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Acceleration Logger and Analyzer

Gizem KAYISOGLU
Istanbul Technical University

Seda CANPOLAT
Istanbul Technical University

Aysenur Dilara AYDIN
Istanbul Technical University

Nehir KUCUKTAS
Istanbul Technical University

Metin HUNER
Istanbul Technical University

Abstract: In the case of high acceleration values, it is important to obtain data on the vehicles used by third parties in order to prevent possible accidents. For this purpose, it is aimed to design an electronic system which will record the acceleration values of a vehicle during its journey and then to analyze it. Thanks to the accelerometer sensor placed in an experimental vehicle, the g force data that the vehicle was exposed to were obtained and analyzed by Arduino to determine which speeds the drivers were subjected to during the journey. The final product created in the study is an electronic device consisting of an Arduino, an accelerometer and an Arduino SD card reader module. After the physical connection between the elements were established, the Arduino interface was installed in the computer to obtain the instantaneous acceleration values in the direction of the acceleration of the accelerometer. After completing the physical installation of the circuit, different routes were determined within the scope of determined route in order to observe the acceleration values for different situations. The axes in each route obtained were analyzed separately by Matlab and the acceleration values were plotted. According to the results of the analysis, a maximum of +0.22 / -0.34 g at the x-axis and +0.26 / -0.25 g at the y-axis and +0.15 / -0.17 g at the z-axis were encountered during a normal driving. In contrast, in the case of unsafe use of the same vehicle, the values of +0.41 / -0.63 g on the highest x-axis, +0.33 / -0.36 g on the y-axis and +0.18 / -0.18 g on the z-axis were encountered. When the results obtained are shared with the sector and their view are received, the results of our study have been shown to be supportive of the data that the companies have already pursued, and have the characteristics that can meet the needs of the sector.

Keywords: Acceleration, Arduino, Matlab, Acceleration Logger, Sensor

Introduction

Although many positive developments have been achieved in the transportation sector today, the increase in traffic accidents raises the issue of taking some precautions. Traffic accidents, which causes both material and nonmaterial consequences for individuals and companies, have increased from 440,000 to 1,203,000 in a period of 15 years. Mortality rates in these accidents also doubled in the same period (TURKSTAT, 2018).

One of the prominent forces that act on the vehicle during accidents or their journeys is the gravitational force (G force). The force G is defined as the force exerted by gravity on a free falling object and is named after the word “gravitational”. Acceleration values that can be measured with accelerometers are called g force. That is, the “weight” value that an object produces in any direction by accelerating and decelerating by a force applied

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to it is called g-force (URL 1). A car is exposed to g-force in the direction of the component of the resistance forces exerted by the ground and air. This force can reach up to 2 g on high speed cars used in motor sports and up to 5.3 g during hard cornering (URL 2).

The human body has different tolerances to the g force. This tolerance depends on the duration, direction, intensity, body position and the center of the g force the person is exposed to (URL 1). For example, a violent slap can create momentary force up to hundreds of g, but the intensity is low. If the same event occurs a few minutes at 10-15 g, it can be fatal. In general, a normal human body is resistant to about 1 g of force. In the experiments performed, forces of 2 g or more are unusual forces and the tolerance limit of a human body can be referred to as being around 5 g (URL 1). For such reasons, it is important that data is obtained on how drivers drive during the day in company vehicles, especially in cargo companies, in order to warn drivers and prevent possible accidents when high acceleration values are recorded.

Alongside individual effects, financial losses caused by traffic accidents will also have a great impact on the logistics sector companies operating on the highway. Given the undeniable growth of the logistics sector, the identification of the factors causing traffic accidents and any positive development in any of these factors will undoubtedly have a reducing effect on these accident rates. The aim of this study was determined by considering these situations and the issue of damaged parcels which is common in customer returns for the cargo sector and has negative effects on customer satisfaction. In terms of safety of life and property, the acceleration values the vehicles have while traveling must not exceed certain limits. Otherwise, passengers and cargo will be subjected to great forces and the above-mentioned traffic accidents or customer satisfaction reducing events will occur. For the purpose of this study, we aim to obtain data on how the drivers' drive during the day and to determine what kind of dangerous situations may arise and to prevent the material and nonmaterial losses.

For this purpose, the aim is to design an electronic system to record the acceleration values of a land vehicle during its journey and then to analyze it. An accelerometer mounted on a vehicle is used in conjunction with an Arduino microprocessor, the g forces the vehicle is exposed to are obtained and later analyzed to determine the forces corresponding to different driving behaviors.

Literature Review

According to the information obtained from the literature, there are various forces acting on a vehicle. In this study, the effect of gravitational force on the vehicle and its contents is examined. During the literature review, various studies were found in this context.

In 2014, Mane and Rana demonstrated that the accelerometer can be used as a vehicle's impact or tipping detector during and after a collision, so that dangerous driving can be detected. They have used many modules such as AVR controller, accelerometer, GSM and GPS. In their architecture, when the system is found to be abnormal, it is confirmed that the accident occurred. The vehicle's vibration / acceleration is detected by the accelerometer to confirm the cause of the accident. The alarm turns on as soon as an accident is detected. In the event of a minor accident, the key remains open and messaging is terminated. In the event of a major accident, the key remains closed and a message is automatically sent to the rescue team after the location is detected by the GPS (Mane & Rana, 2014).

A similar study was conducted in 2017 by Mahamud et al. They have also developed an accident prevention system that reduces the likelihood of accidents that may occur on the roads every day, while simultaneously determining and transmitting the accident location automatically when an accident occurs. They developed an Arduino based system using Global Positioning System (GPS) and Global System for Mobile Communication (GSM). When the vehicle hits something, the speed of the vehicle and the amount of tilt are measured by an accelerometer. When the car's speed is greater than the maximum speed defined for the road, a warning is automatically issued. In addition, whenever an accident occurs, the GPS finds the geographic coordinates of that location and sends SMS using GSM (Mahamud, Monsur, & Zishan, 2017). Thus, it has been proven that a vehicle accident can be detected by an accelerometer and Arduino, which is an economical microcontroller platform.

Methodology

The method steps for the purpose of the study were completed as follows;
- circuit installation,
- writing the required codes,
- obtaining the data related to the targeted scenarios,
- displaying the written data,
- analyzing the obtained data and
- conducting the target group interviews

For these purposes, the materials used during the execution of the study are as follows;
- Arduino Uno R3
- ADXL345 3 Axis Accelerometer
- Micro SD Card Module
- Micro SD Card
- Cables
- Breadboard
- Resistance

After procuring the necessary parts, the originally planned module was started to put together. In this context, first, ADXL345 sensor connections were made with Arduino microcontroller as in Figure 1.

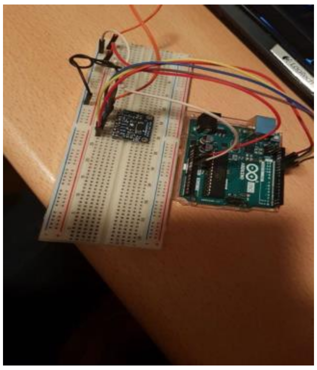


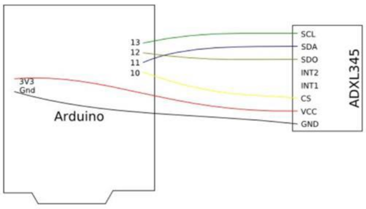
Figure 1. Connection of Arduino and ADXL 345 sensor

SPI (Serial Peripheral Interface) communication technique was used instead of I2C communication technique because of high data transfer requirements in this study. I2C is an example of synchronous communication from serial communication types. Due to the high number of transmission lines, it is not preferred for long distance communications. It is often used where short range and low data transfer rates are sufficient. SPI is one of the synchronous serial communication types that Arduino supports. In SPI protocol, unlike I2C, the data lines are unidirectional. In addition, the peripheral devices (slaves) do not need to have addresses. SPI communication technique has been chosen as the data transfer rate is suitable for this study (URL 3).

In the SPI protocol, there is one Master device just like I2C. This device controls peripheral devices connected to the transmission bus. There are three SPI lines, MISO (Master In Slave Out), MOSI (Master Out Slave In) and SCK (Serial Clock) connected to the master and peripheral devices (URL 3).
- MISO: The line where data sent from the peripheral devices (slave) is read by the master device.
- MOSI: The line where data sent from the master device is read by peripheral devices.
- SCK: This is the line where the clock signal that synchronizes the SPI communication is. The clock signal is generated by the master device.

Each peripheral device has a selection pin. This pin is called SS (Slave Select). The number of these lines is equal to the number of peripheral devices used. A separate SS line is output from the master device for each device. The peripheral device with the SS line at the LOW (0 volt) level starts to communicate with the master device. This is called “Active Low” (URL 3).

The connections between devices is made with the understanding gathered from the operating manuals of the Arduino and the accelerometer, the technical data sheets and the above information. Accordingly, the connections with the structure as in Figure 2 are made between the two devices. In Figure 2, SDA and SDI pins are described as MOSI and SDO pin is described as MISO.



Arduino Pin	ADXL345 Pin
10	CS
11	SDA
12	SDO
13	SCL
3V3	VCC
Gnd	GND

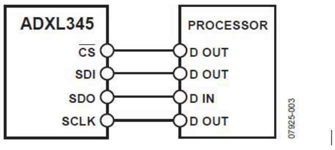


Figure 2. Arduino and ADXL345 accelerometer connection diagram

The SPI communication has either 3- or 4-wire configurations. A 4-wire configuration (CS, MOSI, MISO, SCLK) was used in this study. According to the ADXL345 accelerometer technical data sheet, it is necessary to reset bit D6 in the DATA_FORMAT register at address 0x31 to select the 4-wire SPI configuration. The maximum SPI clock speed is 5MHZ and the timing scheme follows clock polarity (CPOL) = 1 and clock phase (CPHA) = 1 (URL, 4).

The CS is the line for enabling serial communication and is controlled by the SPI master. As in Figure 3, when the data transfer starts, the CS is drawn to "low" and it becomes "high" at the end of the data transfer. SCLK is the clock of serial communication and is supplied by the SPI master. SCLK is "high" position, unless there is any data transfer. SDI and SDO are serial data input and serial data output respectively. Data is shifted on the falling edge of the SCLK and is sampled on the rising edge. To read or write multiple bytes in a single transport, the multi-byte bit must be set to "1" after the R / W bit in the first byte transfer (MB in Figure 3 and Figure 4). After the register at the address and the first data byte, each subsequent set of clock pulses (eight clock pulses) causes the ADXL345 to point to the next register for a read or write. This scroll continues until the clock pulses stop.

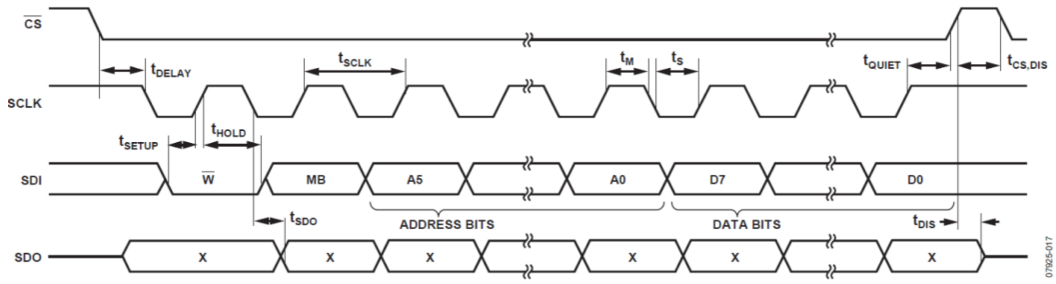


Figure 3. 4-Wire SPI writing

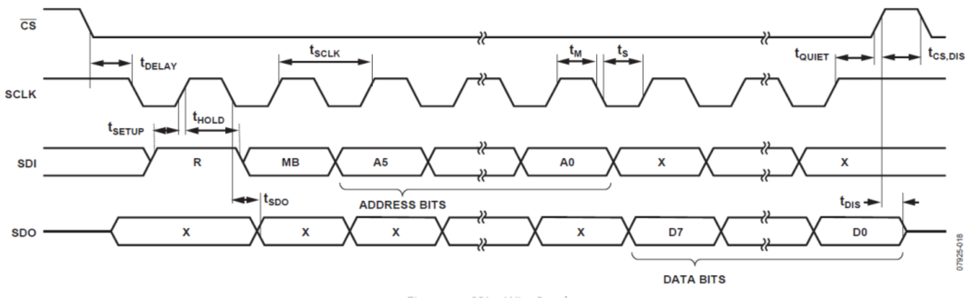


Figure 4. 4-Wire SPI reading

The use of 3200 Hz and 1600 Hz output data rates is recommended only at SPI communication speeds greater than or equal to 2 MHz. The 800 Hz output data rate is recommended only for communication rates equal to or greater than 400 kHz, and the remaining data rates are proportionally scaled. For example, for a 200 Hz output data rate, the recommended minimum communication speed is 100 kHz. Operating at an output data rate above the maximum recommended value may cause unwanted effects on acceleration data, including missing samples or additional noise. In the study, the default SPI clock speed of Arduino of 4 MHz is used.

When the ADXL345 is used on an SPI bus with multiple devices, the CS pin is kept in the “high” position while the Arduino (host) communicates with other devices (SD card) (URL 4).

The circuit established after performing the steps according to the specified method is as shown in Figure 5.

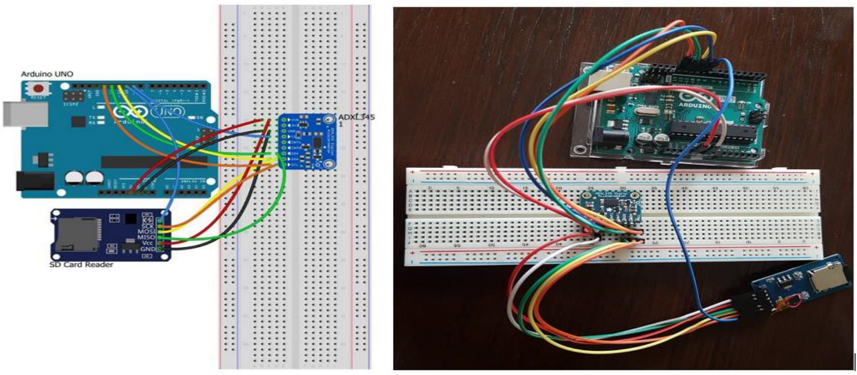


Figure 5. Completed circuit design

After the circuit was established, library codes in IDE language were added by using Arduino program and SPI communication was performed by receiving data from the sensor. In order to use SPI methods in Arduino, we had to add the library "SPI.h" to the study. The functions that initiate the SPI communication and take the SPI pins to their initial positions, set the time of the SPI communication, send or receive data to the SPI line became available when the library was added to study. First, the communication between the sensor and the Arduino with the written code was carried out with the help of the library of the ADXL345 sensor. The data was taken from the sensor and observed on the Arduino screen. In the last case, SPI communication with the sensor is provided by writing Arduino libraries and additional codes and the data is saved to SD card.

In brief, all codes are written in Arduino program in accordance with the technical information written in the user manual of the sensor and SD card and thus the data exchange of the installed circuit is ensured and the data obtained are recorded in the SD card (URL 5, 6).

Obtaining and Analyzing Data

In the process of obtaining the data, the circuit design was positioned in a vehicle and the routes determined before were followed. During this process, the computer screen for recording the path and data was recorded. After the data was written to SD card, necessary analysis process was completed via MATLAB.

Obtaining Data

In order to see changes in acceleration values, Istanbul Technical University Ayazaga Campus is chosen as the test location where many bumps, bends, slopes and distorted road characteristics are present. Before the discovery tour on the campus, the routes for the scenarios considered were determined. Afterwards, the necessary data were obtained by normal driving first and then unsafe driving based on the same starting and ending points on these routes. Unsafe driving is mainly intended to test situations that would adversely affect passenger comfort or endanger property. In addition, proceeding with two steps, namely normal and unsafe driving, makes it possible to observe the effects of changes on acceleration values according to driving style. In all figures given during routes, the first display represents normal and the second display represents unsafe driving.

Our first route is a route with certain small-scale bumps, normal bends and less inclined slopes. While there are no clear changes in the x and z coordinates while there is no skidding on a straight path along the route, the example of the magnitude of the value in y coordinate which shows an increase-decrease due to acceleration is as shown in Figure 6.

Figure 6. Route 1 speeding status

In addition, when constant speed and acceleration cases at the same locations during route 1 were examined, lower values in the y-axis was observed in the first case and greater values in the second case Figure 7.

Figure 7. Route 1 constant speed and accelerating comparison

Changes in the case of sudden braking at a constant speed or on a speeding road are as shown in Figure 8. In this scenario, positive values are read on y axis during acceleration and negative acceleration values are read on y axis when braking. The second display is for unsafe driving and it is clear that the values are more aggressive than normal driving.

Figure 8. Route 1 sudden braking attempt

As it is seen in Figure 9, while passing over a small-scale bump in our first route, the value 8 was observed in the first case and the value 13 in the second case in the z coordinates, meaning an acceleration value in the up-down direction.

Figure 9. Route 1 bump comparison

The first route involved some asphalt disturbances. It is also seen in Figure 10 that the vehicle undergoes significant acceleration value changes in all of the x, y and z coordinates while passing this point and these values reach much more prominent levels in unsafe driving.

Figure 10. Route 1 bad road comparison

The data during cornering on this route are shown in Figure 11. Visible changes in the x-coordinate of acceleration changes in the right-left direction and the magnitude of the affected acceleration values depending on the driver during normal or unsafe driving are clearly demonstrated.

Figure 11. Route 1 cornering comparison

The second route involved sharper corners than the first. In this way, we had the opportunity to compare the acceleration value changes to be observed during driving in a normal bend and a sharper bend. When we compare Figure 12 and Figure 13, we see that the values of the x coordinate have opposite signs because the bend direction is the opposite. In addition, the absolute differences in the values also reveal the differences of the sharpness of the bends.

Figure 12. Route 2 normal bend comparison

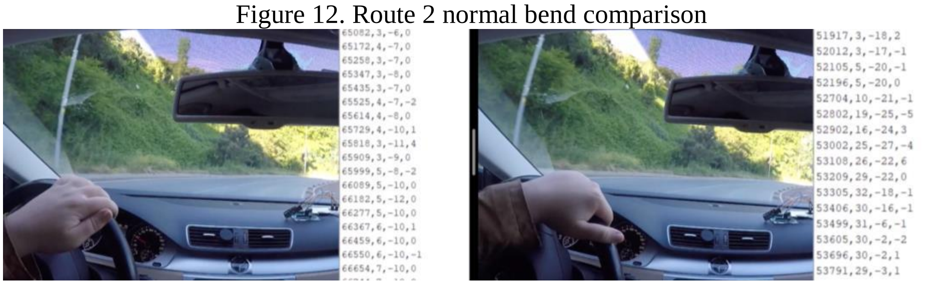


Figure 13. Route 2 sharp bend comparison

During unsafe driving, values while overtaking a vehicle at rest in Route 2 is seen in Figure 14. The x coordinate grows in negative values during the left turn and shows sharper increases in positive values during the right turn.

Figure 14. Route 2 crossover attempt

During unsafe driving of Route 2, the car is stopped with a sudden brake. At this stage, the sudden transition from -32 to 0 in y axis is shown in Figure 15.

Figure 15. Route 2 with sudden braking

In addition to route 1 and route 2, in order not to endanger the traffic and to see the changes more clearly, the parking lot on the campus was determined as route 3, where especially sudden changes in x and y coordinates were observed.

Analyzing Data

It is observed that the acceleration data from test drives have noise. Any noise should be eliminated in order to evaluate the data more accurately. MATLAB was used for the filtering of noise. As a way of filtering, Lowpass Chebyshev Type II filter was utilized. This filter was selected because it has no passband ripples and a sharper cutoff in the transition band. After implementing Fourier Transform to five different data sets acquired from 3 routes, it was realized that most of the valuable data were at 0.1 – 2 Hz. Therefore, cut-off frequency (fc) was determined as 2 Hz. Obtained data values were divided by 64 to turn them into g values, as per data sheet instructions. The noise was eliminated from the data at the time domain then all data set were represented as graphs.

As mentioned before, test drives cover 3 different routes and 2 different styles of driving for each route. The aim of choosing the first route was analyzing the effects of bumps, bad quality roads, and potholes on the acceleration values. Also, effects of bends, accelerating, and braking were also observed at this route.

During normal driving acceleration ranged from +0.22g to -0.31g on the x axis, +0.24g to -0.18g on the y axis, and +0.15g to -0.17g on the z axis.

During unsafe driving that was more careless and faster than the first one, acceleration ranged from +0.41g to -0.45g on the x axis, +0.33g to -0.36g on the y axis, and +0.18g to -0.18g on the z axis. Some of the consequences after these drives are as below.

The driver who was cornering very fast was exposed to an acceleration between +0.41g and -0.45g. The driver who was accelerating rapidly was exposed to about +0.33g. The driver who was braking suddenly was exposed to approximately -0.36g.

Contrary to expectations, the driver who passed a speedbump faster than normal was not subject to meaningfully larger amounts of g force. (+0.18g and -0.18g).

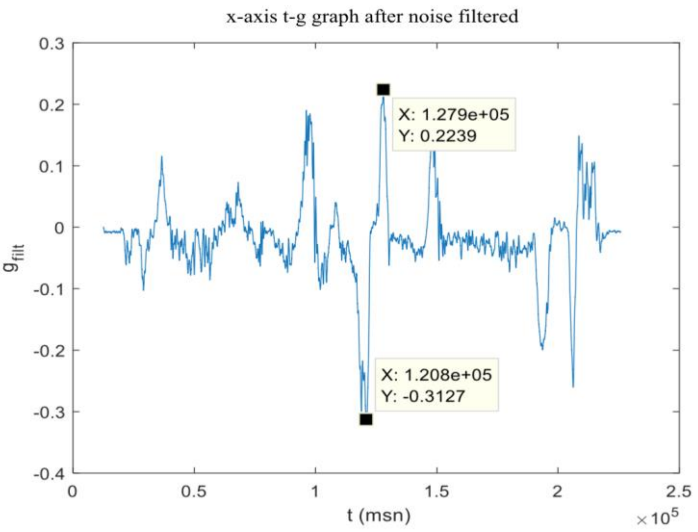


Figure 16. Route 1 x axis for normal driving

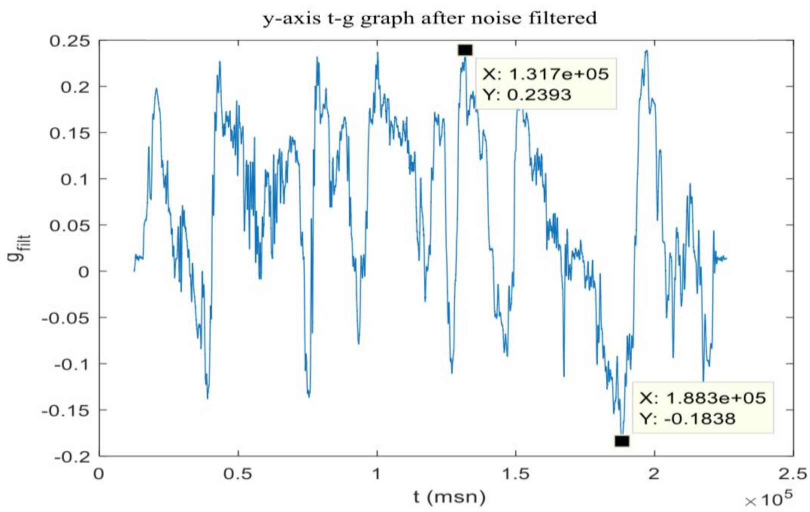


Figure 17. Route 1 y axis for normal driving

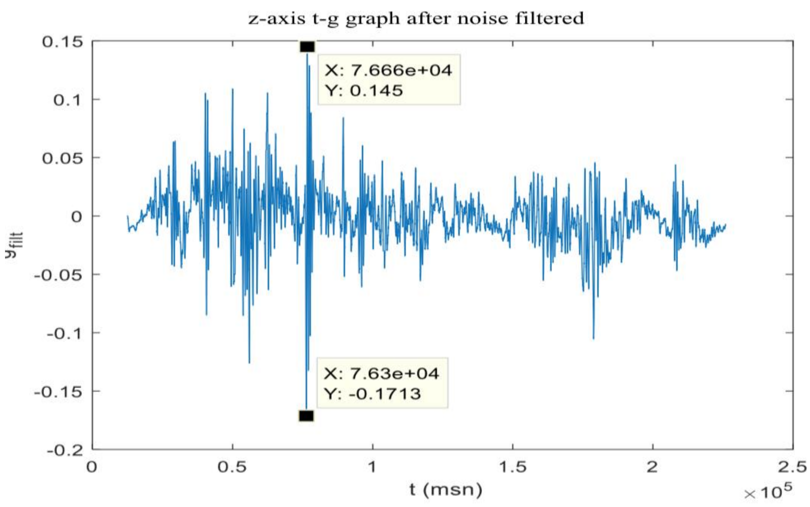


Figure 18. Route 1 z axis for normal driving

On the second route normal driving and unsafe driving were completed. In comparison with Route 1, there are sharper bends on Route 2.

During normal driving acceleration ranged from +0.34g to -0.18g on the x axis, +0.26g to -0.25g on the y axis, and +0.08g to -0.08g on the z axis. Maximum value of x axis on second route is smaller than on first route since we turned the sharper bend safer than the first route. Results for y axis is closer to first route and results for z axis are smaller because of having scarcely any bumps on second route.

During unsafe driving acceleration ranged from +0.51g to -0.39g on the x axis, +0.26g to -0.6g on the y axis, and +0.09g to -0.1g on the z axis. It is observed that these results obtained from unsafe driving are close to similar cases for Route 1.

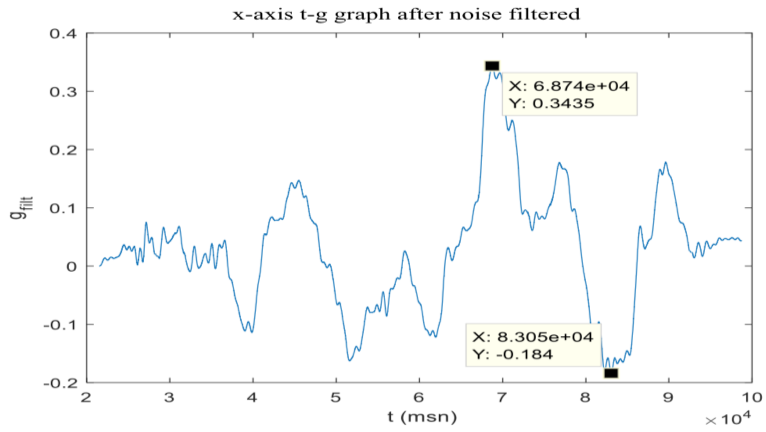


Figure 19. Route 2 x axis for normal driving

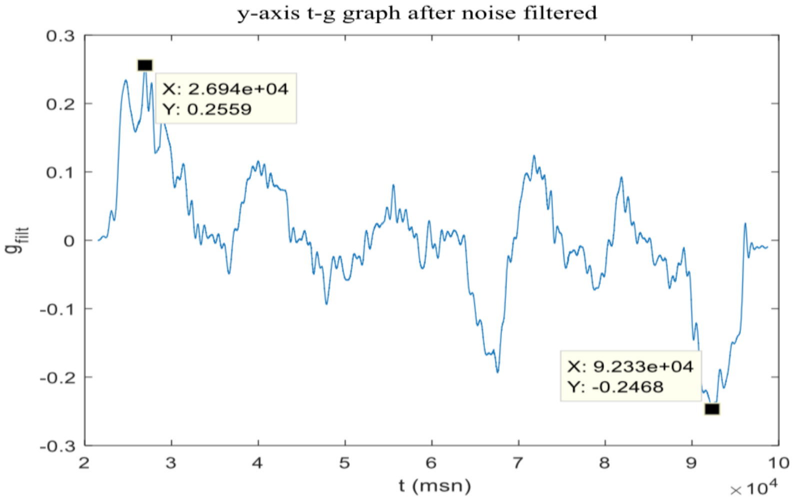


Figure 20. Route 2 y axis for normal driving

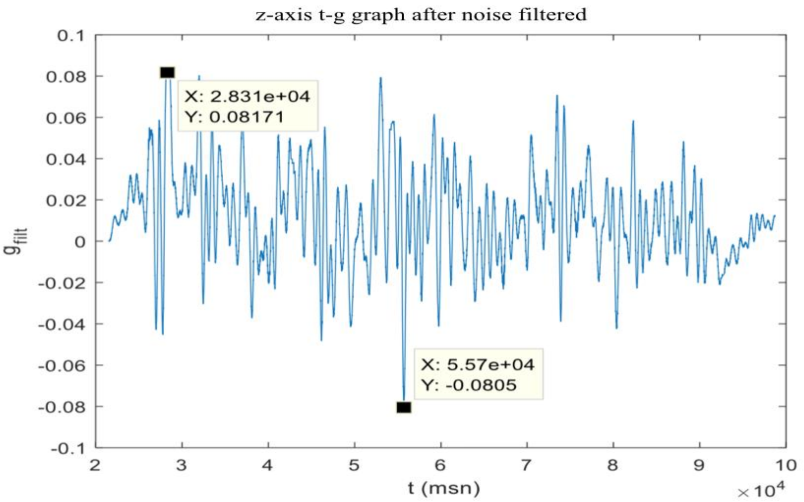


Figure 21. Route 2 z axis for normal driving

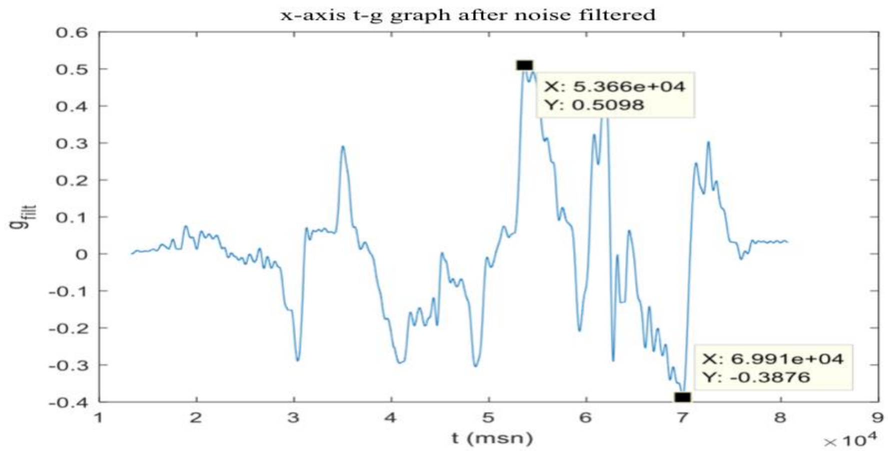


Figure 22. Route 2 x axis for unsafe driving

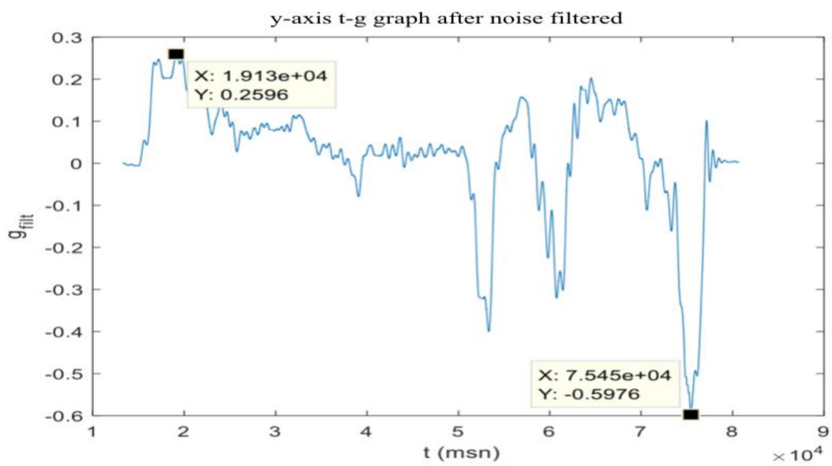


Figure 23. Route 2 y axis for unsafe driving

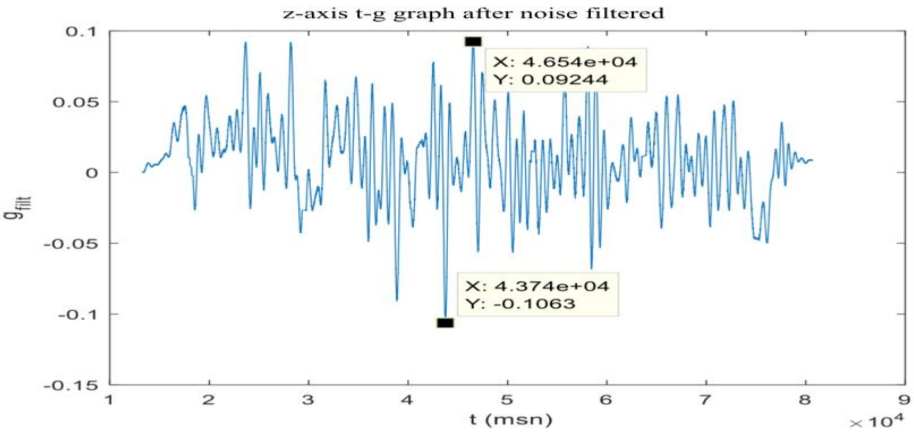


Figure 24. Route 2 z axis for unsafe driving

Route 3 is a straight road with no bumps and only one drive was completed. On this route, we turned the steering wheel hard right and left and acceleration values during speeding and braking were observed.

During driving acceleration ranged from +0.4g to -0.63g on the x axis, +0.17g to -0.35g on the y axis, and +0.04g to -0.08g on the z axis. According to results, acceleration values going up to +0.4g in the +x direction and -0.63g in the -x direction were observed because of sudden steering turns. Compared to Route 1, the values in the negative direction on the x axis were twice as much since we turned the steering wheel to the left to drive 2 or 3 rounds. Also, this driving pattern caused sudden skidding. Besides, it is observed that acceleration results obtained from sudden braking are similar between results from Route 1 and 3.

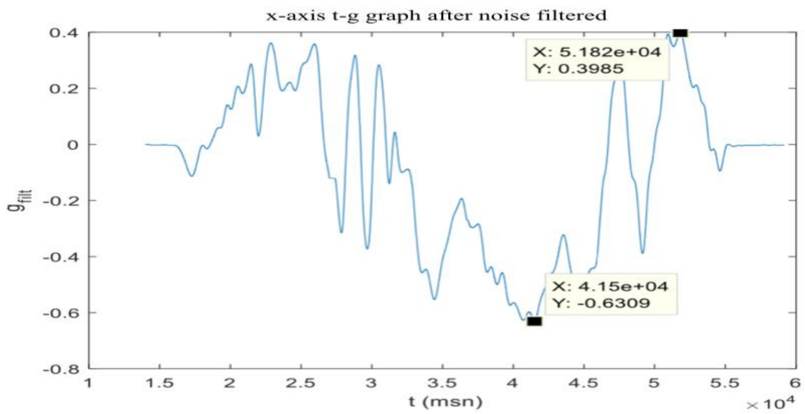


Figure 25. Route 3 x axis for normal driving

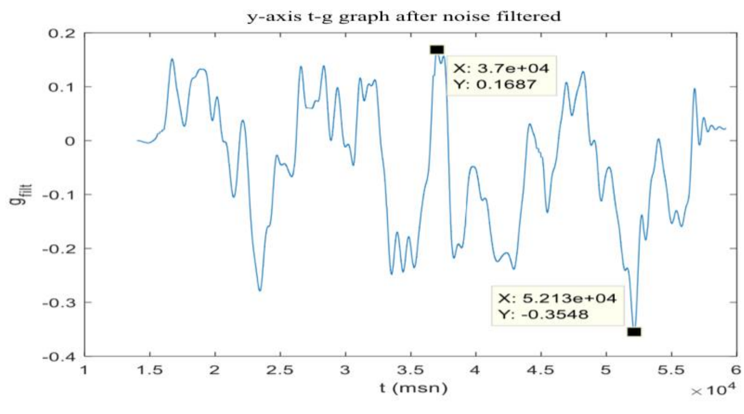


Figure 26. Route 3 y axis for normal driving

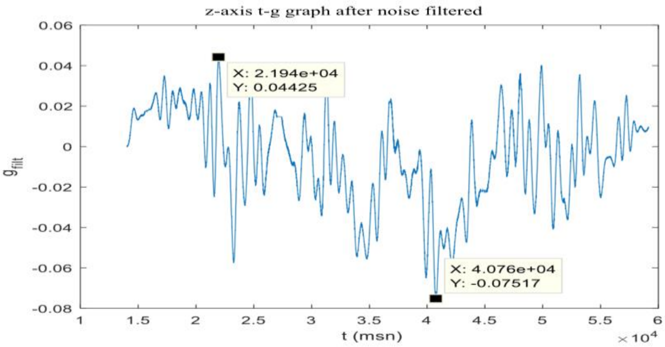


Figure 27. Route 3 z axis for normal driving

Results and Discussion

The data to be analyzed were obtained after performing normal driving and unsafe driving, which is more likely to cause damage to the vehicle, humans or transported cargo, on the specified routes and for the specified scenarios. According to the results obtained after the completion of the analysis process, the acceleration values encountered during normal driving and unsafe driving were as shown in the tables below.

When the tables are examined, we can conclude that we can see the changes to the z-axis more limited since the changes in the x and y axes are more dependent on the driving style, while the changes in the z-axis are more dependent on the road structure of the route. The absence of significant bumps in the routes we conducted our test drives also caused us to see relatively little changes in the values related to the z-axis.

Table 1. Acceleration values for normal and unsafe driving

	Acceleration values (g) (max)		
Axis	Normal driving	Unsafe driving	Difference
x	+0.34	+0.51	**+0.17**
	-0.31	-0.63	**-0.32**
y	+0.26	+0.33	**+0.07**
	-0.25	-0.60	**-0.35**
z	+0.15	+0.18	**+0.03**
	-0.17	-0.18	**-0.01**

Conclusion

In addition to the completion of the study process, one of the main objectives was for this study to address specific needs. We have achieved very positive results in our focus group discussions on the logistics sector, which was our target group. It is possible to say that the data obtained in this study could be very useful and is perceived as a security measure by big and small organizations in this sector, which are currently continuing to use information technologies and planning to do this in a wider way, after we have conducted interviews with them. In addition to this, we have achieved positive results in the questions that we aim to measure the usability for and in fact we have achieved the target of meeting the needs of and reaching the targeted audience.

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Author Information

Gizem Kayisoglu
Istanbul Technical University
Faculty of Electrical and Electronics Engineering
Contact E-mail: *yukselg@itu.edu.tr*

Seda Canpolat
Istanbul Technical University
Faculty of Electrical and Electronics Engineering

Ayşenur Dilara Aydin
Istanbul Technical University
Faculty of Electrical and Electronics Engineering

Nehir Kucuktas
Istanbul Technical University
Faculty of Electrical and Electronics Engineering

Metin Huner
Istanbul Technical University
Faculty of Electrical and Electronics Engineering