

DESIGN AND DEVELOPMENT OF A MICROCONTROLLER-BASED DRIVING BEHAVIOR MONITORING DEVICE AS A FORM OF MASS TRANSPORTATION OVERSIGHT

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ABSTRACT

In this study, the design and development of a microcontroller-based driving behavior monitoring device has been carried out using a research and development method. The output is a prototype that functions as a data logger, capable of recording the activities and driving behaviors of mass transportation drivers utilizing an electronic system with sensor devices, a Global Positioning System (GPS), and a controller to monitor braking activities, speed, maneuvering forces in curves, and to provide signal indications through a mini display, buzzer, and indicator lights when certain standards are exceeded. This research demonstrates that the device is capable of displaying and storing values for speed (velocity), g-force acceleration, braking, and maneuvering in curves under various conditions, including straight roads, inclines/declines, and curves, with high accuracy ranging from 95.99% to 97.62%.

Keywords: bus; driving behavior monitoring; transportation monitoring

INTRODUCTION

One of the mass transport vehicles frequently used to support public transportation in many major cities in Indonesia is the bus. Buses are considered one of the most effective mass transit alternatives applicable in densely populated urban areas with limited road expansion. Buses utilized in public transportation services often encounter accidents during operations. Several causes of these accidents include issues with the braking system and human error factors arising from unsafe driving behaviors. Driving behavior in motor vehicles, particularly in mass transportation, is a crucial component affecting road safety (Sullman, Stephens, & Taylor, 2019). Abrupt braking, maneuvering during turns, and speeds exceeding ideal thresholds may pose dangers to both drivers and passengers, especially in slippery road conditions. Furthermore, excessive braking can lead to damage to vehicle components and impact the roadworthiness of the vehicle (Silvano & Ohlin, 2019).

The Drivers of mass transportation, particularly intercity and interprovincial buses (AKAP), are faced with trips covering relatively long distances on variable road conditions, including turns and inclines/declines. This demands safe driving behavior, which includes maintaining proper maneuvering in curves and being anticipatory regarding acceleration and braking actions. For various reasons, drivers often overlook safety factors, increasing a range of risks from the efficiency of spare parts and fuel consumption to safety aspects.

In light of several accident incidents, particularly involving mass transportation, the National Transportation Safety Committee (KNKT) has issued various improvement recommendations to transportation companies based on field findings. These recommendations include risk management evaluation, vehicle roadworthiness, crew suitability, route safety, and transportation oversight. In order to enhance the effectiveness of these initiatives, it is deemed necessary to develop a driving behavior monitoring device that is expected to serve as a monitoring tool for mass transportation/bus drivers, thus facilitating the mass transportation oversight process for both operators and regulators.

METHOD

This study is applied research, focusing on the experimental resolution of problems through a methodical and sequential process. It begins with a literature review aimed at identifying relevant references related to the identified issue, followed by the design and testing of the developed instrument, ultimately leading to the formulation of conclusions outlined as follows.

Design Concept Formulation

The driving behavior monitoring device is an instrument employed to assess various parameters, including braking smoothness, minimum and maximum speed, average speed, and the forces exerted during turning maneuvers by the driver. The criteria for evaluating the level of braking smoothness are based on established standards, with values ranging from -0.1g to -0.2g indicative of soft or safe braking, while values exceeding -0.2g signify heavy braking. Additionally, the safe limit for turning maneuvers is established at a maximum of +/- 0.14g, and the speed limit on downhill roads is set at 35 km/h (Elbanhawi. Simic. & Jazar. 2015; Turner & Griffin. 1999; Martin & Litwhiler. 2008; Bosetti. Da Lio. & Saroldi. 2014; Bae. Moon. & Seo. 2019). Consequently, a logical formula can be formulated as parameters for assessing braking smoothness, maneuvering, and speed on inclines, as follows.

$$\begin{aligned}
 \text{Cornering Maneuver force} &= \begin{cases} \text{Soft Cornering, } g\text{-force} \leq 0,4g \\ \text{Hard Cornering, } g\text{-force} > 0,4g \end{cases} \\
 \text{Speed of Descending} &= \begin{cases} \text{Safe, } \text{Speed} \leq 35 \text{ km/h} \\ \text{High Risk, } \text{Speed} > 35 \text{ km/h} \end{cases} \\
 \text{Braking Intensity} &= \begin{cases} \text{Soft Braking, } g\text{-force} \leq -0,2g \\ \text{Hard Braking, } g\text{-force} > -0,2g \end{cases}
 \end{aligned}$$

The operation principle of this measuring device is based on the use of GPS for position and time tracking, along with accelerometer and gyroscope sensors to measure forces (Enge. 1994; Kaplan & Hegarty. 2006; French. 1996; Agnihotri. 2023). This data is then displayed on a mini monitor, allowing for the extraction of speed, braking, and maneuvering forces of a vehicle obtained through computation and microcontroller control. The data is subsequently stored on a memory card, which can be extracted for analysis to support the oversight and monitoring of mass transportation.

System Design

The design is conducted comprehensively, consisting of hardware and software design to transform conceptual ideas into an electronic system, as outlined below.

a. Software Design

The software is designed based on algorithms structured to facilitate programming for processing the signals or digital data obtained from the GPS and sensors to produce outputs in the form of measurement values displayed on the mini LCD, auditory indicators from a buzzer, and visual indicators from LED lights. The measurement values are then extracted and stored on an SD card. The program's operation consists of commands in machine language, structured in a pattern/syntax that forms a sequence of instructions (code) through the programming process. The program utilized in this research is developed from a procedure that is a sequence of systematic steps based on the mechanism of data extraction from the GPS and sensors, which is then computed in a logical sequence as follows.

- 1) Checking GPS Status : The system will check whether the GPS is active or whether there is data that can be read
- 2) Read GPS Data: Reading coordinate and time data.
- 3) Read Accselerometer and Gyroscope: Reading the vehicle cornering force on bends and the position of the vehicle
- 4) Calculate GPS data : The system will calculate the Latitude and Longitude coordinate data.
- 5) Store The Value : save the reading results to the secure disk memory card (SD Card).

6) Show Calculation Results : The system will display the GPS data calculation on the mini LCD and display the reading result status (Hard Braking, Soft Braking or Normal Braking)

b. Hardware Design

The hardware design is conducted by assembling the electronic components necessary to support the computing system and data communication control between the GPS, mini LCD, buzzer, and pilot lamp using an Arduino microcontroller, thereby forming a block diagram as shown in figure 1.

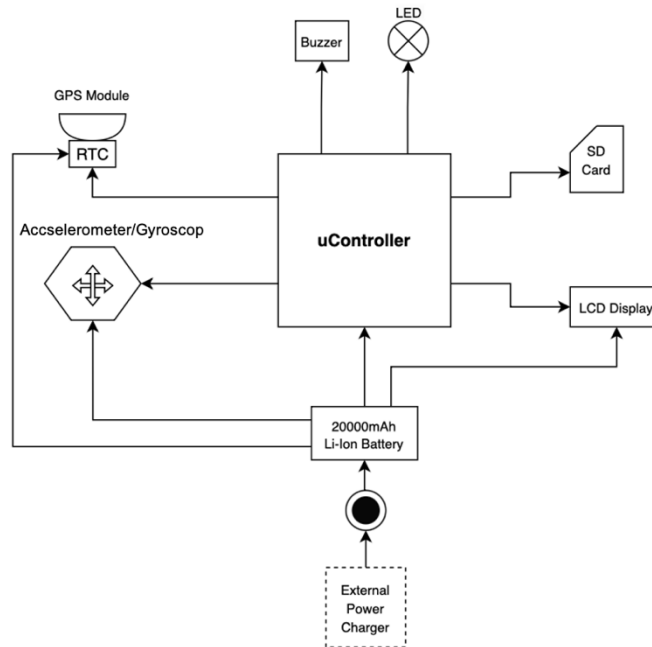


Figure 1. System Block Diagram

Global Positioning System (GPS)

As a position tracker, a GPS module is used that meets the criteria of having the ability to track position accurately and having data communication compatible with the microcontroller controller. In this study, the BELTIAN BN-220 GPS Module is utilized. This module can capture GPS signals, thereby providing output data for latitude, longitude, and altitude (Beitian Co., Limited, 2015). The configuration of the GPS interface and control device is outlined as shown in Figure 2.

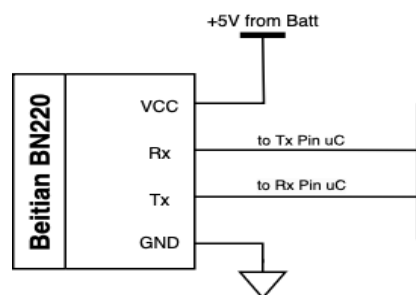


Figure 2. GPS Interface

Accelerometer

To satisfy the system requirements, a suitable accelerometer/gyroscope is essential for measuring forces during cornering and detecting angular measurements to identify the gradients of road inclines or declines (Kirushanth & Kabaso, 2020) (Casilari, Álvarez-Marco, & García-Lagos, 2020). The sensor module used in this study is the MPU6050, noted for its high accuracy

due to integrated hardware that converts analog data into digital format with a resolution of 16 bits per channel. This capability enables concurrent data acquisition from the X, Y, and Z channels within a single time frame (Dadafshar. 2014). Data communication with the sensor controller is facilitated through I2C communication, configured as illustrated in the figure 3.

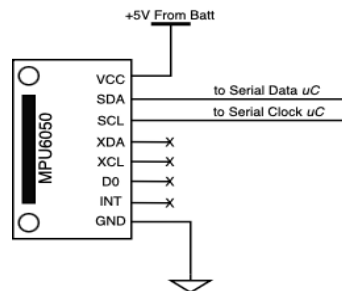


Figure 3. MPU5060 data communication configuration

Secure Disk Card Module

The SD card is interfaced with the module using a 5V power supply and utilizes Serial Peripheral Interface (SPI) communication, comprising Master Out Slave In (MOSI), Master In Slave Out (MISO), Serial Clock (SCK), and Chip Select (CS) signals (Ibrahim, 2010 ; Cameron. 2019). To facilitate effective communication and execution of data storage commands from the microcontroller, the SD Card Module is connected in accordance with the configuration illustrated in Figure 4.

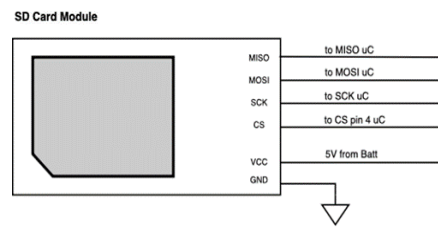


Figure 4. Communication Data Configuration of the SD Card Module

Microkontroller

As the main controller that regulates the process and working mechanism of the proposed system, the Arduino Mega 5660 microcontroller is used. The number of pins and types of data communication needed can be accommodated through the use of this microcontroller so that the communication needs and processing of sensor and GPS input can be operated with the help of embedded software programs with information output through buzzer sound signals, LED lights, and LCD information displays (Arduino.cc, 2024; Purwowibowo, Wijonarko, & Maftukhah, 2019). The interconnection and wiring of the microcontroller with its supporting components can be seen in Figure 5.

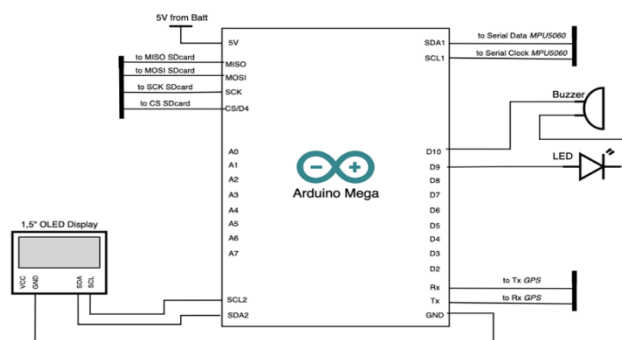


Figure 5. Microcontroller Interconnection

System Calibration

Calibration of the device is performed through a systematic braking test aligned with predefined track standards. The measurements obtained from the instrument are subsequently compared to calculated results to assess accuracy (Weitz, Morseth, Hopstock, & Horsch, 2024). The data collected for calibration encompasses the vehicle's initial speed, braking duration, and the resultant braking force. This data collection is critical for determining the inertial forces that the accelerometer will interpret. Specifically, to measure the longitudinal braking forces, the x-axis of the accelerometer is oriented in the direction of the vehicle's travel. Conversely, to evaluate the forces during cornering maneuvers, the y-axis is oriented parallel to the longitudinal axis of the vehicle, as depicted in Figure 5.

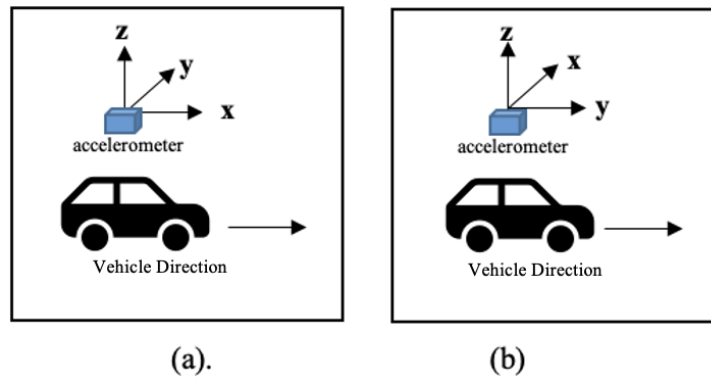


Figure 5. Illustration of accelerometer axis configuration:
 a. Pitching; b. Rolling

Testing Location and Procedures

The test location was carried out in the campus area of the Politeknik Transportasi Darat Bali on the east side, the selection of this location refers to the suitability of the structure and road type that can represent the parameters of driving situations such as straight roads, inclines, and corners. To facilitate the testing procedure, the track is segmented based on the characteristics and contours of the road as shown in Figure 6.

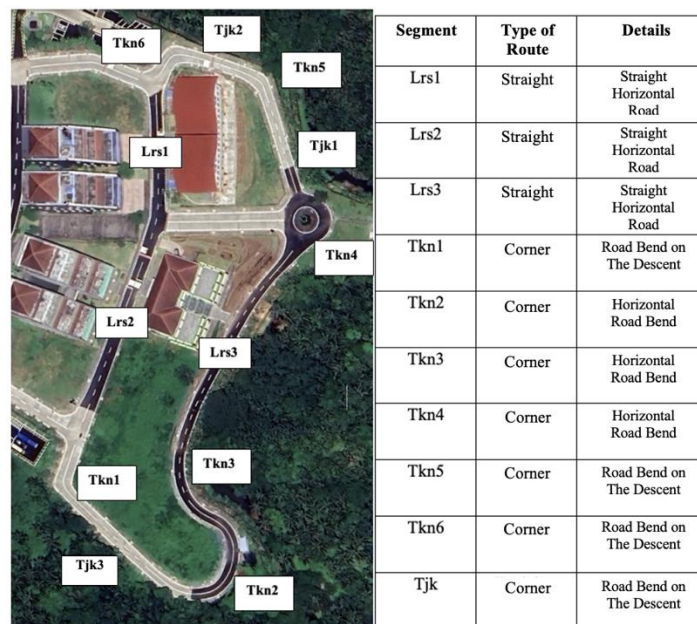


Figure 6. The segmentation of testing location.

The testing was conducted using a minibus, with routes encompassing the testing location comprehensively, both clockwise and counterclockwise. On each driving route, the driver operated the vehicle in a manner reflective of typical driving behavior, without the implementation of specific scenarios, in order to obtain a natural driving behavior.

RESULT AND DISCUSSION

A flowchart has been constructed to represent the execution phases of the program, encompassing all processes—from the signal processing of input data sourced from the GPS and accelerometer to the resultant outputs reflected on the LCD and through auditory indicators as illustrated in Figure 7(a). Based on the flowchart, the corresponding programming code can be articulated utilizing the Arduino Integrated Development Environment (Arduino IDE), with the relevant program listing presented in Figure 7(b).

The component interconnection diagram is used as a guide in the stages of installing electronic components so that the results of the installed hardware components are obtained as shown in Figure 8.

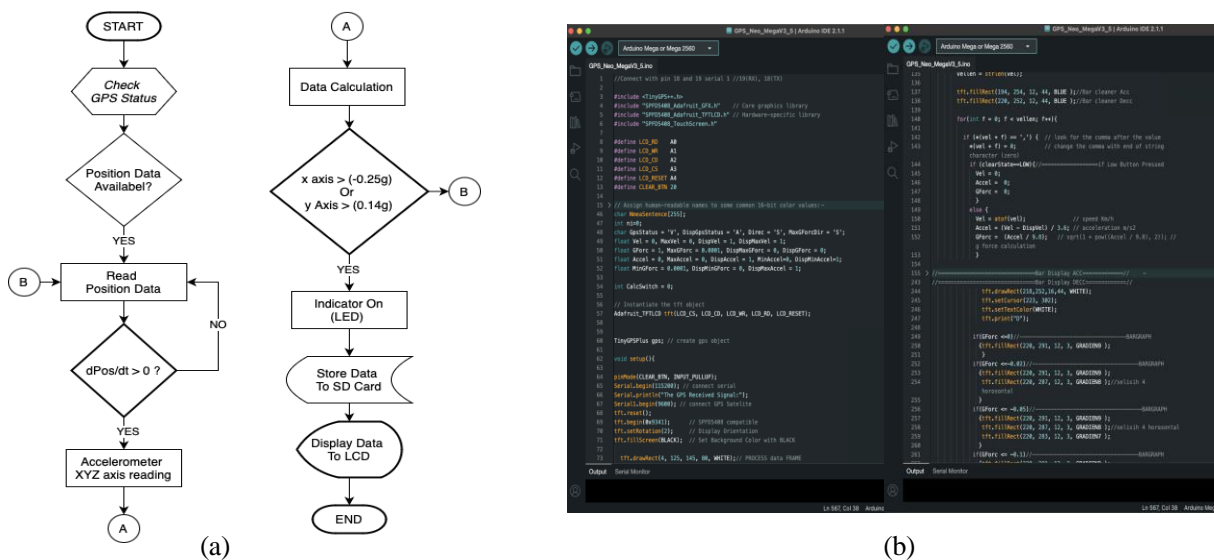


Figure 7. Software design results; (a) program flowchart, (b) listing program

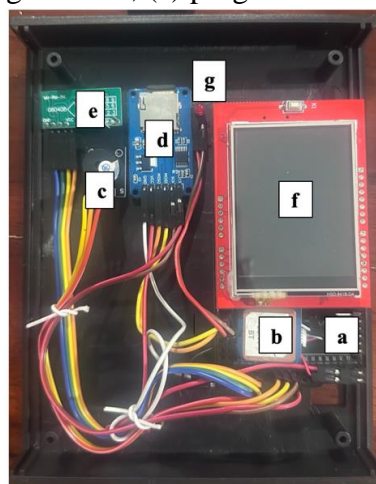


Figure 8. The results of the proposed system installation arrangement:
 (a) Arduino Mega; (b) GPS Module; (c) Buzzer; (d) SDCard Reader; (e) Accelerometer; (f) GPS Module M8N

Function testing was conducted to verify whether the proposed system operates in accordance with the intended objectives outlined in the development of the instrument, prior to conducting tests aimed at addressing the research problem. This testing involved measuring whether the voltage readings from each component met the specified voltage levels required for the device to function effectively. The results of the voltage function testing are presented in Table 1

Table 1.
 Functional test results for each component

No	Components	Voltage Requirements (Volt)	Voltage Read (Volt)
1	Arduino Mega	5.5 – 12.7	5.6
2	GPS Module	3 – 5.5	3.7
3	Accelerometer	3 – 5.5	4.8
4	SD Card Module	3 – 5.5	4.8
5	Li-ion Batt Pack	3.7 – 4.2	4,1
6	Battery Charger	6.8	6.8
7	LED	1.63 – 2.03	2.0
8	Buzzer	5	5
9	LCD	3.3 – 5.6	5.2

Based on the results presented in the Table 1, it is evident that the measured voltage for each component of the proposed system aligns with the required voltage specifications for each component. This compliance ensures that the system can operate effectively according to its intended principles

The calibration process was conducted through ten trials for each accelerometer configuration in accordance with the track standards, maintaining a constant initial velocity. Upon collecting all data from the executed procedures, the information was analyzed and subjected to manual calculations utilizing the formula for uniformly accelerated linear motion to determine the deceleration magnitude, which was subsequently converted into g-force values. This approach allowed for the assessment of deviations between the manually calculated g-force and the values displayed by the instrument for both the x-axis (pitching) and y-axis (rolling) accelerometer configurations. The calibration results revealed an average deviation of 4.01% for the pitching configuration (x-axis accelerometer) across all trials, yielding a mean deviation value of 0.04 with an accuracy of 95.99%. Conversely, the calibration data for the rolling configuration (y-axis accelerometer) indicated a deviation of 2.38%, corresponding to a value of 0.02 and an accuracy of 97.62%. The Comparison of the calibration curves for each accelerometer configuration, illustrating the differences observed before and after the calibration process can be seen in Figure 9.

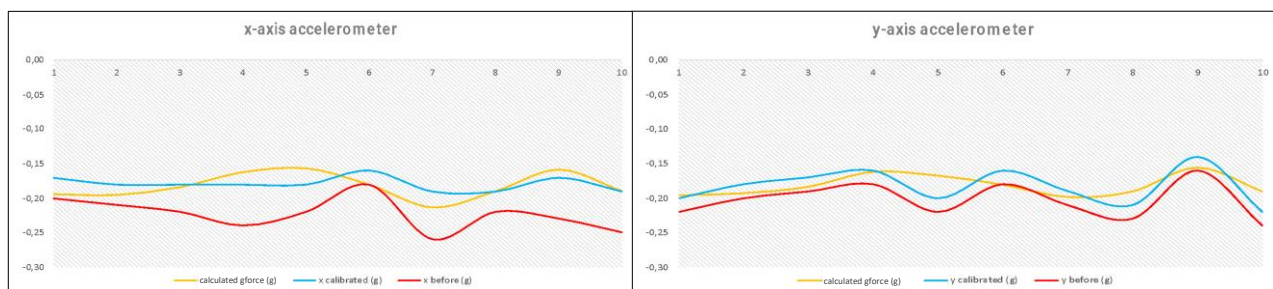


Figure 9. Calibration curve comparison for each accelerometer configuration before and after calibration.

Figure 9 illustrates that post-calibration of the MPU6050 accelerometer resulted in improved accuracy, as evidenced by the device readings aligning closely with the actual values. This improvement is demonstrated by the calibration curve intersecting or coinciding with the curve representing the true values.

The implementation testing of the proposed system was conducted to evaluate its effectiveness as a monitoring tool for driving behavior. The testing procedure involved the use of a minibus to traverse the testing location comprehensively, in both clockwise and counterclockwise directions. During the testing process, data was collected about the device readings of g-force for braking/deceleration, acceleration, and cornering maneuvers to the left and right. The results of the testing can be referenced in Table 2 and Table 3.

Table 2.
Test Data Results on clockwise route

No	Segment	Velocity (m/s)	Gforce Display				Buzzer	Led	SD Card
			Acceleration (g)	Braking (g)	Left Cornering (g)	Right Cornering (g)			
1	Lrs1	5.56	0.11	-0.01	-0.01	-0.01	off	off	Write
2	Lrs2	9.72	0.19	-0.01	-0.01	-0.01	off	off	Write
3	Lrs3	10.56	0.23	-0.01	-0.01	-0.01	on	off	Write
4	Tkn1	6.67	0.01	-0.23	-0.38	-0.01	on	off	Write
5	Tkn2	6.11	0.01	-0.21	-0.34	-0.01	on	off	Write
6	Tkn3	6.39	0.01	-0.32	-0.01	-0.41	on	on	Write
7	Tkn4	6.11	0.01	-0.28	-0.38	-0.01	on	off	Write
8	Tkn5	5.00	0.01	-0.02	-0.35	-0.01	off	off	Write
9	Tkn6	3.89	0.01	-0.02	-0.32	-0.01	off	off	Write
10	Tjk	5.00	0.01	-0.13	-0.01	-0.01	off	off	Write

Table 3.
Test Data Results on counter-clockwise route

No	Segment	Velocity (m/s)	Gforce Display				Buzzer	Led	SD Card
			Acceleration (g)	Braking (g)	Left Cornering (g)	Right Cornering (g)			
1	Lrs1	6.11	0.16	-0.01	-0.01	-0.01	off	off	Write
2	Lrs2	8.89	0.19	-0.01	-0.01	-0.01	off	off	Write
3	Lrs3	9.72	0.25	-0.01	-0.01	-0.01	on	off	Write
4	Tkn1	6.67	0.01	-0.23	-0.01	-0.38	on	off	Write
5	Tkn2	6.39	0.01	-0.31	-0.01	-0.34	on	off	Write
6	Tkn3	6.67	0.01	-0.22	-0.41	-0.01	on	on	Write
7	Tkn4	5.83	0.01	-0.27	-0.01	-0.39	on	off	Write
8	Tkn5	5.00	0.01	-0.02	-0.01	-0.35	off	off	Write
9	Tkn6	3.89	0.01	-0.02	-0.01	-0.32	off	off	Write
10	Tjk	6.11	0.16	-0.01	-0.01	-0.01	off	off	Write

Based on the Table 2 dan Table 3, the performance of the device in monitoring driver behavior can be assessed through the experiments conducted. The device demonstrated the capability to read and display values for velocity and gforce across various measured conditions, including straight roads, inclines, declines, and corners, in both clockwise and counterclockwise directions. The maximum speed detected during the experiments was 38 km/h, with a maximum braking force of -0.32g recorded during horizontal turns on a clockwise route. The highest gforce during cornering maneuvers occurred at -0.41g during horizontal turns on a counterclockwise route.

CONCLUSION

The design and development of a driving behavior monitoring device utilizing GPS, an accelerometer, and an Arduino Mega 2560 microcontroller have been conducted. The components of the device are organized by constructing a block diagram according to the functions and component specifications. The main components include the BN-220 GPS Module as the position tracker, the MPU6050 Accelerometer as the g-force measurement device, and the Micro SD SPI Interface for storing travel data logs. The device is capable of displaying and storing values for velocity, g-force at acceleration, braking, and cornering maneuver under conditions such as straight roads, inclines/declines, and corners, with excellent accuracy ranging from 95.99% to 97.62%.

REFERENCES

- Sullman, M. J., Stephens, A., & Taylor, J. E. (2019). *Dimensions of aberrant driving behaviour and their relation to crash involvement for drivers in New Zealand*. Transportation Research Part F Traffic Psychology and Behaviour 66 . 111-121.
- Silvano, A. P., & Ohlin, M. (2019). Non-collision incidents on buses due to acceleration and braking manoeuvres leading to falling events among standing passengers. *Journal of Transport & Health*.
- Elbanhawi, M., Simic, M., & Jazar, R. (2015). In the Passenger Seat: Investigating Ride Comfort Measures in Autonomous Cars. *IEEE Intell. Transp. Syst. Mag.* 4–17.
- Turner, M., & Griffin, M. (1999). Motion sickness in public road transport: The effect of driver, route and vehicle. *Ergonomics* . 1646–1664.
- Martin, D., & Litwhiler, D. (2008). An Investigation of acceleration and jerk profiles of public transportation vehicles. *ASEE Annual Conference and Exposition*. Pittsburgh.
- Bosetti, P., Da Lio, M., & Saroldi, A. (2014). On the human control of vehicles: An experimental study of acceleration. *Eur. Transp. Res. Rev.*
- Bae, I., Moon, J., & Seo, J. (2019). Toward a Comfortable Driving Experience for a Self-Driving Shuttle Bus. *Electronics*.
- Engel, P. K. (1994). The Global Positioning System: Signals, Measurements, and Performance. *International Journal of Wireless Information Networks*. 83-105.
- Kaplan, E. D., & Hegarty, C. J. (2006). *Understanding GPS Principles and Applications, Second Edition*. London: Artech House, Inc.
- French, G. T. (1996). *Understanding The GPS : An Introduction To The Global Positioning System. What it is. And How It Works*. Maryland (MD, US): GeoResearch, Inc.
- Agnihotri, N. (n.d.). *GPS : Working . Applications and History*. Retrieved february 2023. from Engineers Garage: <https://www.engineersgarage.com/gps-working-applications-and-history/>
- Beitian Co., Limited. (2015). BN-220 GPS Module + Antenna DataSheet.
- Kirushanth, S., & Kabaso, B. (2020). Design and Development of Weigh-In-Motion Using Vehicular Telematics. *Hindawi Journal of Sensors, 2020*.

- Casilari, E., Álvarez-Marco, M., & García-Lagos, F. (2020). A Study of the Use of Gyroscope Measurements in Wearable Fall Detection Systems. *Symmetry Journal*, 12(4).
- Dadafshar, M. (2014). *Application Note 5830: Accelerometer And Gyroscopes Sensors: Operation, Sensing, And Applications*. Maxim Integrated Products, Inc.
- Cameron, Neil. (2019). *SD Card Module: Comprehensive Projects for Everyday Electronics*. 10.1007/978-1-4842-3960-5_12.
- Ibrahim, D. (2010). *SD Card Projects Using the PIC Microcontroller*. Elsevier Ltd.
- Arduino.cc. (2024). *Arduino® Mega 2560 Rev3 : Product Reference Manual SKU: A000067*.
- Purwowibowo, Wijonarko, S., & Maftukhah, T. (2019). GPS Logger Development Using an Atmega 2560 Microcontroller. *Instrumentasi*, 3(2).
- Weitz, M., Morseth, B., Hopstock, L. A., & Horsch, A. (2024). Influence of Accelerometer Calibration on the Estimation of Objectively Measured Physical Activity: The Tromsø Study. *Journal for the Measurement of Physical Behaviour*, 7(1).