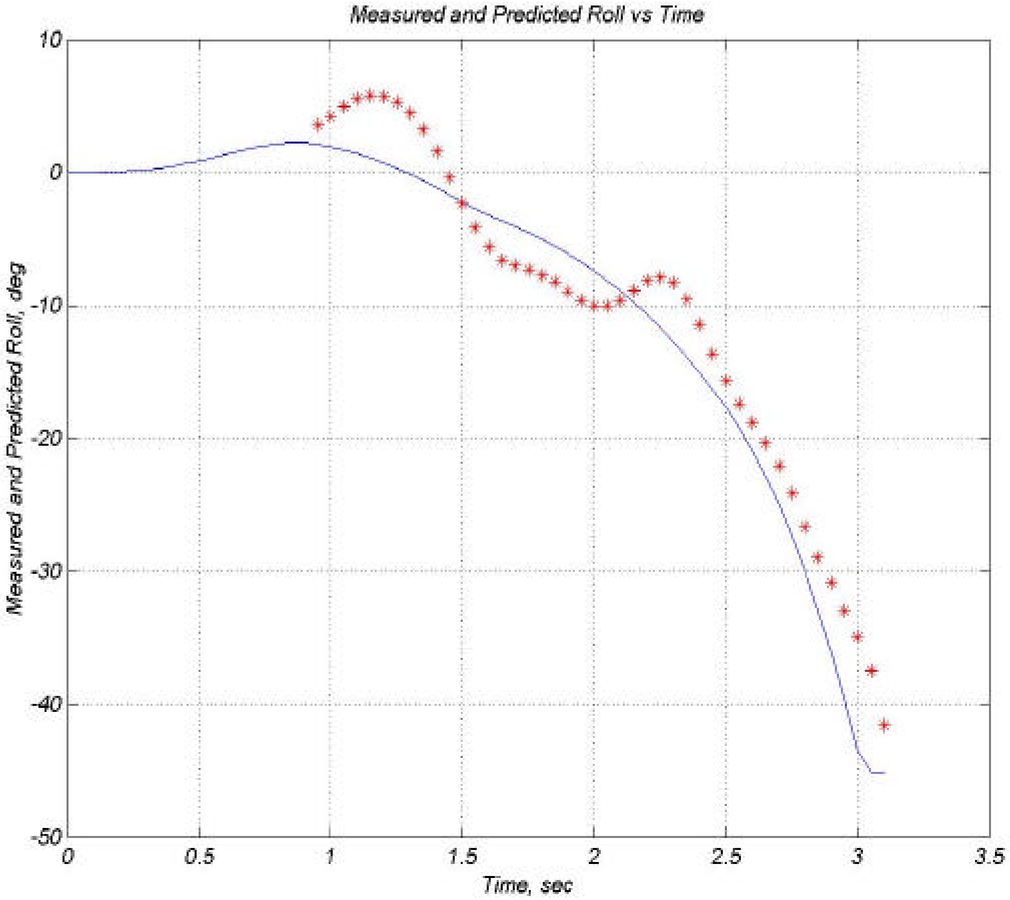

Figure 5: Roll Angle and Predicted Roll Angle Using 10 Samples

As seen in Figure 7 the vehicle will rollover above a certain roll angle (~40°). Likewise above a certain rate, the suspension system of the vehicle is unable to prevent a rollover. Between these two extremes, the combination of angle and rate becomes important. While the present work uses the rate by integrating to angle to fit the polynomial, it did not directly address this effect. This will be addressed in follow-on work.

CONCLUSION

Accurate prediction of the impending rollover has been shown in this study using a simple system composed of low-cost gyroscopic and accelerometer measures. Predictions up to 500 ms beforehand have been demonstrated. With faster rollovers in smaller vehicles, the rollover event is of a higher frequency resulting in rollovers of under 200 ms. In such cases, the roll rate is significantly higher and the prediction occurs much faster. It is envisioned that in such systems the sampling rate can be significantly increased, thus decreasing the time required for rollover prediction. However, detailed investigation of such cases remains a topic of future investigations.

Such predictions enable the use of the signal to trigger traction control and braking control systems actions, which could prevent the rollover from occurring. The signal could furthermore be used to inflate side air bags to prevent passenger injury once a rollover cannot be prevented.

These predictions are based on proprietary FLASP algorithms using accelerometer and gyroscopic inputs to remove the drift and residual effects of the low cost, solid state (MEMS) gyroscopes.

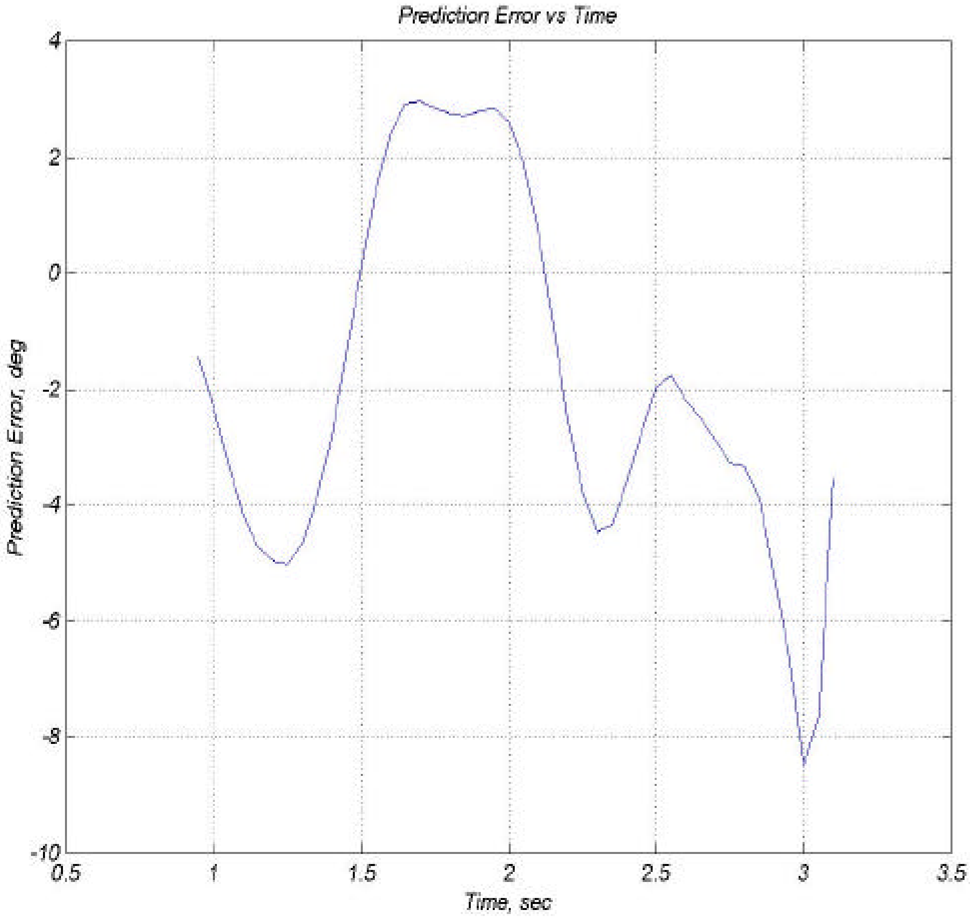

Figure 6: Roll Prediction Error Using 10 Samples

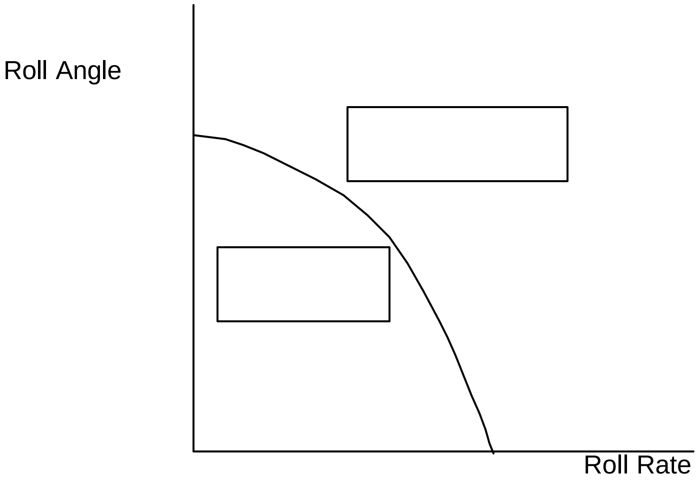

Figure 7: Regions of Stability

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