A System to Comprehend a Motorcycle's Behavior using the Acceleration and Gyro Sensors on a Smartphone

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Abstract

Intelligent transportation systems (ITS), which utilize information communication technology, have been researched and developed recently. Most of them are designed for cars or do not consider to be used for motorcycles. One of the reasons why it is difficult for motorcycle to use the conventional ITS is that mobility and motion of a motorcycle are different from a car. To comprehend such behaviours, we equip a motorcycle with a smartphone and utilize the acceleration and gyro sensors on the smartphone. We develop an application to collect the data of the behaviours, and we discuss a way to remove the noises from the obtained data.
Keywords: motion sensing, vehicle behavior, motorcycle, smartphone, ITS

Introduction

Recently, intelligent transportation systems (ITS) have attracted considerable notice. ITS utilizes information technology to realize safety and efficiently for traffic and road. There are many research fields for ITS such as development of an advanced high technology car navigation system and optimization of traffic management. One of them is a safety driving system, and it has been researched actively. In Japan, major automotive companies have become enrolled in a project named ASV (advanced safety vehicle) [1] by Japanese government. The ASV project includes collision avoidance systems; safety drive assistants with stereo cameras; dissemination of traffic jam information and danger area information with inter-vehicle communication and road-to-vehicle communication. These systems are not developed only for cars (four-wheel vehicles), but they do not consider to be used for motorcycles (two-wheel vehicles).

The behaviors of motorcycle are much different from that of car. For example, a motorcycle can run through neighboring cars, and it leans its body to turn a corner whereas a car does not lean. Such differences between motorcycle and car are classified by the reasons: its hardware, handling method, body behavior and mobility. As the differences of hardware, the size of a motorcycle's body is smaller than that of a car, and a motorcycle cannot be self-standing. When a motorcycle is involved in a traffic accident, the rider is easy to fall in a danger situation because a motorcycle's body is small and it does not protect the rider. According to the statistics of traffic by Japanese National Police Agency in 2011 [2], motorcycle riders is much more likely to have a death or heavy injury than car drivers at a traffic accident. Since the body size of a motorcycle is small, it is not easy for other drives to notice the presence of a motorcycle. In addition a motorcycle has less space to equip ITS devices than a car. As a result, motorcycle could not equip with a system which implements a convenient ITS services designed for a car.

In this research, we aim at accident avoidance for motorcycle. In order to comprehend the vehicle state of a motorcycle, we develop a system to correct the behavior of a motorcycle. We utilize the tri-axial acceleration sensor, the tri-axial gyro sensor and the GPS receiver on a smartphone to realize the system at low cost.

In this paper, we propose a system to correct measuring data of a motorcycle's behavior from the sensors on a smartphone. Many ITS services have been developed so far, but most of them have not become common. One of the major reasons is that a vehicle needs to equip expensive devices to receive the benefit of services. A smartphone is becoming popular in the world and has a lot of sensors such as a GPS receiver, an acceleration sensor and a gyro sensor. Therefore we use sensors in a smartphone to comprehend a motorcycle's behaviors without installing new devices. Also a smartphone can be used as a platform of ITS application.

To comprehend a motorcycle's behavior, we make our proposed system discriminate the following behaviors: going forward, stopping, turning left or right, running through neighboring vehicles from sensed values. First of all, we make our system to be able to discriminate the following primitive behaviors of motorcycle. The primitive behaviors consist of the following four primitive motilities: speed up, slow down, constant velocity, and stopping and the following three primitive attitudes: uprightness, tilt to right, tilt to left. A variety of the behaviors can be expressed by combining these two types of primitives. Therefore, if it is possible that the system distinguishes from these primitives by the value of the sensor, the system becomes possible to comprehend the behavior. For example, when in the case that the derived mobility is speed up, speed down or constant velocity, and the derived primitive attitude is uprightness, the system can conclude that the behavior is going forward. We develop a sensing application for collecting sensing data to derive the primitives.

Related Work

Japanese major automotive companies have become enrolled in a project named ASV (advanced safety vehicle) [1]. In the ASV project, HONDA has developed a

system to prevent to drive erratically [3]. This system is implemented into a car navigation system. It gets a value of the speed sensor and the gyro sensor and calculates the trajectory of the car with the obtained data. This system gives warning to the driver if the derived trajectory turns away from standard value. Most of existing ITS services are designed for a car, and they are not considered to be used for motorcycle.
There are many differences between car and motorcycle as shown in Table1.

Table 1 Characteristics of Car and Motorcycle

Compare	Motorcycle	Car
How to turn a corner	Lean the body	Turn the steering wheel
Shinny through	Possible	Impossible
Rooms for devices	Less	Enough
At an accident	A rider damages directly	The cabin protects a driver
Visibility	Low	High

The rider on a motorcycle is in more dangerous than the driver on a car at an accident. A motorcycle's body does not protect the rider whereas the cabin of a car protects the driver and passengers. A rider is more likely to be injured than a car driver. Nevertheless, ITS services for motorcycles are few.

The differences between motorcycle and car are classified into the four aspects: hardware, handling way, body behavior and mobility. From the stand point of hardware, a motorcycle's body is smaller than that of a car, and a motorcycle cannot stand on its own. Due to the small body, it is not easy for other drives to notice the presence of a motorcycle. In addition a motorcycle has less space to equip ITS devices. As a result, it is difficult for a motorcycle to equip with a system which implements a convenient ITS services designed for a car.

Since a motorcycle cannot be self-standing, a rider must balance during riding it. To turn a corner, a rider needs to lean the motorcycle's body. To ride a motorcycle needs a different handling method comparing to driving a car. The behaviors of a motorcycle are also different from that of a car. From our preliminary experiment where we used a tri-axial acceleration sensor installed on a motorcycle and a car, the obtained acceleration values of on a motorcycle are different from that on a car at a corner [4].

Since the body size is small, a motorcycle can go through the roads which a car cannot do and only motorcycles can run through between neighboring cars. Such a motorcycle's mobility makes it harder for other car drivers to find neighboring motorcycles. This is one reason of traffic accidents with a motorcycle due to escaping the attention of the motorcycle.

In this research, we aim at accident avoidance for motorcycles. In order to comprehend the vehicle state of a motorcycle, we develop a system to correct data of the behavior of a motorcycle. We utilize the tri-axial acceleration sensor, the tri-axial gyro sensor and the GPS receiver on a smartphone to realize the system inexpensively.

Activity sensing

The research area for recognizing human activity has been getting the attention. There is a research for collecting a lot of human activity data and making its database. This research by Human Activity sensing Consortium (HASC) [5] uses GPS, acceleration sensor, gyro sensor and pneumatic sensor. This is a challenge of make big database for help to recognize human activity.

There are also researches: recognizing human activity with acceleration sensors [6,7] and driving analysis based on car mobility prediction [8]. These method cannot directly use to motorcycles because motorcycles' behaviors are some different from human or car. Motorcycle's behavior recognition is used for improving turning performance at motoGP, but it does not focus on street.

A motorcycle behavior collecting system with a smartphone

To realize a traffic safety for motorcycles, we need to comprehend their behaviors and to develop an ITS service considering the vehicle state. As the first phase of this research, in this paper, we develop a smartphone application with the acceleration sensor, the gyro sensor and the GPS receiver on a smartphone to collect the data during riding on a motorcycle. This section provides the detail of the proposed smartphone application and its system architecture.

System architecture

We mount a smart-phone on a motor-cycle's handle to collect sensing data of the acceleration sensor, the gyro sensor and the GPS on it.

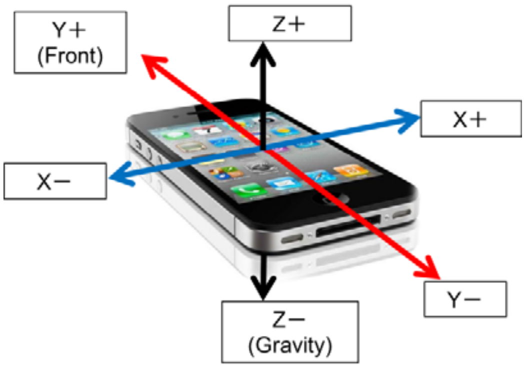


Figure 1 : Axes of the acceralation and gyro sensors

A tri-axial acceleration sensor gets three dimensional acceleration values (X, Y, Z). By this acceleration sensor, it will be possible to get back and forth, side to side and up and down acceleration. If we set a smartphone on a motorcycle turning up the smartphone's display as shown in Figure 1, when the motorcycle is speeding up, the acceleration sensor gets negative Y value, and when the motorcycle is slowing down, the acceleration sensor gets positive Y value.

Similarly, a tri-axial gyro sensor gets three dimensional angular velocities (X, Y, Z) as shown in Figure 1. By this gyro sensor, it will be possible to get pitching, rolling and yawing motion. The pitching motion is obtained as change of X-axis value and clockwise rotation leads positive value. Also, the rolling motion and the yawing motion are obtained from Y-axis value and Z-axis value, respectively.

The purpose of system

The purpose of this system is to comprehend a motorcycle's behaviors. To comprehend the motorcycle's behavior, we make our proposed system discriminate the following five behaviors: going forward, stopping, turning left or right, running through neighboring vehicles from sensed value.

First of all, we make our system to be able to discriminate the primitive behaviors of motorcycle. The primitive behaviors consist of the primitive states of speed: speed up, speed down, constant velocity, and stopping and the primitive attitudes: uprightness, tilt to right, tilt to left. A variety of the behaviors can be expressed by combining these primitives. Therefore, if it is possible that the system distinguishes from these primitives by the value of the sensor, the system becomes possible to comprehend the behaviors. For example, when the comprehended primitive state of state is speed up, speed down or constant velocity, and the comprehended primitive attitude is uprightness, the system can decide that the behavior is going forward. We develop a sensing application for collecting sensing data to discriminate the primitives.

Develop an application

In this paper, we use Apple iPhone4S as a smartphone, and develop iPhone application that outputs CSV-data with the acceleration sensor's value, the gyro sensor's value, the GPS receiver's value and time. According to our test application, application on iPhone4S can sample these sensors' values at 80Hz maximum without any other application loaded. We set the sampling rate of the proposed application for 50Hz for stability. The application stores the data within iPhone4S, and after we examine and analyze that data later.

Data collection from the smartphone on a motorcycle

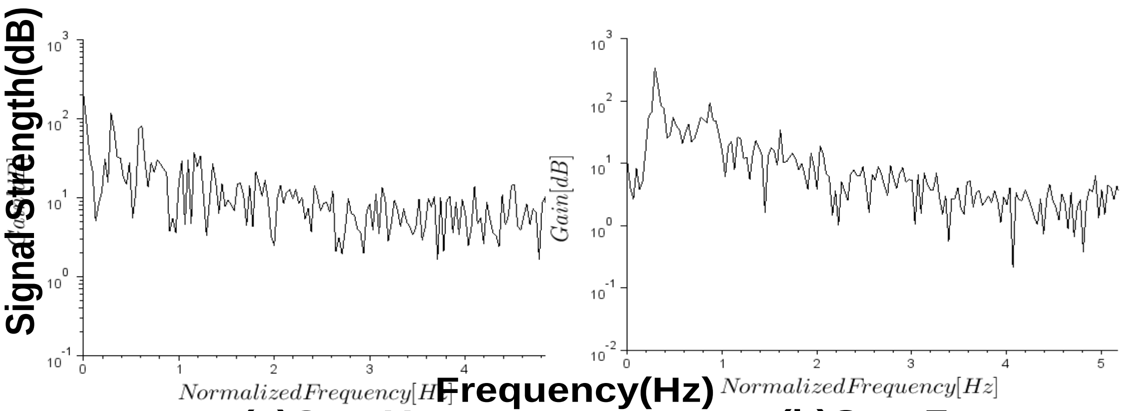
In this section, we analyze sensing data from the smartphone on a motorcycle. As a result, noise becomes something of a problem.

Collecting sensing data

Data collected by a smartphone includes the behaviors of riding operation as well as noise. The frequency of human motion has limitations and that of noises is, generally, much higher. A smartphone on a motorcycle gets vibrations from the engine and the road during running. These vibrations make large amounts of noise for the acceleration and gyro sensors' values. It is difficult to comprehend the behavior of a motorcycle with such noises. Therefore we need to remove noises to get the right signals of the behavior. Such noises consist of engine noise, road noise and noise from wind. The frequency of engine noise is proportional to the number of revolutions of the engine and it is 20Hz when the engine is idling with 1200rpm and it is 100Hz when running at 6000rpm. Road noise is from the vibration of tire hitting the road's bumps. The frequencies of road noise and wind noise are proportional to the speed of a motorcycle. The frequencies of these noises are higher than the signal of the motorcycle's behavior handled by human. Given the handling frequency of a motor-cycle as $\mathrm{H}_{\mathrm{behaivior}}$ and the noise frequency as $\mathrm{H}_{\mathrm{noise}}$, the following equality holds

$$\mathrm{H}_{\mathrm{noise}} \gg \mathrm{H}_{\mathrm{behaivior}}.$$

The quickest behavior of a motorcycle can be considered as overtaking and pass through other vehicles. Thus, we assume that the behavior of 10m-interval slalom as the fastest behavior, and we remove higher-frequency signals than the signal of 10m-interval slalom. Figure2 shows the result of Fourier analysis of the signal of 10m-interval slalom with a 600cc standard-type motorcycle (Yamaha FZ6N). As shown in Figure2, each signal, Y-axis Gyro and Z-axis Gyro, has two peaks at about 0.3Hz and 0.6Hz. The peak of 0.6Hz is considered to denote the throttle control, and that of 0.3Hz denotes the body turning for slalom. Therefore, it is considered that the maximum frequency of the behavior of a motorcycle by the rider is less than 1Hz.



(a)GyroY (b)GyroZ

Figure 2: FFT result of signals of 10m-interval sralom

Low Pass Filter (LPF)

To remove the noises from the acquired sensing raw data, we use a low-pass filter (LPF). We examine the two types of LPF: a finite impulse response (FIR) circuit and an infinite impulse response (IIR) circuit. We show the characteristics of LPF in Table2. M[x] denotes the modified data at time x, R[x] denotes the raw data at time x, N denotes the number of samples and x is the index of the sample.

IIR is often used in smartphone application because it needs less CPU power and less storage space. It can reduce the strength of signals with higher frequency, but it cannot remove the signals with higher frequency well because of the lack of flexibility for the parameter α. Thus, in this research, we adopt FIR as LPF.

Table 2 FIR vs IIR

FIR	IIR
$M[x]=\sum_{x=0}^{N}\alpha_i R[x-i]$	$M[x]=\alpha\cdot R[x]+(1-\alpha)\cdot M[x-1]$
• A lot of flexibility of $\boldsymbol{\alpha_i}$ • It can remove over any frequency with apposite $\boldsymbol{\alpha_i}$. • It needs to keep old data	• Just one flexibility of α. • The cutoff performance is low • Amount of calculation is low. • It is most commonly used in smartphone application. • Do not need to keep old data.

With a filter designing application [9], we configure FIR's parameters $\boldsymbol{\alpha_i}$. The original signals for Figures 3 and 4 are from 12-turn slalom. Figure 3 shows the signals after FIR filter under the following setting: N is 24, the sampling rate is 50Hz and the cutoff frequency is 1Hz, and Figure 4 shows that of under the following settings: N is 50 and the other parameters are same as Figure 3. Note that the cutoff frequency means the frequency where the gain of the signal strength is -20dB.

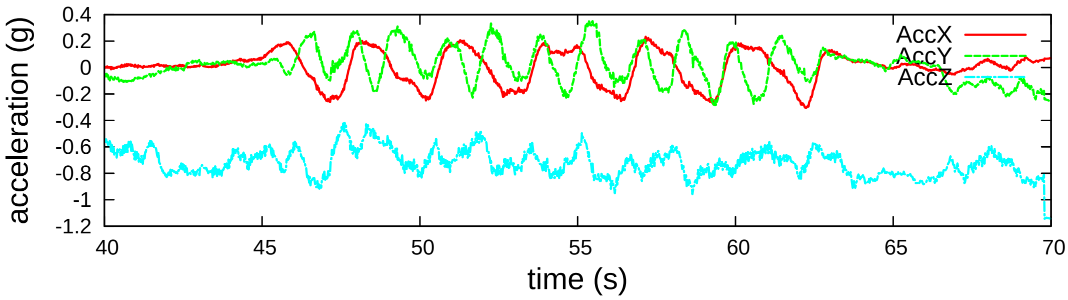


Figure 3:FIR with N = 24

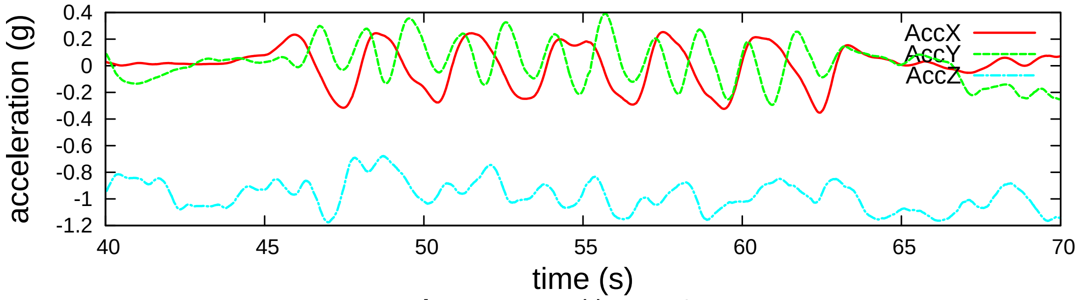


Figure 4:FIR with N = 50

The larger N leads the better cutoff result but the larger N leads the longer response time. In this case, 50 samples correspond to 1 second, and we assume that 1 second is allowable for our research. Therefore, we decide to use FIR with N=50.

Experiments

In this section, we describe our experiments and then present and discuss our results for comprehending a motorcycle's behavior.

Description of Experiments

Two types of experiment have been performed: (1) to investigate which sensor value is suitable to discriminate each behavior, and (2) to confirm if the sensors on a smartphone are enough to discriminate each behavior.

The first experiment was performed along the peripheral road (400mx300m) of Hamamatsu campus, Shizuoka University. We used a 50cc scooter-type motorcycle (Suzuki Let's 4) as an experimental vehicle and iPhone4S as smart-phone. The author rode the motorcycle and run the road six times.

In the second experiment, we used two additional dedicated sensors to confirm whether the sensors on a smartphone are enough to comprehend the behaviors. We developed a dedicated sensor that consists of a tri-axial acceleration sensor, a tri-axial gyro sensor and a GPS receiver. The sampling rate of the acceleration and gyro sensors is set to 100Hz. In this experiment, we used a 400cc sport-type motorcycle (Honda RVF), put a smartphone on a handle and put two of the dedicated sensors on the front tire house and on the top of the gas tank to see the difference between the top of and under the front suspension.

Result

(1) Figure 5 shows the obtained GPS data. We can know where it ran from the data, but it is not enough to use for safety drive assist because this data have some amount of measurement error.

Figure 5:result of GPS

Figure 6 shows the obtained tri-axial acceleration sensor data. It is possible to discriminate "slow down" or "speed up" from the value of Y-axis. Since Y-axis value is rising at the time 25, 110, 150, 210 and 240 sec., respectively, this behavior can be determined as "slow down."

Figure 7 shows the angler velocity of Y-axis from the gyro sensor, and Figure 8 shows that of Z-axis. As shown in Figure7, at some points, Gyro-Y value transits from minus to plus, and these time points correspond to the time when turning left. It is because the motorcycle leans left, at that time the value becomes minus, and it raises its body, at that time the value becomes plus. Similarly, as shown in Figure8, Gyro-Z value becomes plus when turning left. The values, Gyro-Y and Gyro-Z, can be used to detect when a motorcycle turns at a corner and the direction, left or right.

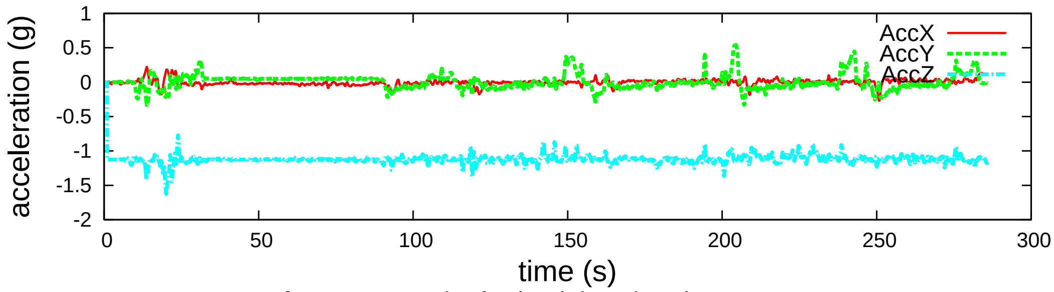


Figure 6: Result of Tri-axial accleration sensor

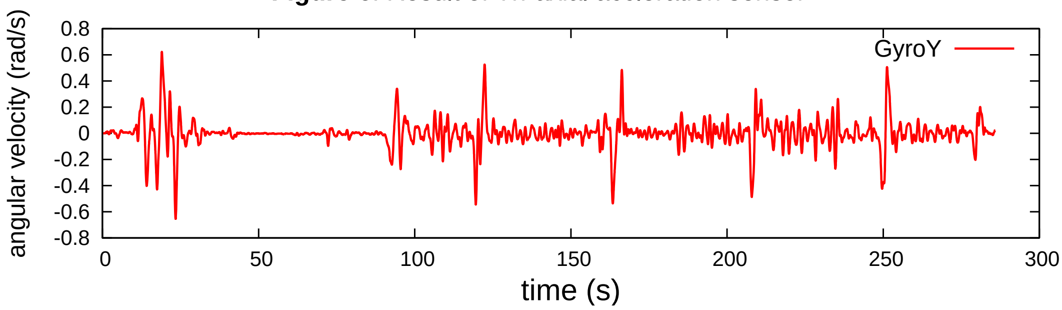


Figure 7: Result of GyroY

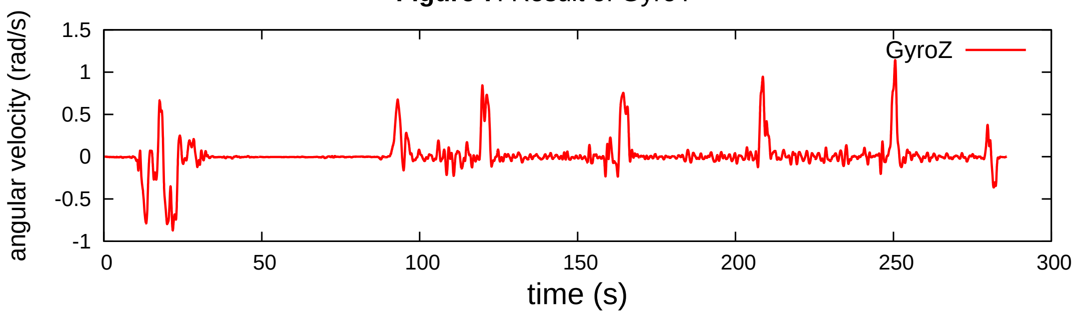


Figure 8:Result of GyroZ

(2) Figure 9 shows the obtained sensor data of the smart-phone and Figure10 shows that of the dedicated sensors. The value of Gyro-Z on the handle shown in Figure 9 is very similar to that on the tire house shown in Figure10 (Gyro1_Z) because the handle and the tire house on the same rigid body. Comparing these two values, a smartphone sensor can perform as same as a dedicated sensor. Additionally, to equip a motorcycle with two or more sensors leads some interesting result, e.g. Gyro1_Z and Gyro2_Z as shown in Figure 10. In future work, we will investigate those features.

Conclusion

In this paper, we have proposed a system to comprehend a motorcycle's behavior using a smartphone in the way of the first phase of developing a safety driving system for motorcycle. We collected sensor data with a smartphone and remove d noises with LPF. As the LPF, we adopted FIR and evaluated the parameters of FIR for our system. To comprehend motor cycle's behavior is possible to select best suited to sensor data for each behavior.

As future work, we need to investigate more data from develop a software will improve our proposal system to recognize motor cycle's distinct behavior like run through between neighboring cars.

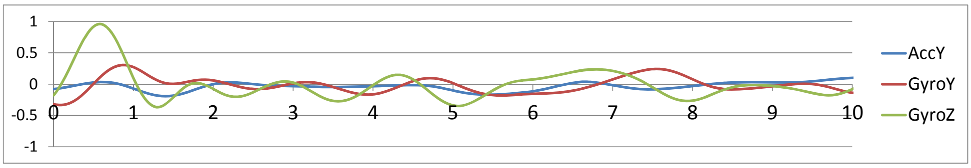


Figure 9: Obtained data from the smartphone's sensor on the handle

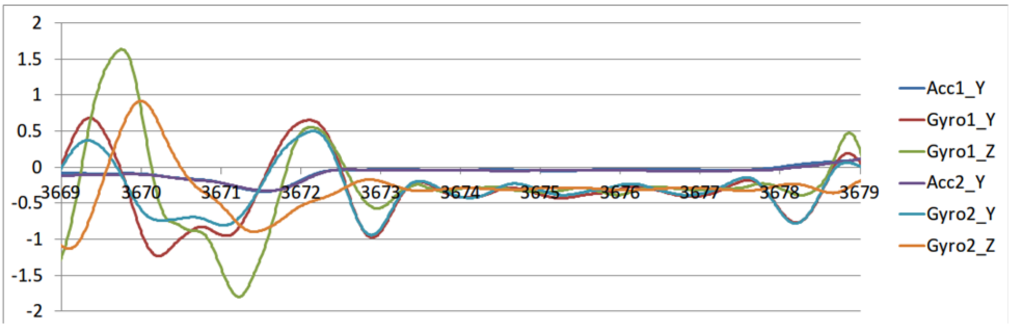


Figure 10: Obtained data from the dedicated sensors (*1: on the tire house, *2: on the gas tank)

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