Low Cost Data Acquisition System for Road-Vehicle Interaction Using Arduino Board

Harinder Pal Singh¹ and Ramandeep Singh²

¹ Lovely Professional University Phagwara, Jalandhar, India
² Lovely Professional University Phagwara, Jalandhar, India
E-mail: harinder85@gmail.com

Abstract: Roads are used to travel and transfer of goods from one place to another using vehicles like passenger cars or goods carriers. Roads may get damaged due to overloading, weather conditions or end of life. Vehicles moving on the road can be used to access the road condition along with other parameters like driving behavior, presence of traffic, vehicle accident detection, vehicle suspension health monitoring etc. To monitor this, vehicle and road interaction could be acquired by fitting accelerometers on the vehicle. 3-axis accelerometers can provide acceleration data for the vertical, longitudinal and lateral axis of the vehicle. GPS coordinates could be recorded using a GPS receiver along with vehicle speed. Data from accelerometers could be used to detect road anomalies like speed bumps and potholes, braking and acceleration events and turning of the vehicle. GPS receiver can be used to collect longitude and latitude coordinates to mark the location of the event along with speed of the vehicle. In this paper we are proposing an Arduino microcontroller board based low cost data acquisition system for road and vehicle interaction that could be used for various purposes like road anomaly detection, driver behavior detection, road traffic detection and detection of vehicle collision.

Keywords: Accelerometer, Arduino, GPS, Data Acquisition, Road Anomaly, Driver Behavior Detection

1. Introduction

Roads play a major role in the economy of a country. Roads are used to access health, social, employment and educational services. In India, length of road network is 5.8 million KM. 64.5 percent of goods are transferred using road network. 90 percent of people commute using road network [1]. Length of National Highways in India is 132,500 KM and growing at a very high rate [2]. Developing roads is a one time job but maintenance is required continuously. Weather, water logging, heavy loads, aging are some of the main reasons for road condition deterioration [3],[4]. This leads to development of road anomalies like potholes and cracks to appear on road surface. Potholes are the pavement distress caused by water logging, weak asphalt, weather and aging [5]. Potholes are one of the reasons for road accident and sometimes casualty [6]. Speed bumps, used as speed calming device, are raised structure on road surface [7]. Speed bumps cause discomfort to the passengers and may cause damage to the underbody and suspension of the vehicle [8]. These road anomalies increases the operational and maintenance cost of the vehicle [9]. Vehicle driving behavior is another aspect. Events like braking, acceleration and turns could play a major role in accessing road condition and the behavior of driver specially in case of fleet management.

Road management authorities are using manual as well as automated methods for detection of road surface anomalies. Manual inspection is done by road inspectors. This is a time consuming process and could get biased as per the observations of the observer. Roads are dynamic. Surface conditions keep on changing with the passage of time. So it requires continues inspection.

Automated inspection is done by specially designed vehicles containing road profilers, bump integrator [10], ground penetrating RADAR, video camera and GPS unit bundled with specially designed software to control the equipment and process the generated data [11], [12]. These systems provide good results but the cost of the system is very high and speed of monitoring is very slow. Roads under inspection need to be closed for commuters.
Many researchers are working towards this area and are proposing different methods to capture the data related to vehicle-road interaction that can further be processed to extract road anomaly information. Dedicated embedded systems containing accelerometer or gyroscope sensors are used [13], [14]. Some researchers have proposed the use of smart phones built in accelerometer, gyroscope and GPS receiver to acquire the data related to road-vehicle interaction [15], [16]. In this paper we are proposing Arduino Uno board based low cost data acquisition system containing two 3-axis accelerometers and GPS receiver to capture data related to road profile based on vehicle-road interaction.

This paper is divided as per following sections. Section 2 discusses related work. Section 3 describes the design of data acquisition system based on an arduino board. In section 4 results are presented. Section 5 focuses on conclusion and challenges.

2. Related Work

Accelerometer or inertial sensors are used to measure the change of acceleration with respect to earth’s gravitational force. Commonly found sensors can measure up to +/-16G where 1G is equivalent to 9.807 m/s². These +/-sensors are found in a variety of applications like in smartphones for phone’s orientation detection, fitness bands for body movement detection, camera stabilization, driving behavior detection are some of the examples.

Human body motion detection is an area of interest for many researchers since long back. Accelerometer sensors are a preferred device for the same. In [17], the authors proposed a novel system for human activity detection with the help of three, one-axis accelerometers. Focus of the paper was on calibration of accelerometer reading to improve the results and sensor fusion was used for the same. Researchers in [18], [19] proposed a smartphone based system for human activity recognition system (HAR) for detecting activities like sitting, walking, standing, running, walking downstairs and upstairs. It was assumed that the smart phone was in right pocket of the trouser. Sensor fusion results were discussed by using combinations of accelerometer, magnetometer and gyroscope sensors present in phones.

Road traffic monitoring with the help of smart phone’s embedded GPS receiver is another area of interest. In this traffic condition is detected on the basis of number of persons/vehicles present on road and the speed of vehicle with active location services on phone [20], [21]. Google Maps is an example for the same. Mobile phone’s (smart) location data is used for crowd sourcing related to traffic in Google Maps [22]. This system may provide false data [23]

Intelligent Transportation systems are growing as vehicles are getting connected to the internet for various purposes like vehicle tracking, traffic management, logistics, fleet management etc [24]. This has become possible due to fitting of different sensors and communication devices within cars like GPRS modules. ITSS(IEEE Intelligent Transportation Systems Society) is a group of researchers working towards new challenges and opportunities in ITS [25].

Driving behavior detection and vehicle motion detection are trending in the field of research. In [26] the researchers discussed recognizing four states of the vehicle as driving, parked, parking and stopped. Proposed system was designed by mounting a smart phone on a car and using its inertial sensors for data collection and processing. An advancement proposed in the fleet management system for reckless driving detection was proposed in [27] by adding accelerometer sensors to GPS based systems. Data related to tilt angle, speed and location were of the interest. SenseFleet, an event detection system based on inertial sensors integrated in smartphones [28]. Fuzzy logic was used to detect the events of speeding, braking and over steering.

Vehicle related data acquisition systems are used for various purposes, like vehicle vibration detection, suspension control in luxury cars, engine knocking detection, vehicle tracking system etc. In [29] authors
proposed a system to generate and collect road roughness data from accelerometers fitted in specific vehicles to estimate road roughness condition. Vehicle simulation was used to test the model and establish relation between vehicle acceleration and road profile. In [30] A. Gonzales et. al proposed Arduino based system to acquire vehicle acceleration data under 80Hz frequency range that could be used for various purposes related to vehicle dynamics, focus of research was to design low cost data acquisition system(ADAQ). GPS receiver, accelerometers and gyroscope were used for demonstration purposes to acquire data related to vehicles. It was concluded that if more data is acquired then sample frequency of the system will get reduced so more acquisition systems could be used.

3. Arduino Board Based Proposed Data Acquisition System

Our proposed data acquisition system is based on the hypothesis that there is a relation between road surface and vertical acceleration of the vehicle. Proposed system is designed using an Arduino Uno board that consists of an AtMega328 microcontroller [31]. It is an open source development board that can be used to read sensor inputs. It is a cost effective development platform that could be programmed easily using Arduino IDE. It consists of I2C communication that can connect multiple sensors on same the line [32].

![Fig 1: Block diagram of proposed system](image)

3.1 Arduino UNO Microcontroller Board

Arduino board provides communication with peripherals using I2C bus, SPI interface and multiple analog and digital input/output lines. It uses an 8-bit ATmega328P microcontroller fabricated by MicroChip Technology. The Arduino board is programmed using Arduino IDE which is very simple to use. The Arduino board is connected to computer in serial mode using USB cable. It draws power from the computer’s USB port. Arduino UNO contains 32KB Flash and 2KB SRAM, although it seems less but enough for most of the low cost applications. Operating voltage of the arduino is 5V and the clock frequency is 16MHz.
3.2 3-Axis Accelerometer

ADXL345 is a 3-Axis digital accelerometer. It provides 13-bit resolution output and +/-16g is the measurement for acceleration. ADXL345 can be connected using SCL or I²C bus. Using alternate address pin two ADXL345 could be connected over I²C bus. ALT Address/SDO pin is used for providing alternate address over I²C bus, for SCL bus it is serial data out line. If the ALT address line is high then device address is 0X1D otherwise 0X53.

![ADXL 345 3-Axis accelerometer](image)

Fig3: ADXL 345 3-Axis accelerometer

| Pin Number | Pin Name  | Purpose                              |
|------------|-----------|--------------------------------------|
| 1          | GND       | Ground Voltage                       |
| 2          | VCC       | +5 Voltage                           |
| 3          | CS        | Chip Select                          |
| 4          | INT1      | Interrupt 1                          |
| 5          | INT2      | Interrupt 2                          |
| 6          | SDO/ALT   | Serial Output Data/Alternate Address |
| 7          | SDA       | Serial Data                          |
| 8          | SCL       | Serial Clock                         |

3.3 GPS Receiver

UBlox Neo 6-M GPS module is used for location tagging purposes [33]. It provides latitude and longitude data related to the location of the vehicle that can be used along acceleration data for marking anomalies present on road. GPS transceiver provides data as per NEMA format. This GPS receiver includes ceramic antenna. Cold start time for the GPS is 30seconds. It includes an onboard battery also for quick start. Vehicle speed could also be monitored based on GPS data [34]. This GPS receiver needs to be fitted on windscreen of the vehicle to have better visibility/connectivity to GPS satellites.

![Ublox Neo 6-M GPS Transceiver with Antenna](image)

Fig 4: Ublox Neo 6-M GPS Transceiver with Antenna
Table 2. Pin Description UBlox Neo 6-M GPS Transceiver Module

| Pin Number | Pin Name | Purpose                  |
|------------|----------|--------------------------|
| 1          | VCC      | +5 Voltage               |
| 2          | RX       | Input Data(Serial)       |
| 3          | TX       | Output Data(Serial)      |
| 4          | GND      | Ground Voltage           |

3.4 Programming Arduino UNO

Arduino microcontroller board is programmed using *Arduino IDE*, rich set of libraries is available and could be imported in program using `#include<Library_Name>` directive. Based on requirement, new libraries could also be added to Arduino IDE. In our system design we have used following libraries:

*Wire.h* to communicate over I2C bus.

*TinyGPS++.h* to communicate with UBlox Neo 6M GPS Transceiver.

*SoftwareSerial.h* library is used to communicate with devices in serial mode using digital pins.

We defined the functions to generate 3-axis acceleration data from ADXL345 accelerometer as:

```c
void getAccelration(int accelSensor, int calX, int calY, int calZ)
```

Where:

- `int AccelSensor` parameter is address of accelerometer
- `int calX` is X-Axis calibration value
- `int calY` is Y-Axis calibration value
- `int calZ` is Z-Axis calibration value

Built in function `sprint()` is used to give output string of acceleration data in 3-axis as per the following:

```c
sprintf(output,"%d,%d,%d  ",x-calX, y-calY, z-calZ)
```

For GPS data *TinyGPS++*.h library’s built-in functions are used to provide data related to latitude, longitude and speed. The functions are:

```c
gps.location.lat()  // provides Latitude value as Float in Arduino UNO
gps.location.lng()  // provides Longitude value as Float in Arduino UNO
gps.speed.kmph()    // provides speed in kilometer as Float in Arduino UNO
```

here `gps` is an object of TinyGPSPlus library.
3.5 Data Set Generated

As per the system design and logic, following features can be extracted using the data acquisition system designed.

| Variable Name | Data Type | Size | Description                           |
|---------------|-----------|------|---------------------------------------|
| X1            | Int       | 2 Byte | X-Axis of Accelerometer 1             |
| Y1            | Int       | 2 Byte | Y-Axis of Accelerometer 1             |
| Z1            | Int       | 2 Byte | Z-Axis of Accelerometer 1             |
| X2            | Int       | 2 Byte | X-Axis of Accelerometer 2             |
| Y2            | Int       | 2 Byte | Y-Axis of Accelerometer 2             |
| Z2            | Int       | 2 Byte | Z-Axis of Accelerometer 2             |
| GPS Lat.      | Float     | 6 Byte | GPS Latitude(NEMA Format)             |
| GPS Long.     | Float     | 6 Byte | GPS Longitude(NEMA Format)            |
| Speed         | Float     | 6 Byte | Ground Speed in KMPH                  |

Sketch designed for arduino could be easily modified depending upon requirements, like increasing or decreasing data acquisition speed, removing or adding more features etc.

Fig 5: Flow chart of proposed data acquisition system
Designed data acquisition system generates 60 Byte data per sample.

### Table 4. Acquired sample data set using proposed system

| X1  | Y1  | Z1  | X2  | Y2  | Z2  | GPS Lat   | GPS Long   | Speed  |
|-----|-----|-----|-----|-----|-----|-----------|------------|--------|
| 5   | 21  | -14 | -5  | 3   | 0   | 30.921106 | 75.617477 | 43.47  |
| 4   | -9  | 3   | 6   | 5   | -9  | 30.921106 | 75.617477 | 43.47  |
| -6  | -11 | 23  | 3   | -4  | 0   | 30.921106 | 75.617477 | 43.47  |
| 3   | 14  | -8  | -12 | -17 | -2  | 30.921106 | 75.617477 | 43.47  |
| 4   | 12  | -11 | 2   | -9  | -2  | 30.921106 | 75.617477 | 43.47  |
| -6  | 0   | 4   | -9  | 10  | 0   | 30.921106 | 75.617477 | 43.47  |
| 2   | -6  | -3  | -6  | -2  | -7  | 30.921106 | 75.617477 | 43.47  |
| 1   | -3  | 5   | 4   | 6   | -31 | 30.921106 | 75.61724  | 45.19  |
| -2  | -1  | -14 | 3   | -8  | 25  | 30.921012 | 75.61724  | 45.19  |
| 13  | -1  | 15  | -14 | 1   | -7  | 30.921012 | 75.61724  | 45.19  |
| 0   | 22  | 22  | 12  | -31 | 12  | 30.921012 | 75.61724  | 45.19  |
| 2   | -14 | 27  | 2   | 23  | -22 | 30.921012 | 75.61724  | 45.19  |
| 7   | 26  | -55 | 2   | -24 | 0   | 30.921012 | 75.61724  | 45.19  |
| 5   | 9   | -30 | -9  | 34  | -50 | 30.921012 | 75.61724  | 45.19  |
| 17  | -8  | 44  | -21 | -10 | 11  | 30.921012 | 75.617118 | 45.19  |
| 10  | 14  | 1   | -12 | 10  | -24 | 30.920965 | 75.617118 | 45.19  |
| 9   | 8   | -19 | -13 | -9  | -8  | 30.920965 | 75.617118 | 45.19  |
| 19  | 1   | 5   | -20 | -9  | 3   | 30.920965 | 75.617118 | 45.19  |
| 15  | -5  | -1  | -18 | 5   | -9  | 30.920965 | 75.617118 | 45.19  |
| 21  | 9   | 5   | -18 | -11 | 6   | 30.920965 | 75.617118 | 45.19  |
| 21  | 5   | -11 | -17 | 3   | -20 | 30.920915 | 75.616996 | 45.24  |
| 20  | -8  | 10  | -23 | -20 | 15  | 30.920915 | 75.616996 | 45.24  |

### 3.6 Interfacing

The I2C bus follows I2C communication protocol that allows multiple, up to 128, devices to communicate using 2-wire connections, SCL (serial clock) and SDA (serial data). The I2C bus of the Arduino UNO can go up to 400Kbps of data transfer speed. This can be changed by using below given function of Wire.h library:

\[
\text{Wire.setClock(<data\_rate>)}
\]

It uses serial clock (SCL) and serial data (SDA) lines. Different peripherals designed to communicate using I2C bus have different addresses. In our data acquisition system two ADXL345 3-axis accelerometers are used. Both have the same address but they could be addressed separately by using SDO/Alternate address line [35]. First sensor address is 0x1D and the second sensor uses an alternate address as 0x53. First accelerometer provides acceleration change for the front left side of the vehicle and the second for the front right side of the vehicle. GPS transceiver, UBlox Neo 6M, is connected at digital pin 7 of the Arduino board. In this design we are just receiving GPS data so the transmit pin of the GPS transceiver is not used.
3.7 Calibration problem

Designed system need to be fitted in a vehicle for data collection purposes. Challenge is vehicle profile, like ground clearance, varies from one company or model to another. This could result in wrong data generation if threshold limits of acceleration are to be used.

Calibration of the designed system is required as per vehicle profile. In our proposed system this is taken care of by getting the accelerometer reading of the vehicle when the designed system is powered up, the vehicle would be stationary at this time. Designed system is programmed to receive the reading in the setup block, afterwards the same is used for self-calibration of the system as per vehicle profile. Below given functions are designed to generate calibration data:

```c
void getCal1D(int accelSensor) // for Accelerometer1 and generates calX1, calY2, calZ2 variables
void getCal53(int accelSensor) // for Accelerometer2 and generates calX2, calY2, calZ2 variables
```

Further these calibration values generated by the above given functions are passed to getAcceleration() Function as:

```c
void getAcceleration(int accelSensor, int calX, int calY, int calZ)
```

and used to generate data after considering vehicles stationary when the circuit is powered up. This is done every time when the circuit is powered up. Calibration data is generated in the `setup()` block and used multiple times in the `loop()` block of Arduino. Below given line of code considers calibration data to generate acceleration data:

```c
sprintf(output,"%d,%d,%d  ",x-calX, y-calY, z-calZ)
```
4. Results and discussions

The designed system was tested in the real life environment to generate data. Accelerometers were fitted near to the internal body of the car, one near to the accelerometer paddle and other on the opposite side. The GPS receiver was fitted near to the windscreen of the car. Tata Indica Vista car was used for experimentation purposes. ADXL345 accelerometer uses 13-bit resolution for the acceleration data and it can go upto +/-16g of acceleration. It could be configured for different resolutions using Range bits D0 and D1 of the DATA_FORMAT register addressed 0x31. In our experiment it was set to 8g range.

| D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|----|----|----|----|----|----|----|----|
| SELF_TEST | SPI | INT_INVERT | 0 | FULL_RES | JUSTIFY | RANGE |

Following are the graphs generated from collected data:

![Graph of Vertical Acceleration(Z1 and Z2)](image)
Graphs designed from the data acquired using the proposed system provides vehicle acceleration in 3-Axis format namely Vertical(Z) axis, Lateral(Y) axis, Longitudinal(X) axis. Vertical axis shows change of vehicle acceleration due to road anomalies like speed bumps, potholes etc. Lateral axis changes are due to steering of the vehicle in the left or the right direction. When brakes are applied to the vehicle, it causes a change in longitudinal axis. This 3-axis data along with the speed data could be used to understand the road-vehicle interaction.
4.1 Applications

4.1.1. Accident: if there is a sudden change in the vehicle speed and longitudinal acceleration, it could be a road accident. This event could be detected by the data generated from the proposed system and based on the same alarm could be generated so the nearby emergency task force could be informed based on GPS location of the vehicle.

4.1.2. Driver behavior detection: Changes in lateral axis acceleration represent steering of the vehicle; quick lane changing, overtaking are the events that generate this effect. These parameters could be used to detect driving behavior of the driver. This could be used by insurance companies, fleet management, vehicle owner to understand the driver behavior.

4.1.3. Road anomaly: Vertical acceleration changes due to road anomalies. Data generated from the proposed system clearly shows the relation between road anomalies and vertical acceleration of the vehicle. When the vehicle hits a road anomaly like a speed bump or a pothole, it causes a change in vertical acceleration of the vehicle. This data along with speed and GPS location could be used to design algorithms to identify road condition so it could be repaired and informed in advance to the road users. This could prevent road accidents due to bad roads.

4.1.4. Road traffic monitoring: GPS coordinates received from the proposed system could be used for crowd sourcing to detect traffic on roads. Advantage of this will be in gathering accurate data because one vehicle will have only one GPS device as compared to multiple persons having GPS of smart phone enabled in the same vehicle [22] [23].

4.1.5. Vehicle suspension maintenance schedule: Data generated from the proposed system, after analysis, can be used to detect vehicle suspension and wheel alignment. Vehicle service stations can access the data related to use of vehicle on different road conditions. Based on this vehicle condition could be accessed and preventive maintenance schedule could be prepared.

5. Conclusion

Main objective of this research was to create a low cost data acquisition system that can acquire vehicle acceleration based on road interaction in 3-Axis coordinate system. Prototype of the proposed system was designed and tested successfully by fitting in the car. Arduino microcontroller board, 3-axis accelerometer and GPS are used for this purpose. Vehicle acceleration data was obtained in the X,Y and Z plane. Speed of the vehicle was also obtained along with GPS coordinates. This captured data could be used for road profile detection, road traffic monitoring, driver behavior detection etc. parameters to be captured based on application could be updated. Frequency of capturing data could be adjusted very easily. Cost of the proposed system is very low. System could be calibrated as per the profile of the vehicle. So it could be used in different vehicle types. Proposed system can be used by researchers to detect road anomalies and classify the roads so road authorities and road users can plan accordingly.

Improvement of the system could be done in better filtration of the data. Improvement in capturing GPS coordinate could also be done to reduce GPS error to mark the location accurately. This data can be made available to road authorities, road users and other public administrative departments to plan or schedule for future.
References

[1] I. B. E. Foundation, “Road Network in India_ National Highways, Projects, Govt Initiatives _ IBEF.” [Online]. Available: https://www.ibef.org/industry/roads-india.aspx.

[2] N. H. A. of India, “The details of National Highways ( New No .) in the country and their length.”

[3] Z. Bin Rashid and R. Gupta, “Study of Defects in Flexible Pavement and Its Maintenance,” Int. J. Recent Eng. Res. Dev., vol. 2, no. 6, pp. 30–37, 2017.

[4] M. M. E. Zumrawi, “Investigating Causes of Pavement Deterioration in Khartoum State , Sudan,” Int. J. Civ. Environ. Eng., vol. 9, no. 11, pp. 1458–1463, 2015.

[5] P. Wang, Y. Hu, Y. Dai, and M. Tian, “Asphalt Pavement Pothole Detection and Segmentation Based on Wavelet Energy Field,” vol. 2017, 2017.

[6] The Economic Times, “Supreme Court takes note of 3,597 deaths due to pothole-related accidents in 2017 - The Economic Times,” The Economic Times, New Delhi, 18-Sep-2018.

[7] M. Parkhill, P. Eng, R. Sooklall, M. A. Sc, G. Bahar, and P. Eng, “Updated Guidelines for the Design and Application of Speed Humps,” in CITE 2007 Conference, 2007.

[8] A. Ullah, S. Hussain, A. Wasim, and M. Jahanzaib, “Usage and impacts of speed humps on vehicles : A review Akademia Baru Journal of Advanced Review on Scientific Usage and impacts of speed humps on vehicles : A review,” J. Adv. Rev. Sci. Res., vol. 28, no. August 2017, pp. 1–17, 2016.

[9] V. Astarita et al., “A mobile application for road surface quality control : UNIquALroad,” in Procedia - Social and Behavioral Sciences 54 ( 2012 ) 1135 – 1144 EWGT, 2012, vol. 54, pp. 1135–1144.

[10] C. Central Road Reserch Institute, “Bump Integrator | CSIR - Central Road Research Institute.” [Online]. Available: https://crridom.gov.in/content/bump-integrator.

[11] ROMDAS, “ROMDAS System _ Road Survey Equipment , Road Condition Survey.” [Online]. Available: https://romdas.com/romdas-system.html.

[12] R. Pavements, STATE OF THE ART IN MONITORING ROAD CONDITION AND ROAD / VEHICLE INTERACTION. France: World Road Association (PIARC), 2016.

[13] J. Eriksson, L. Girod, B. Hull, R. Newton, S. Madden, and H. Balakrishnan, “The pothole patrol: using a mobile sensor network for road surface monitoring,” Proceeding 6th Int. Conf. Mob. Syst. Appl. Serv. - MobiSys ’08, p. 29, 2008.

[14] R. Madli, S. Hebbar, P. Pattar, and G. V Prasad, “Automatic Detection and Notification of Potholes and Humps on Roads to Aid Drivers,” IEEE Sensors Journal, vol. 15, no. 8, pp. 4313-4318, Aug. 2015., vol. 15, no. c, 2015.

[15] A. Mednis, G. Strazdins, R. Zviedris, G. Kanonirs, and L. Selavo, “Real Time Pothole Detection using Android Smartphones with Accelerometers,” IEEE Int. Conf. Distrib. Comput. Sens. Syst. Work., vol. 7th, no. 10, pp. 1–6, 2011.

[16] G. Alessandroni et al., “SmartRoadSense : Collaborative Road Surface Condition Monitoring,” in UBICOMM 2014 : The Eighth International Conference on Mobile Ubiquitous Computing, Systems, Services and Technologies, 2014, no. c, pp. 210–215.

[17] J. Lee, “Sensor Fusion and Calibration for Motion Captures using Accelerometers,” in Proceedings of the 1999 IEEE International Conference on Robotics & Automation (Cat. No.99CH36288C) Detroit, Michigan, 1999, no. May, pp. 1954–1959 vol.3.

[18] C. V. S. Buenaventura and N. M. C. Tiglao, “Basic Human Activity Recognition Based on Sensor Fusion in Smartphones,” in 2017 IFIP/IEEE Symposium on Integrated Network and Service Management (IM), Lisbon, 2017, pp. 1182–1185.
[19] M. C. Sorkun, “ALGILAYICILARIN VE PENCERE BOYUNUN ETKISI HUMAN ACTIVITY RECOGNITION WITH MOBILE PHONE SENSORS: IMPACT OF SENSORS AND WINDOW SIZE,” in 2018 26th Signal Processing and Communications Applications Conference (SIU), Izmir, 2018, pp. 1–4.

[20] P. Mohan, V. N. Padmanabhan, and R. Ramjee, “Nericell: Rich Monitoring of Road and Traffic Conditions using Mobile Smartphones,” in Proceedings of the 6th ACM conference on Embedded network sensor systems - SenSys ’08, 2008, pp. 323–336.

[21] R. Bhoraskar, N. Vankadhara, B. Raman, and P. Kulkarni, “Wolverine: Traffic and Road Condition Estimation using Smartphone Sensors,” in 2012 Fourth International Conference on Communication Systems and Networks (COMSNETS 2012), 2012, pp. 1–6.

[22] T. Stenovec, “How Google Maps knows about traffic - Business Insider,” Business Insider, 2015. [Online]. Available: https://www.businessinsider.com/how-google-maps-knows-about-traffic-2015-11?r=US&IR=T. [Accessed: 29-Aug-2020].

[23] R. Cerejo, “Google Maps Hack. Company Responds to Video of Fake Traffic Jam Created by 99 Smartphones - Technology News,” Gadgets 360, 2020. [Online]. Available: https://gadgets.ndtv.com/apps/news/google-maps-hack-berlin-simon-weckert-99-phones-response-2174592. [Accessed: 29-Sep-2020].

[24] G. Dimitrakopoulos, “Intelligent Transportation Systems based on Internet-Connected Vehicles: Fundamental Research Areas and Challenges,” in 11th International Conference on ITS Telecommunications Intelligent, 2011, pp. 145–151.

[25] I. Transactions, O. N. Intelligent, and T. Systems, “Guest Editorial Developing and Improving Transportation Systems: The Structure and Operation of IEEE Intelligent,” IEEE Trans. Intell. Transp. Syst., vol. 6, no. 3, pp. 261–264, 2005.

[26] A. Classification, J. Cervantes-villanueva, D. Carrillo-zapata, F. Terroso-saenz, M. Valdes-vela, and A. F. Skarmeta, “Vehicle Maneuver Detection with Accelerometer-Based Classification,” Sensors, vol. 16, no. 10, p. 1618, 2016.

[27] J. M. Schietekat and M. J. Booysen, “Detection of reckless driving in the Sub-Saharan informal public transportation system using acceleration-sensing telematics,” in EUROCON, 2013 IEEE, 2015, no. January 2013, pp. 597–601.

[28] G. Castignani, T. Derrmann, R. Frank, and T. Engel, “Driver behavior profiling using smartphones: A low-cost platform for driver monitoring,” IEEE Intell. Transp. Syst. Mag., vol. 7, no. 1, pp. 91–102, 2015.

[29] A. González, E. J. O, Y. Li, and K. Cashell, “The use of vehicle acceleration measurements to estimate road roughness,” Veh. Syst. Dyn. Int. J. Veh. Mech. Mobil., vol. 46, no. 6, pp. 483–499, 2008.

[30] A. González, J. L. Olazagoitia, and J. Vinolas, “A low-cost data acquisition system for automobile dynamics applications,” Sensors (Switzerland), vol. 18, no. 2, 2018.

[31] Arduino, “Arduino Uno Rev3 Arduino Official Store.” [Online]. Available: https://store.arduino.cc/usa/arduino-uno-rev3.

[32] I2c-bus.org, “I2C - What’s That - I2C Bus.” [Online]. Available: https://www.i2c-bus.org/.

[33] Electroschematics.com, “NEO-6M GPS Module — An Introduction.” [Online]. Available: https://www.electroschematics.com/neom-6m-gps-module/.

[34] L. Chen, Y. Lai, Y. Yeh, J. Lin, C. Lai, and H. Weng, “Enhanced Mechanisms for Navigation and Tracking Services in Smart Phones,” J. Appl. Res. Technol. JART, vol. 11, no. April, pp. 272–282, 2013.

[35] Analog Devices, “ADXL345 Datasheet and Product Info Analog Devices.” [Online]. Available: https://www.analog.com/en/products/adxl345.html#product-overview.