CALIFORNIA STATE UNIVERSITY, NORTHRIDGE

Barometer Sensing for Mobile Applications

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Software Engineering

By Arahik Torosian

December 2022

The thesis of Arahik Torosian is approved:

Professor Vahe Karamian | Date

Katya Mkrtchyan, Ph.D. | Date

Ani Nahapetian, Ph.D., Chair | Date

California State University, Northridge

Table of Contents

List of Figures

Abstract

Barometer Sensing for Mobile Applications

By Arahik Torosian

Master of Science in Software Engineering

This thesis evaluates the ability to use a smartphone's barometer sensor for a range of applications other than its original, intended application of altitude sensing. This work shows that the barometer sensor registers not just altitude changes but other environmental and contextual changes as well. Several environmental and contextual influences are investigated, including location, sound, interaction, and road traffic. The results confirm that the barometer is a powerful sensor that can be used in a range of novel applications.

1 Introduction

Today's smartphones are equipped with powerful and varied sensors. Leveraging these sensors for a range of new applications has the power to improve our lives, especially since smartphones are ubiquitous in society. Smartphones have long been equipped with accelerometers, gyroscopes, and magnetometers. Barometers, a more recent addition, have now become standardized on premium commercial smartphones. Barometers measure atmospheric pressure, and in smartphones, they are primarily used to calculate altitude. Zhang et al. stated in the article that the barometer with other sensors had been used to increase vertical positioning precision [8].

Although the barometer on mobile phones has traditionally been used for localization and improved navigation accuracy, this thesis examines how the barometer can be leveraged for a variety of new applications. The new applications include 1) localization beyond just altitude, 2) smartphone interaction classification, 3) adjacent sound and music detection and classification, and 4) car traffic monitoring. In the applications considered, only the readings from the barometer sensor are accessed and utilized. No other sensors available on the smartphone are used, and the experimental results show that the barometer is indeed able to pick up subtle environmental and contextual changes.

The remainder of the thesis is organized into the following chapters. Chapter 2 presents a review of the literature. Chapter 3 presents the approach, including the system prototype that was developed. Chapter 4 presents the evaluation of the various applications and their experimental results. Chapter 5 concludes the thesis.

2 Related Work

In recent years, many of the sensors included in modern smartphones have been shown to be valuable for new applications outside of their original intended purpose. The barometer, available on most high-end smartphones, including the popular Samsung Galaxy series and iPhone devices, measures air pressure and acts as a proxy for altitude. In this thesis, the potential for expanded uses of barometer sensor readings on smartphones is explored.

The research literature has looked at various ways to use the barometer sensor in smartphones.

2.1 Indoor Localization

Indoor navigation using smartphone motion sensors is common. Recently, researchers have looked at fusing the barometer data with the motion sensor data to improve localization accuracy and indoor navigation. Since the Global Positioning System (GPS) has low accuracy in positioning vertical positions, barometer sensors can be used to improve indoor navigation [8]. Lara et al. Stated that using a barometer with another sensor can determine whether the user is inside a building or not [6].

The barometer has been used for applications other than altitude detection in the research literature. The barometer is used for indoor localization, including the detection of air pressure changes across the various levels of a building [5]. Muralidharan et al. were able to accurately determine if a user has changed floors in a building and the apparatus used, such as an escalator, elevator, or stairs, by using a J48 classifier on the smartphone barometer readings [5].

A barometer can detect height and floor changes. However, if the building is not equipped with a barometer—referred to as "reference pressure," an additional sensor should be installed in the structure. The device's precise location can be determined by comparing the information collected from the installed sensor with the sensor on the smartphone [1].

2.2 Door Opening Determination

It has also been investigated to use the barometer to tell whether a door has been opened or closed. Most buildings are pressurized in order to provide air conditioning [1]. The door opening and closing of such pressurized structures will have a high impact on barometer readings. The pressure inside the building is released and combines with the outside pressure when the door is opened. When the door shuts, it creates compression, and after a while, it returns to the earlier state before the door was opened.

2.3 Barometer Based Monitoring

Manivannan et al. stated that it is possible to accurately detect human mobility in interior spaces by using "an array of barometric sensors." The variation caused by transition reveals the location of the user in the building [1]. For instance, it will be clear where a door has been opened or closed in a building if one of the barometers displays compression or discharge.

2.4 Finger Tap Detection

The barometer has been shown to detect finger presses on the phone screen [2][3]. Alireza Hafez stated in the article that since smartphones are almost fully sealed, the internal air pressure increases when the screen is touched and settles after a brief time [2]. Hafez et al. Employ the strategy of dividing the smartphone screen into nine rows and columns and considering each region [3]. Each time the screen is touched, the degree of freedom is gathered, and the SVM classifier is used to estimate finger tap positions [3].

2.5 Speaker Activity Detection

Speaker and earpiece activity have an impact on the barometer as well. Small vents are present on smartphones so the barometer can detect the pressure [3]. Hafez et al. were able to distinguish whether an external speaker or an earpiece speaker was playing. When the speaker plays, the air tends to move, but because the vents are tiny, the air cannot travel quickly, which results in compression and subsequent pressure fluctuations [3].

2.6 Challenges

There are several known challenges with working with the barometer sensor. Muralidharan et al. showed that smartphone barometer readings change over the course of a day. Even though the device was stationary and other variables were constant, "absolute pressure variation" was detected [5]. Barometer readings varied across different dates, with all the other conditions constant [5].

Muralidharan et al. also found that even when smartphones are stationary, using the same model, and in the same environment, there is "inner- and intra- phone model variance," which results in each smartphone reading the air pressure differently [5].

Haibo et al. found that the maximum barometric pressure difference in a half-hour was 1.2 hPa, which is a large number [4]. This number causes an altitude inaccuracy of around 10 meters [4].

In their study, Manivannan et al. and Xia et al. stated that in the lack of a barometer sensor, "reference pressure" should be utilized to get correct vertical positioning [1][7]. The barometer sensor is able to show the vertical changes, but a fine-calibrated “reference pressure” is needed to pinpoint the device location more accurately.

Another issue is that most buildings are pressured for air conditioning, as the air pressure will read differently depending on how the air conditioning operates [1]. Other factors, such as “platforms” and electricity, can cause noise and different readings [7].

3 Approach

This work explores the new applications that become available if the smartphone barometer sensor is leveraged for uses beyond simply vertical positioning. For use in the experiments carried out, a system prototype was developed. Novel applications for barometers were proposed and then investigated. A few challenges with the smartphone barometer sensor were also confirmed.

3.1 Prototype

A prototype was developed to explore the range of applications possible with just the readings from a smartphone's barometer. The prototype included a commercial smartphone, the smartphone's barometer, data collection, display app, and data cloud storage.

A popular commercial smartphone, a Samsung Galaxy S10, was used for the experiments. The smartphone's barometer sensor was used. The prototype was able to measure 300 barometer values per minute, giving a 5Hz data rate.

A bespoke software application was developed to capture the barometer readings in real time, display the values on the screen, graph the values on the screen, and save the values to the cloud. The barometer readings were collected using the OnSensorChanged method. After being measured, the data was transmitted to Google Drive using the smartphone's Wi-Fi. The collected data was visualized using MS Excel.

The barometric sensor values were obtained using a Java application created with the Android Studio IDE. The raw values are displayed on the screen. Also, the recent values are graphed in real-time to assist with the data collection and experimentation.

The screenshots of the app are shown in Figure 3.1. The screenshots show the app splash screen, the view before the data collection, the view during the data collection, and the data sharing selection screen.

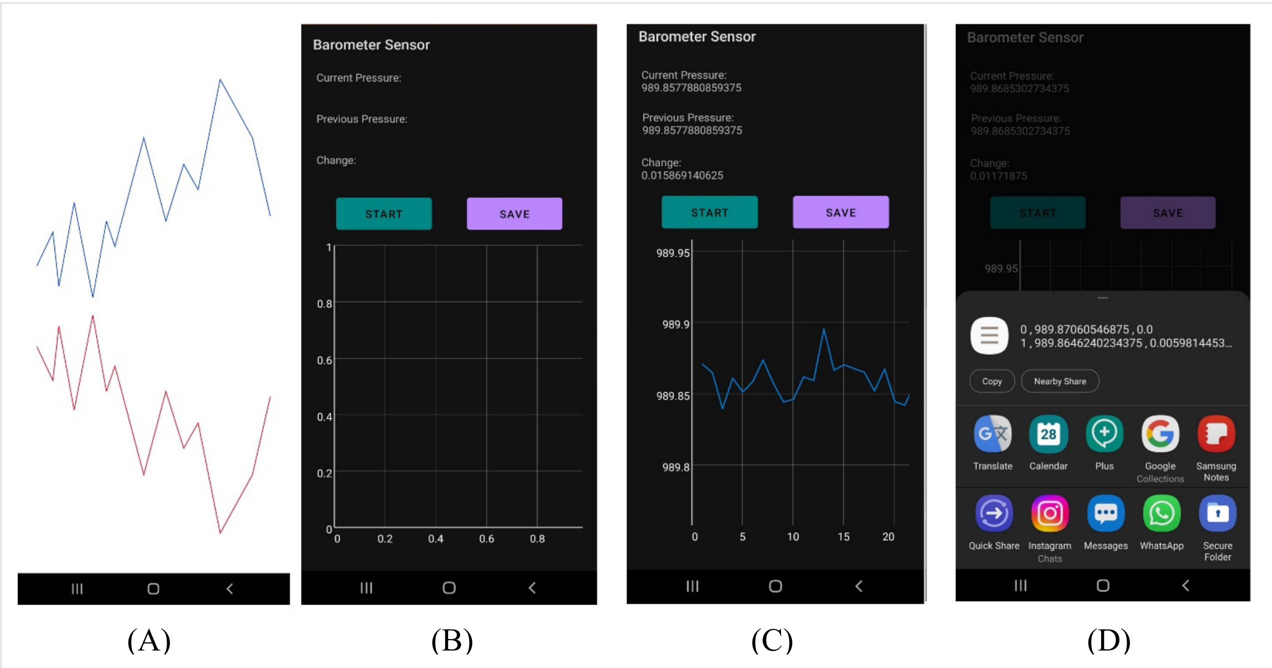

Figure 3.1 Screenshots of the prototype's software app, namely (A) app splash screen, (B) app screen prior to starting data collection, (C) app screen during data collection, and (D) screenshot of selecting the data sharing application.

3.2 Application Areas

An important component of this research was the development of new applications which leverage the smartphone barometer and the evaluation of the environmental and contextual information reflected in the barometer readings. The proposed application areas can be grouped into localization, music detection, smartphone interaction, and vehicular context monitoring.

3.3 Challenges

The barometer sensor readings exhibit variability that presents a unique challenge. For example, even where there is no movement of the smartphone and no other explicit environmental changes, there is still an oscillation in the barometer readings. The barometer sensor readings are also impacted by the time of the day.

An experiment was conducted to demonstrate the change in the variation over the course of 15 minutes. In another experiment, the difference between performing the test at night and in the morning is demonstrated. During these experiments, variation in changes and different readings can be seen even though the smartphone is stationary and other known environmental factors are not changed.

3.3.1 Readings When Stationary

An experiment was carried out to determine whether there would be any change in the barometric readings in case there was no movement. Figure 3.2 shows the result of this experiment, where the smartphone was placed in a room with an open door. The smartphone position/height has not been changed during the experiment.

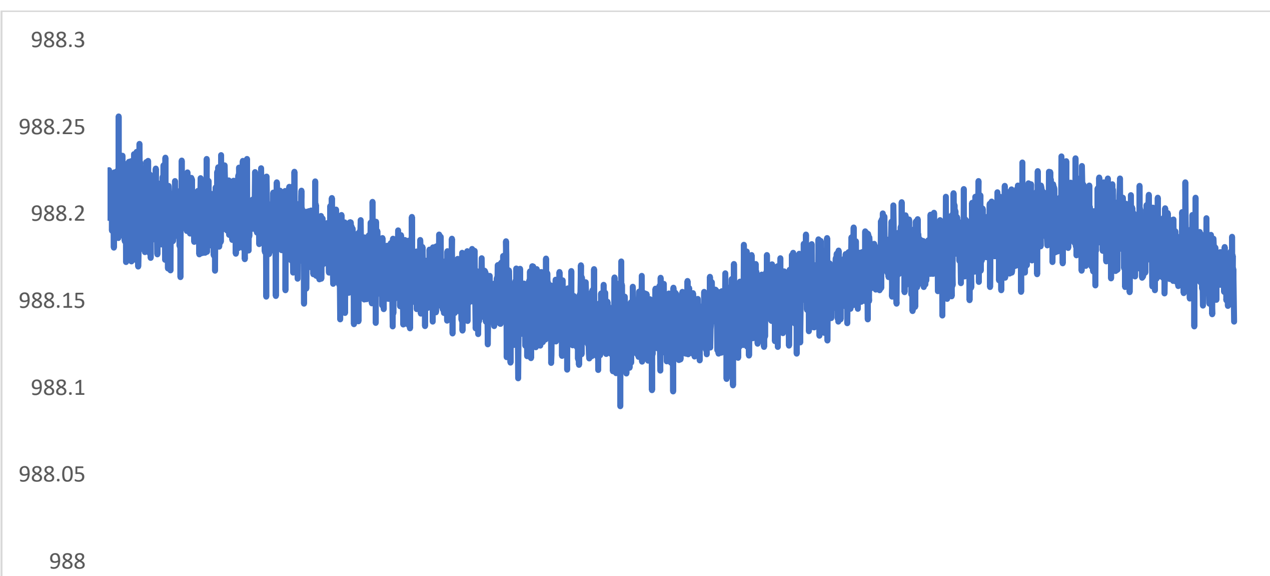

Figure 3.2 Change in barometric pressure while no movement is encountered. The x-axis is the time. The y-axis is the barometer reading in hPa (mbar).

This experiment demonstrates that even though there was no movement, the barometric pressure varies. The results of this experiment have been gathered over a period of 15 minutes.

3.3.2 Day Versus Night Readings

An experiment was carried out to determine whether different times of a day would cause different readings. In this experiment, the smartphone was placed in a room with an open door both at night and in the morning. The results are shown in Figure 3.3. The smartphone's position and height were not changed during the experiment.

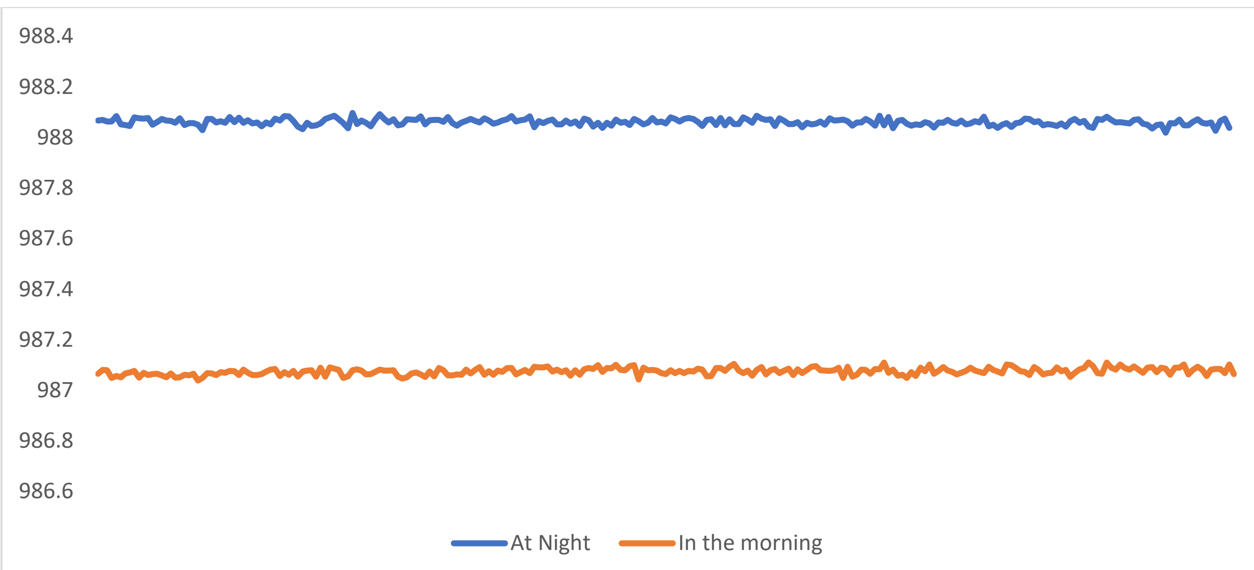

Figure 3.3 Change in barometric pressure during a different time of a day. The x-axis is the time. The y-axis is the barometer reading in hPa (mbar). The first data series of measurements, displayed in blue, was taken at night. The second data series of measurements, displayed in orange, was taken in the morning.

This experiment demonstrates that even though the position of the cellphone has not been changed during the two times of day, the readings are different. The morning readings, shown in orange, have lower air pressure than the night readings, shown in blue.

4 Experimentation

A series of experiments were conducted using the barometer sensor of a Samsung Galaxy S10 smartphone to determine the effectiveness of using changes in air pressure to determine location, adjacent sounds, user interactions with the smartphone, and neighboring vehicular traffic.

4.1 Impact of Location

The barometer sensor readings can be significantly impacted by changing the height. The idea for this series of experiments is to analyze if a change in a floor or the height of the phone on the same floor will change the readings and its created patterns. The barometer would indicate the floor change, whether the mode of transportation is by foot, elevator, or escalator. Based on the speed, each mode of transition creates a unique pattern that can be differentiated. Moreover, the sensor is sensitive enough to show if the smartphone has moved vertically within a room, even for as little as 1 foot.

In the following experiments, the position of the phone at different heights, the changes in the floor of a building, and the impact of a door opening and closing are explored. The results can be used to support using the barometer for relatively fine-grained indoor localization.

4.1.1 Placing The Smartphone at Various Heights

An experiment was carried out to determine whether a change in smartphone position/height would be distinguished. In this experiment, the smartphone was placed in a room, and generated results are shown in Figure 4.1. The smartphone was first placed on the floor, then on a table, and then it was held at ceiling height. Following that, it was placed on the floor again. The smartphone was kept in each position for approximately 20 seconds. The height of the table is 29 inches. Moreover, the distance from the table to the ceiling is approximately 67 inches, with the ceiling height being 96 inches.

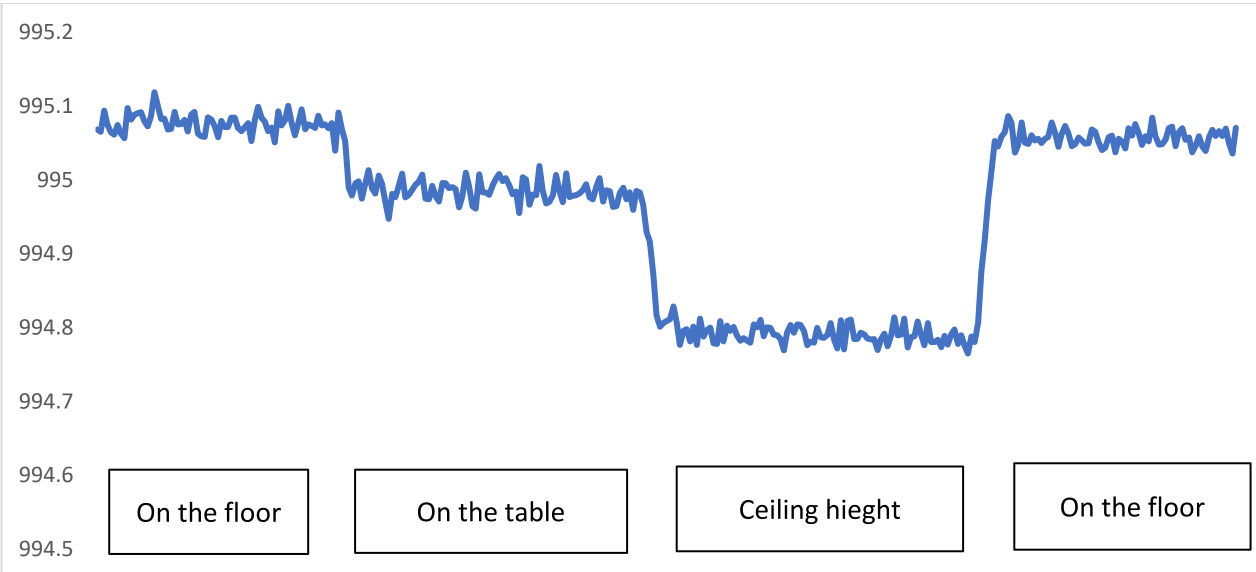

Figure 4.1 Changing the height of the smartphone. The x-axis is the time, as the height is increased and decreased. The y-axis is the barometer reading in hPa (mbar).

This experiment demonstrates that the barometer can be used to determine the height. The second time the smartphone was placed on the floor, it duplicated what was generated the first time. It can be seen in the graph that the barometer is sensitive to even small changes in height.

4.1.2 Floor Change Detection

An experiment was conducted to determine whether a floor change can be indicated with a change in the data readings. This experiment was carried out in Jacaranda Hall on the California State University, Northridge Campus. The device was held at an approximately 45-degree angle as it was walked from the fourth floor down to the first floor via the stairs. The barometer reading was recorded, visualized, and analyzed, as shown in Figure 4.2.

Figure 4.2 Change in barometric pressure from the Fourth floor to the first floor. The x-axis is the time. The y-axis is the barometer reading in hPa (mbar).

This experiment demonstrates that air pressure was increased by walking down the stairs from the fourth floor to the first floor. On each floor, there was a couple of seconds pause before continuing. This experiment demonstrates that air pressure varies during different levels of a building.

4.1.3 Elevator Versus Escalator

An experiment was conducted to determine if the pattern of barometric readings would be differentiated if an elevator and escalator were used. Figure 4.3 shows the result of the experiment where the cell phone was held in hand at an approximately 45-degree angle on both transitioning modes. A transition occurred from the second floor to the first floor at both modes.

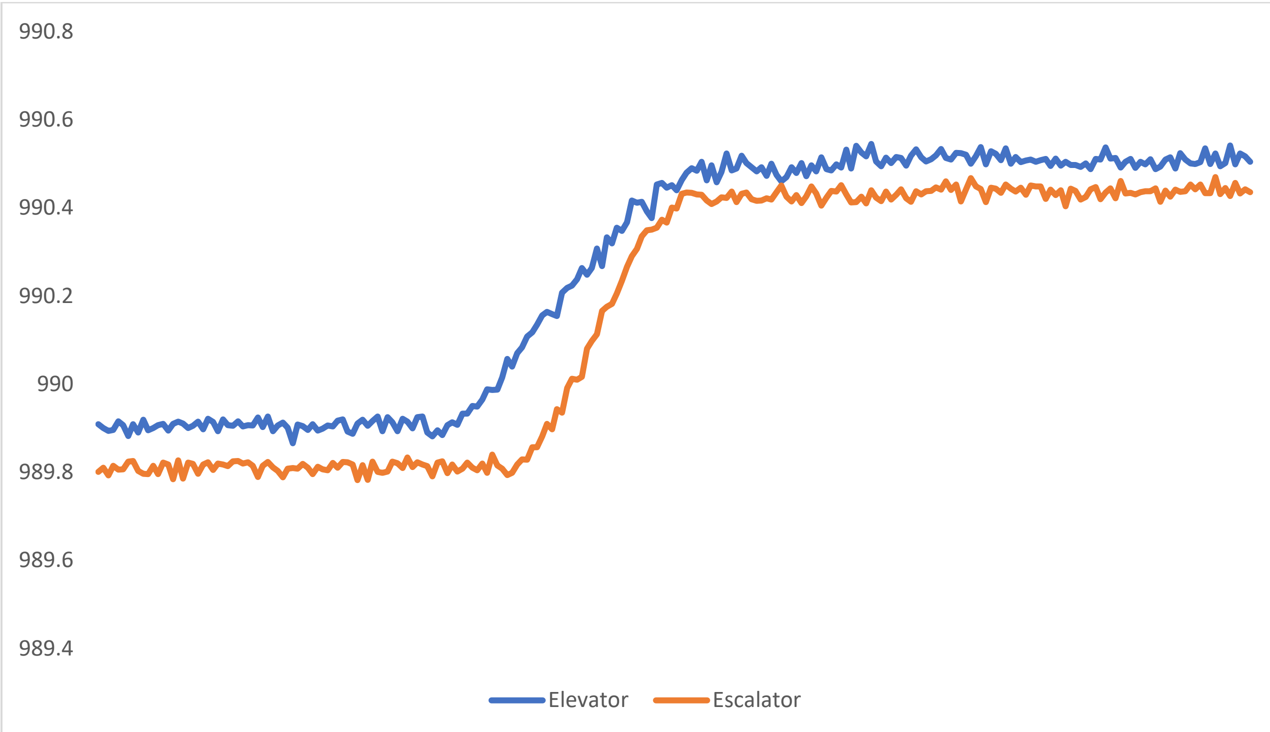

Figure 4.3 Change in barometric pressure while transitioning from the second floor to the first floor. The x-axis is the time. The y-axis is the barometer reading in hPa (mbar). The first data series shown in blue is transitioning using an escalator. The second data series shown in orange is transitioning using an elevator.

This experiment demonstrates similar barometric readings in both modes. There are two differences shown in the graph. First, even though the elevator and escalator are on the same floor, the data series associated with the escalator is somewhat greater than the other due to the presence of stairs in the building. Second, the speed of transitioning mode causes the pattern to be slightly different. In the experiment, the speed of the elevator was faster compared to the escalator and hence caused a faster movement in the graph. Moreover, the escalator had greater variability due to its lower speed of movement.

4.1.4 Walking And No Movement

The barometer sensor can show different data created by human activity. The idea of this experiment is to determine if the barometer sensor can distinguish between walking and no movement. For this experiment, three different modes have been tested.

An experiment was carried out to determine whether the barometer could be used to distinguish walking. In this experiment, three mods have been explored, and the results are shown in Figure 4.4. First, the cell phone was held in hand at an approximately 45-degrees angle while walking; then, the cell phone was placed in the pocket and continued walking. At last, the cell phone was held in hand, and no movements were performed.

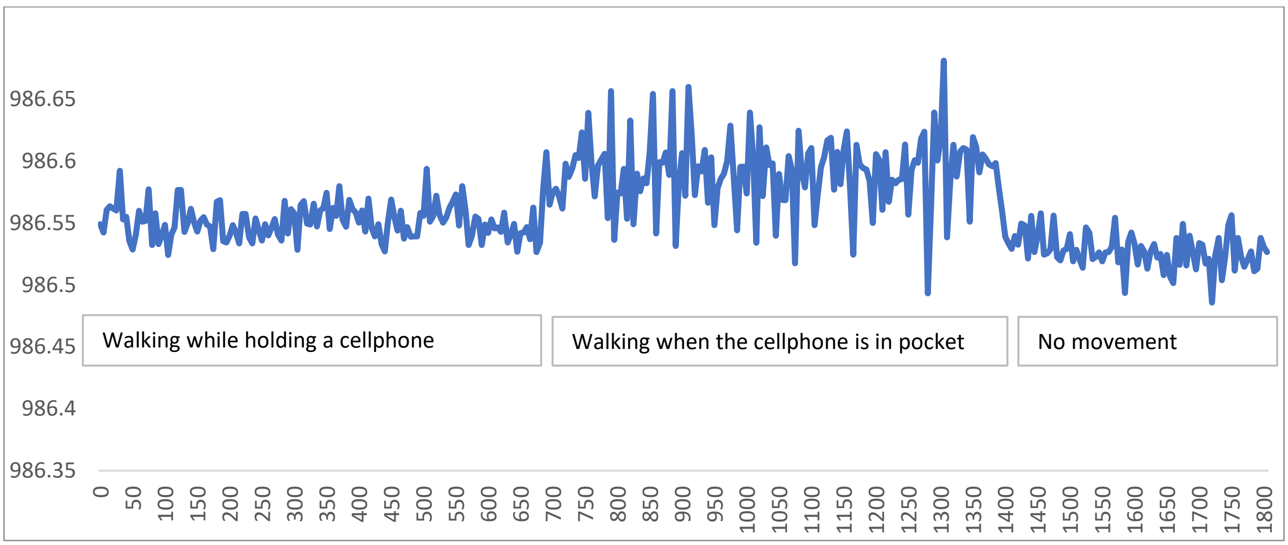

Figure 4.4 Change in barometric pressure while walking, and no movement is encountered. The x-axis is the time. The y-axis is the barometer reading in hPa (mbar). The first section is walking while the cell phone is held in hand. The second section is walking while the cell phone is in the pocket. The third section is about holding the cell phone in hand and not moving.

This experiment demonstrates the different patterns created by the position/mode of the cellphone. The sensor could more accurately identify walking while the user's smartphone is in their pocket or handbag. In this case, it produces a pattern where the pressure change gets denser in a short period of time.

If the smartphone is held in hand, the sensor is unable to detect shakes due to the filtering of movement induced by holding the smartphone, resulting in a smooth and filtered pattern that makes it hard to determine if the user is walking or not. Although no movement has been performed in the third event, there is still noise, and its pattern is similar to the first event. It can be inferred that the walking pattern is clearly different from the other two events.

4.1.5 Forcefully Opening and Closing a Door

The door opening and closing can impact the barometer sensor readings. Experiments were conducted to determine the impact of transition. The majority of buildings are pressurized for air conditioning purposes, and when the transition happens, it causes a large and sudden change in the data readings [1]. Even with non-pressurized buildings, when the door is forcefully closed or opened, it causes significant change. On the other hand, with non-pressurized buildings, if the door closing and opening happen slowly, it will not cause a major change.

An experiment was carried out to determine if the barometer could be used to detect the forceful opening and closing of a nearby door. Figure 4.5 shows the result of this experiment, where the phone was placed on the table inside a room. The table was one foot from the entrance, with the mobile phone in the center of the table, making it three feet from the door.

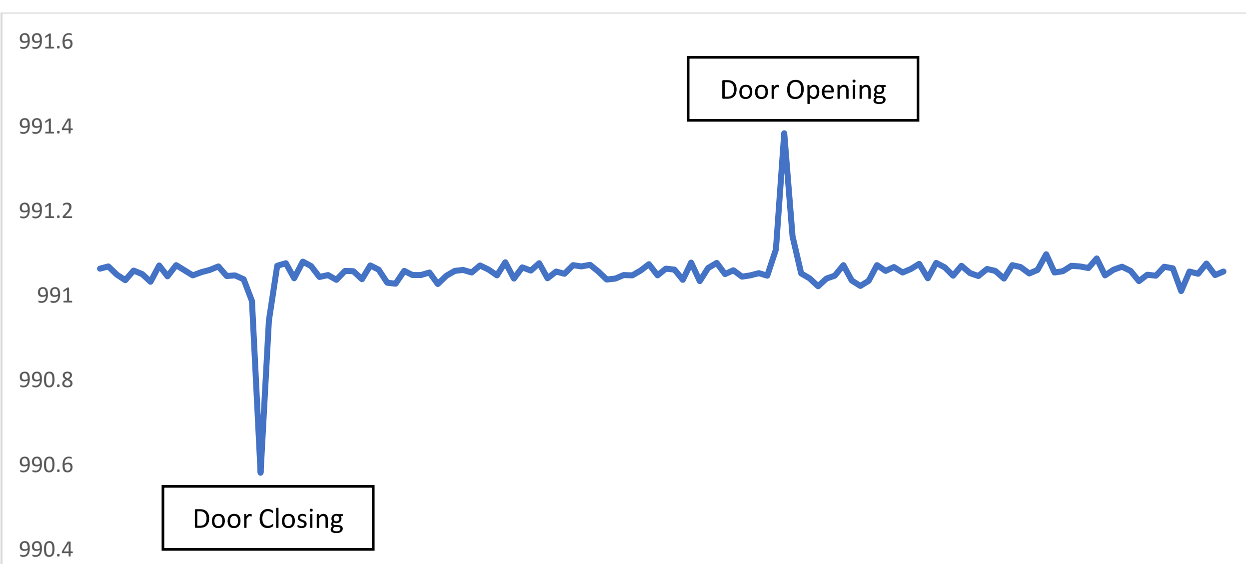

Figure 4.5 Door Opening and Closing. The x-axis is the time, as the door is forcefully closed and opened. The y-axis is the barometer reading in hPa (mbar). The door closing caused compression, and the door opening caused expansion.

The door was initially open. Then, it was quickly closed, causing the first event in the data, the dip in the pressure reading. Subsequently, after a few seconds, the pressure value stabilized. Then the door was quickly reopened, causing the second event, the spike in the pressure reading. Again, after a few seconds, the pressure stabilized.

This experiment demonstrates that a door being opened or closed causes a large spike or dip in the pressure reading. In a pressurized environment, forcefully closing or opening a door causes a noticeable change in the data. After a short period of time, the effect of air compression or decompression caused by the door opening or closing subsides, and the barometric pressure readings return to their original state.

4.1.6 Gently Opening and Closing a Door

An experiment was conducted to determine if gently opening and closing a door would produce the same result as opening and closing it forcefully. Figure 4.6 shows the result of this experiment, where the phone was placed on the table inside a room. The table was one foot from the entrance, with the mobile phone in the center of the table, making it three feet from the door.

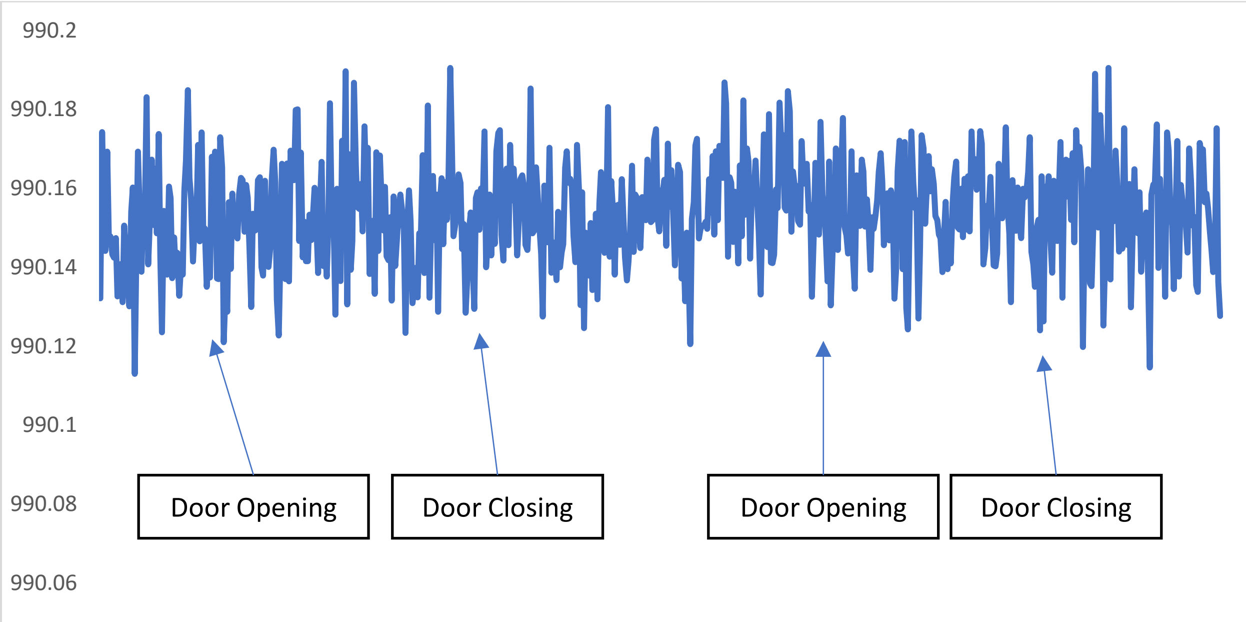

Figure 4.6 Gently Opening and Closing a Door, as the door is being slowly closed and opened. The y-axis is the barometer reading in hPa (mbar). Slowly closing and opening a door does not cause any major change.

This experiment demonstrates that a door slowly being opened or closed does not cause a major change in the graph. It should be noted that this outcome will emerge if the building is not pressurized.

4.2 Impact of Sound

The presence of speech and music has an impact on the barometer sensor as well. Large speakers are capable of changing air pressure rapidly and drastically. A series of experiments were conducted to demonstrate the impact of the presence of speech and music. To further highlight the findings, some of the trials were conducted in a vehicle. The majority of the experiment's data series contains both speech or music and silence parts. The idea was to examine each part separately and calculate the mean or average, and then illustrate their influence using the mean and average.

4.2.1 Detecting The Presence of Speech Nearby

An experiment was conducted to determine if someone speaking nearby could be detected by the barometer of the smartphone. In this experiment, three short statements were made 1-foot away from the smartphone. The statements were "Today is a sunny day," "Today is a beautiful day," and "Tomorrow will be a rainy day. "Figure 4.7 show the result of the experiment where the speech started at data point 0 and was halted at data point 120. No speech was generated after data point 120.

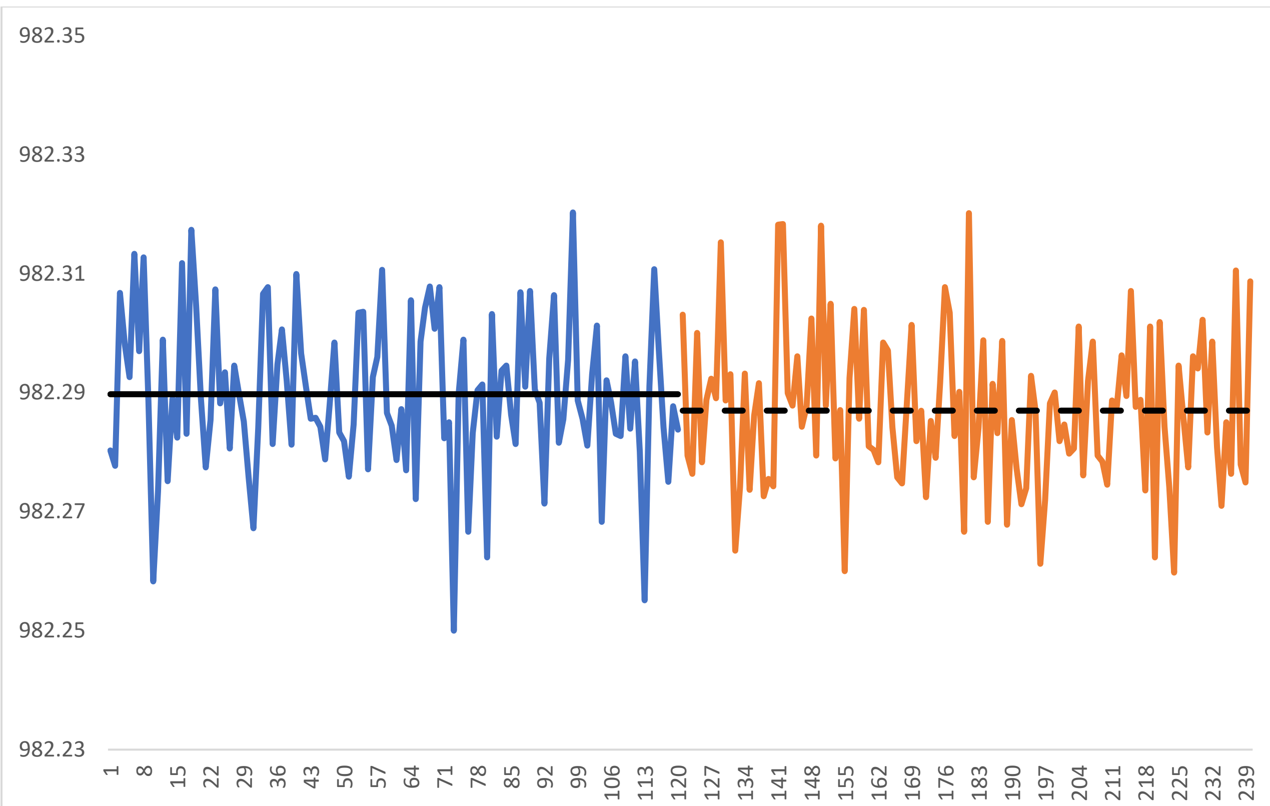

Figure 4.7 Detecting the Presence of Speech Nearby. The x-axis is the points, as the speech is present in the first data series, shown in blue, and not present in the second data series, shown in orange. The y-axis is the barometer reading in hPa (mbar). The average of the first series is displayed with a solid black line. The average of the second series is displayed with a dashed black line.

In this experiment, the mean of the first data series with speech and the second data series without speech has been calculated separately. It can be seen from the graph that the first data series, with speech, has a slightly higher average than the second data series.

4.2.2 Playing Music and Gradually Decreasing the Volume

An experiment was carried out to determine whether the volume of the music can change the barometric readings. In this experiment, both the smartphone and the speaker were placed in a closed-door room and remained stationary. Music was played on a JBL speaker at a distance of 18 feet. The signal-to-noise ratio of the JBL speaker used in this experiment is less than 80 dB. In the beginning, the volume of music is at its highest. The volume of the music is then progressively reduced while the speaker and smartphone remain in the same position. Figure 4.8 show the result of this experiment.

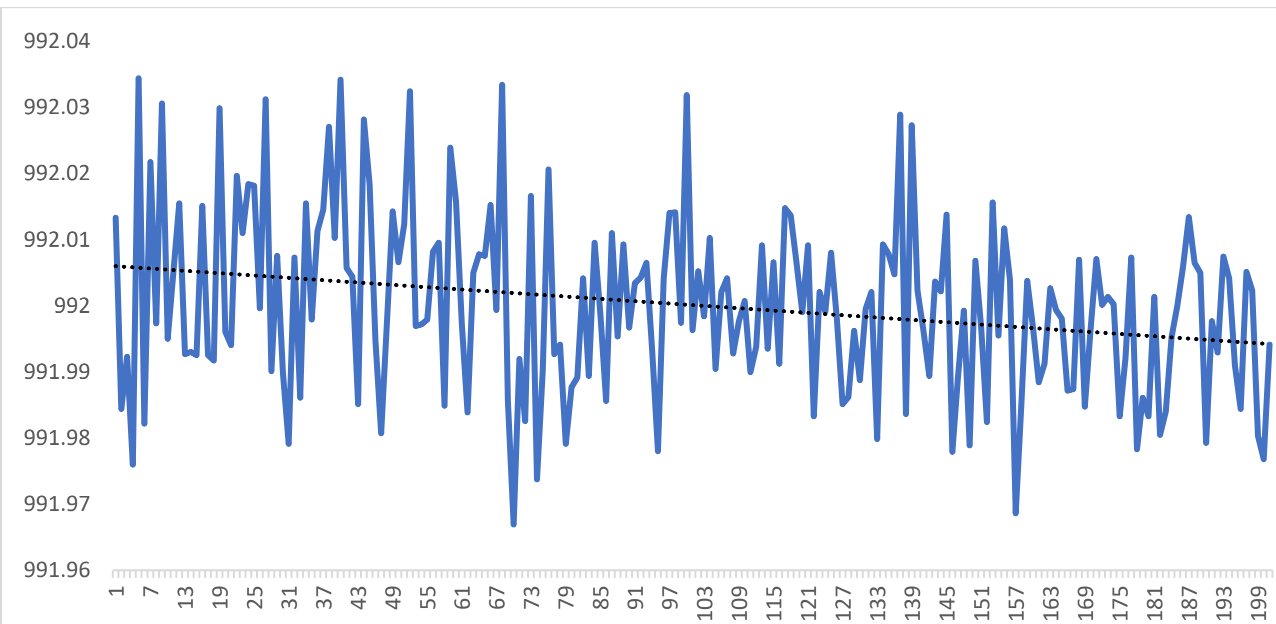

Figure 4.8 Playing Music. Music is played on a neighboring speaker, and the volume is gradually decreased. The x-axis is the time, as the volume is decreasing. The y-axis is the barometer reading in hPa (mbar).

This experiment demonstrates that playing music can impact barometric pressure. It can be seen in the graph that the pressure variation is gradually decreasing as the volume decreases. Additionally, the experiment's trend line demonstrates that as the sound volume gradually decreases, the pressure variation also decreases.

4.2.3 Speaker Playing and Getting Close

An experiment was carried out to determine whether a nearby speaker playing would change the barometric readings. In this experiment, both the smartphone and a speaker are placed in a closed-door room. Figure 4.9 shows the result of the experiment, where the music was played on a JBL speaker at a distance of 18 feet, as it was moved closer to the smartphone every 5 seconds. The volume of music was set to its highest, and the smartphone remained stationary during this experiment.

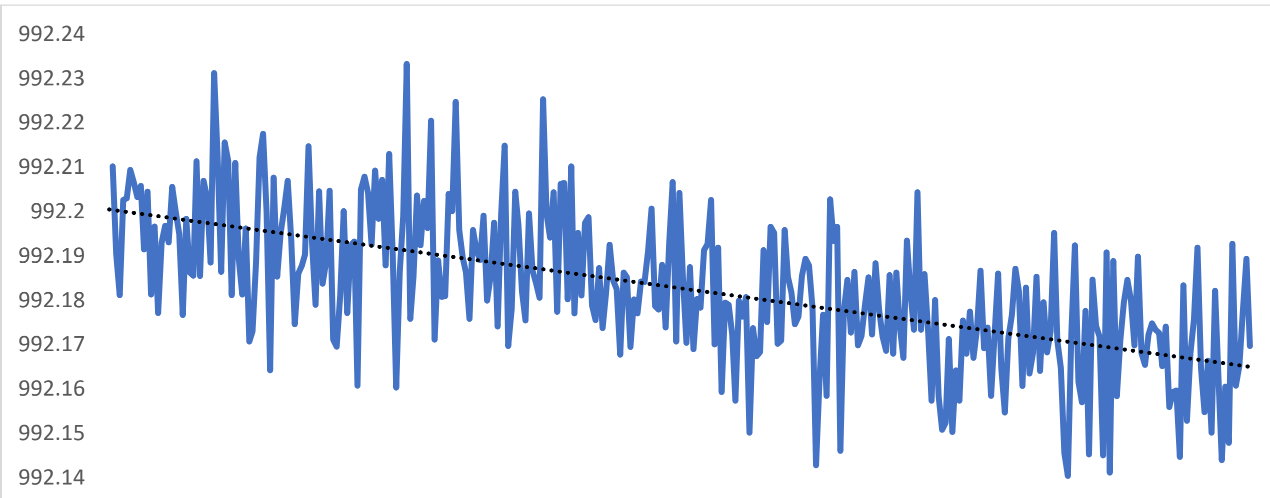

Figure 4.9 Speaker is playing and getting close. The x-axis is the time as the music is being played. The y-axis is the barometer reading in hPa (mbar).

This experiment demonstrates the effect of playing nearby music on data readings. The air pressure decreased as the speaker got close to it.

This result is unexpected, as the expectation was that playing nearby music would increase the pressure reading, not decrease it. It is possible that other factors may interfere with the data reading and result in inaccurate readings.

4.2.4 Music Genre Impact

An experiment was conducted to determine whether playing different music genres would change barometric readings. In this experiment, a car is parked on a deserted avenue, and the smartphone is placed on the car's console. Figure 4.10 shows the results of this experiment, where each music genre was played at its loudest volume.

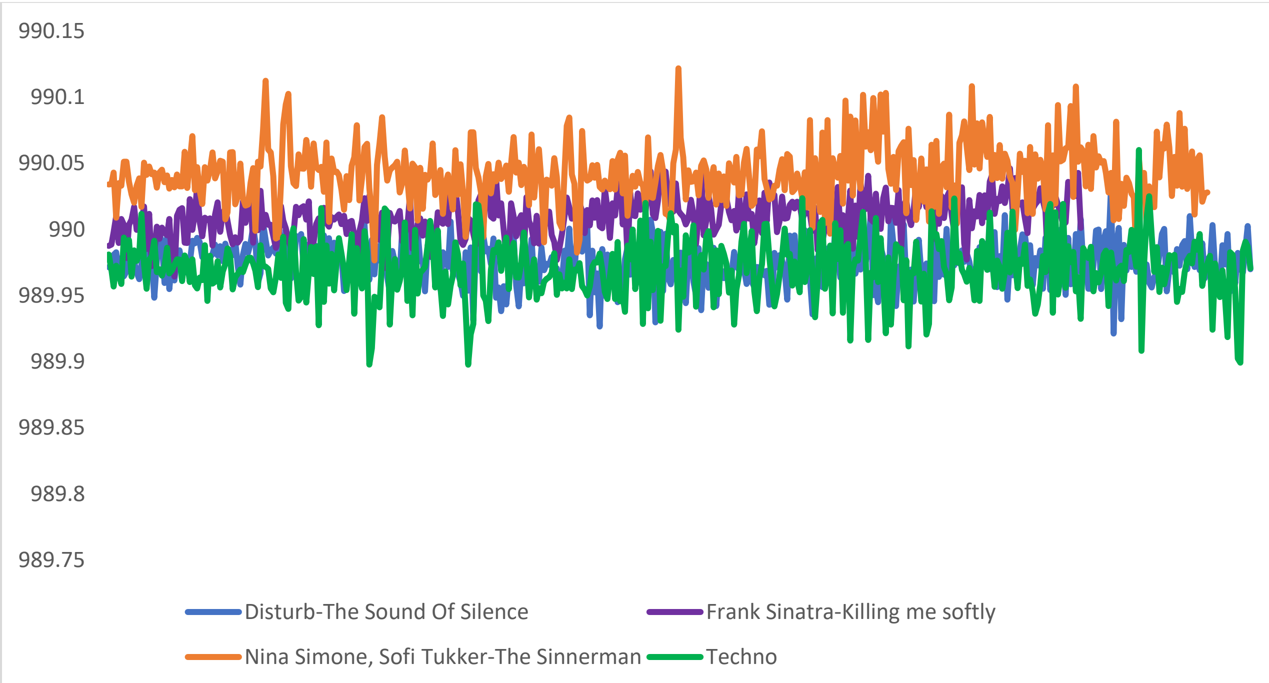

Figure 4.10 Music genre effect. The x-axis is the time as the music is being played. The y-axis is the barometer reading in hPa (mbar).

This experiment demonstrates the impact of different music genres on the data readings. As shown in the graph, the rhythmic and bass-heavy genre music has the most significant variations in change. The orange date series is Nina Simone, Sofi Tukker – Sinnerman music, and the green data series is a techno mix. The purple data series is Frank Sinatra-Killing me softly music, and the blue data series is Disturbed - The Sound Of Silence music. The orange and green data series are clearly visible; however, the other two, which have a little lower tempo genre, are hardly visible.

The second run of the experiment demonstrates the impact of three other genres, as shown in Figure 4.11. In this run, two other series have been compared with techno music.

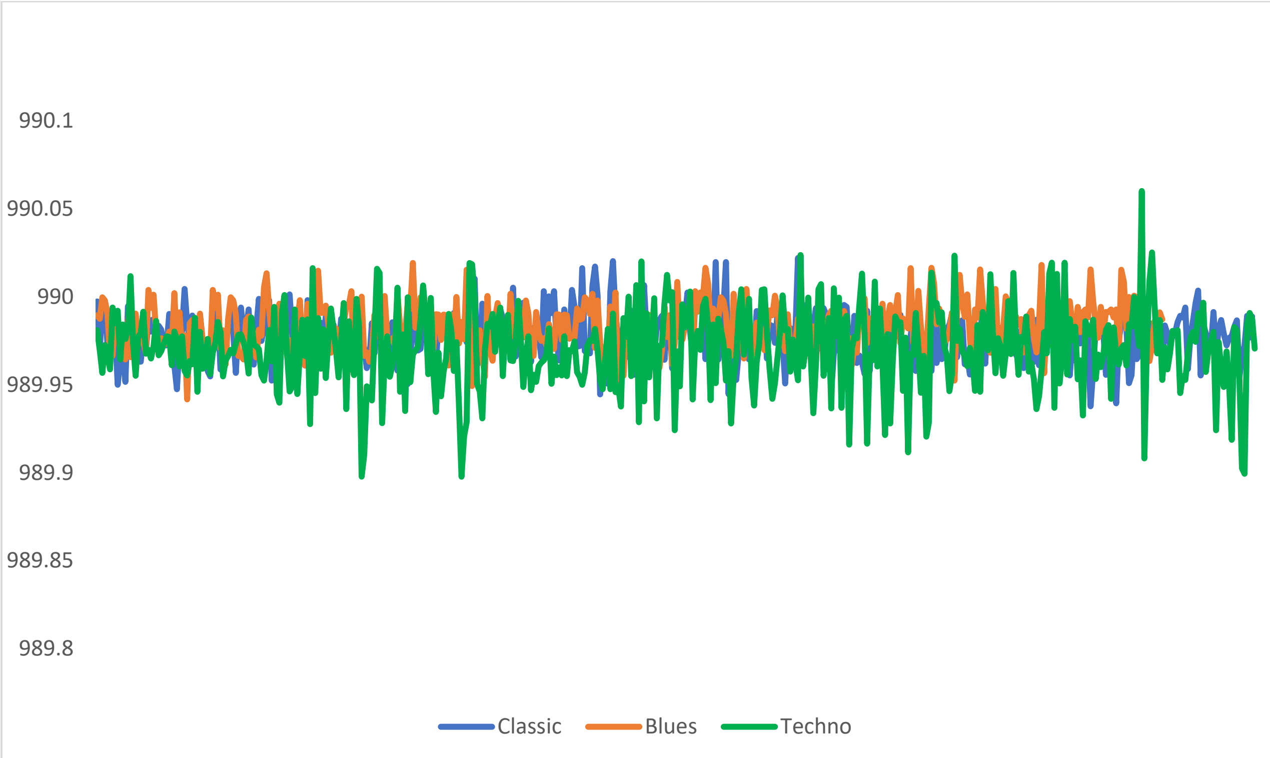

Figure 4.11 Music genre effect. The x-axis is the time as the music is being played. The y-axis is the barometer reading in hPa (mbar).

This experiment demonstrates the differences between the three data series. It can be inferred that rhythmic and bass-heavy genre music have a higher impact on the data readings. In this run, the blue data series is classical music, and the orange data series is blues genre music. Furthermore, the third data series, indicated in green, is techno, with the most remarkable variation changes.

4.3 Impact of Interaction

Experiments were conducted to determine whether the barometer sensor readings would change if the user interacted with the smartphone. This series of experiments aims to make interactions in different time intervals and measure different barometric readings. The interactions are tapping, firmly pressing the screen, and blowing and gasping.

4.3.1 Tapping And Stop Tapping the Number Pad

Tapping and pressing the screen of a cellphone has an impact on the barometer sensor as well. Experiments were conducted to determine whether the barometer sensor readings would change if the screen were tapped or pressed. In an experiment, the average of the data series is calculated and displayed. The data series contain both tapping and no-tapping activities. The idea was to examine each part separately and calculate the average, and then illustrate their influence using the average.

An experiment was carried out to determine whether tapping on the screen of a cellphone would cause a change in the barometric readings. The smartphone was placed on a table in a closed-door room and remained stationary during this experiment. Figure 4.12 show the result of this experiment.

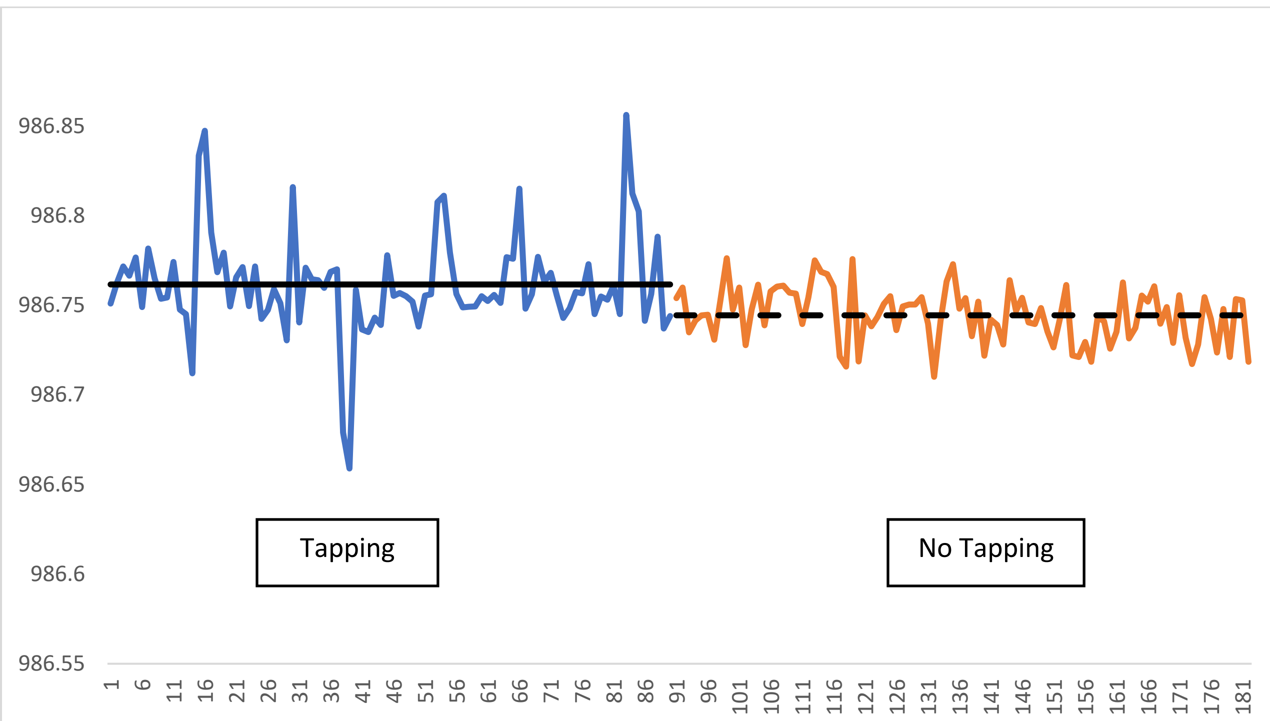

Figure 4.12 Tapping and Stop Tapping the Number Pad. The first data series, which spans from the beginning to data point 90, represents tapping. The second data series, which spans after the first series, represents no tapping. The y-axis is the barometer reading in hPa (mbar). The average of the first series is displayed with a solid black line, and the average of the second series is displayed with a dashed black line.

This experiment demonstrates that tapping on the screen of a smartphone will cause a change in the readings of the barometric sensor. In this experiment, the cellphone screen was tapped constantly from the beginning until point 90, and no tapping occurred afterward. It is evident from the graph that the first event had a larger change in variation and average. It can be seen that both positive and negative changes are present in the first event, while the second event's variation and average value are relatively smaller.

4.3.2 Firmly Pressing the Number Pad

An experiment was carried out to determine whether firmly pressing the screen of a smartphone would change the barometric readings. In this experiment, the cellphone screen was pressed firmly at various intervals while the smartphone was stationary. The smartphone was located in a closed-door room and placed on a table. Figure 4.13 show the result of this experiment.

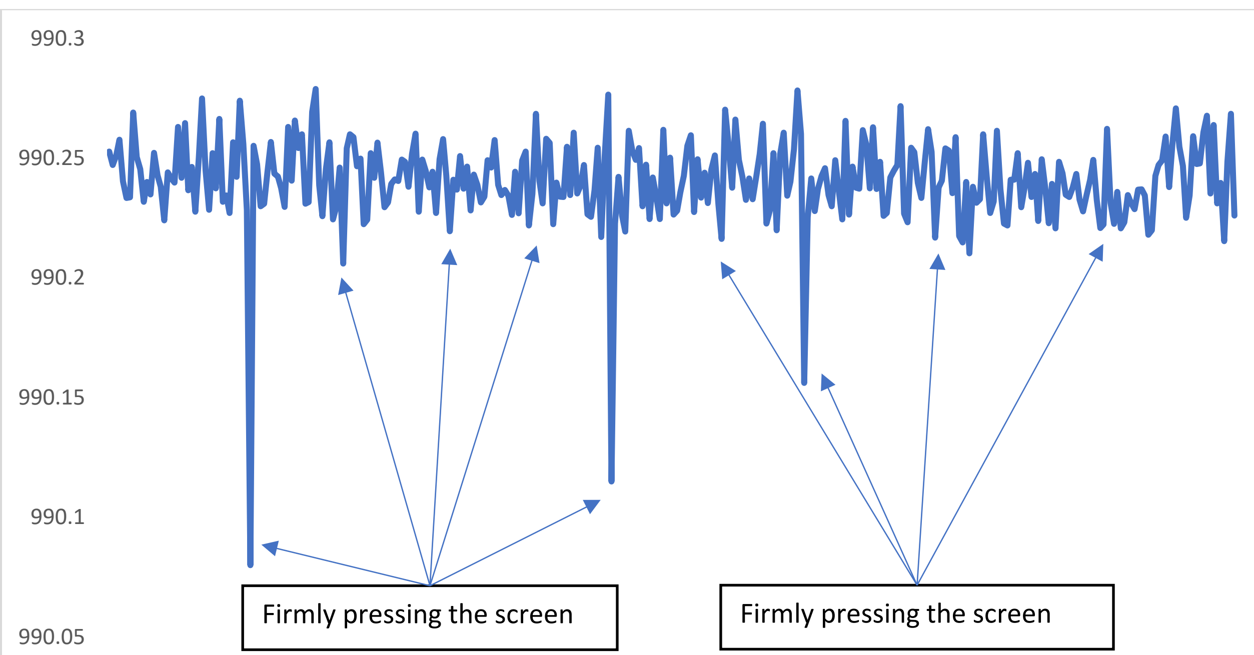

Figure 4.13 Firmly pressing the Number Pad. The x-axis is the time, as the screen has been pressed. The y-axis is the barometer reading in hPa (mbar).

This experiment demonstrates that pressing firmly on the screen of a smartphone will cause a change in the readings of the barometric sensor. For this experiment, the screen was pressed firmly and then abruptly released. When the screen is squeezed, the air pressure of the internal components is compressed, which briefly raises the air pressure. Decompression occurs when the pressing is released. As a result of pressing and releasing, a spike can be seen in the graph. The size of this spike depends on how hard this screen has been pressed during the experiment. It should also be mentioned that the screen was pushed 9 times throughout this experiment, but only a few presses were strong enough to produce the change and register clearly on the graph.

4.3.3 Blowing and Gasping

The barometer sensor readings can be impacted by blowing and gasping. The idea was to compare blowing and gasping created results. In order to perform this experiment, the small vent provided on the smartphone was used.

An experiment was carried out to determine whether blowing and gasping would affect data readings. The results are shown in Figure 4.14. as the cellphone is first blown a couple of times and then it has been gasped. In this experiment, the smartphone is placed on the table.

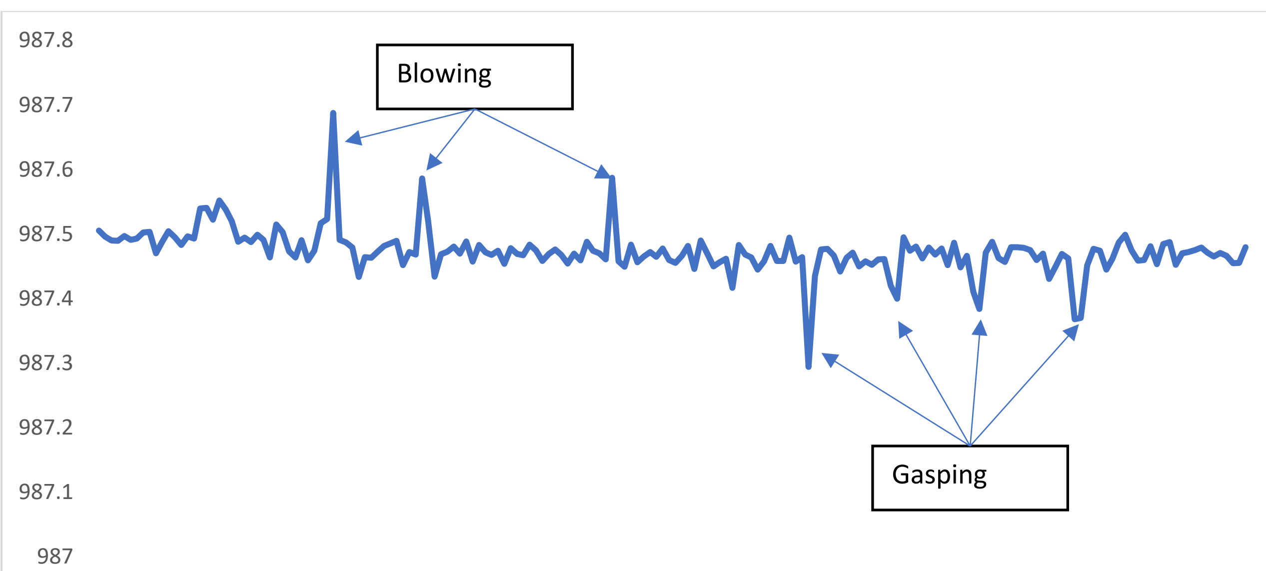

Figure 4.14 Blowing and Gasping. The x-axis is the time. The y-axis is the barometer reading in hPa (mbar).

This experiment demonstrates that blowing and gasping have an effect on the data readings. The first series of events are related to the blowing, and the second series of events are related to gasping. As expected, the blowing caused a temporary increase in pressure, followed by stabilizing. On the other hand, the gasping caused a temporary decompression and stabilized shortly.

4.4 Impact of Vehicular Traffic

A passing vehicle has a significant impact on the barometer sensor readings. The sensor can detect the impact of a crossing vehicle in case the parked vehicle window is open or closed. A series of experiments were conducted to demonstrate the impact of crossing vehicles. The size, speed, and distance between two vehicles play a significant role in these experiments. Crossing large-size, high-speed, and close-distance vehicles will cause a more significant change in the data series.

4.4.1 Detecting Crossing Vehicles

An experiment was carried out to determine whether a crossing car would make changes in the barometric readings. In this experiment, a car is parked on a moderately congested street, and the smartphone is placed on the car's console. The distance between passing vehicles and the parked car is approximately 4-6 feet. For this experiment, the driver's side window was left open. Figure 4.15 shows the result of this experiment.

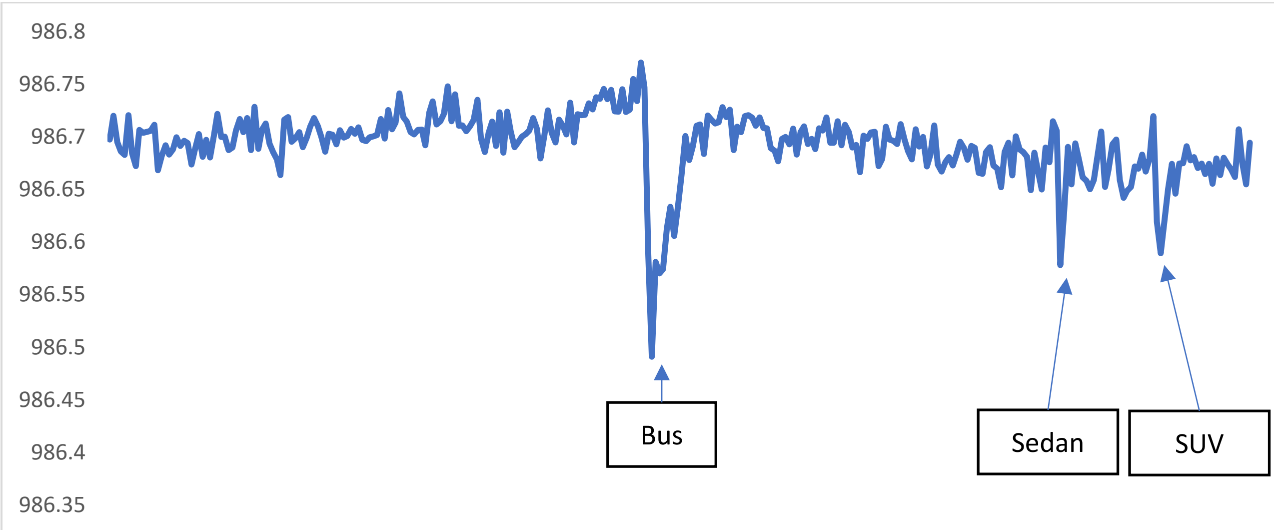

Figure 4.15 Detection of crossing different types of vehicles. The x-axis is the time as vehicles pass by. The y-axis is the barometer reading in hPa (mbar).

This experiment demonstrates the impact of crossing vehicles on data readings. In this experiment, three different types of vehicles have passed. The first event in the graph is caused by a crossing bus/charter bus; its impact is significant. The second event on the graph is caused by a crossing sedan, while a crossing SUV triggers the third event.

Although a sedan is smaller than an SUV in terms of size, other aspects, such as speed, appear to be having a significant influence. Moreover, the other factor that has a significant influence is the distance between the two vehicles. During the experiment runs, it has been noted that the distance between the passing car and the parked car plays a major role. In addition, another factor that significantly influences the data readings is the speed. Each of the passing vehicles had a different speed because there was no control over it, and as a result, each of them changed the data readings differently.

Figure 4.16 displays the outcomes of a further run of the same experiment with the same setup. It can be inferred that larger size vehicles will cause larger impacts on the data readings.

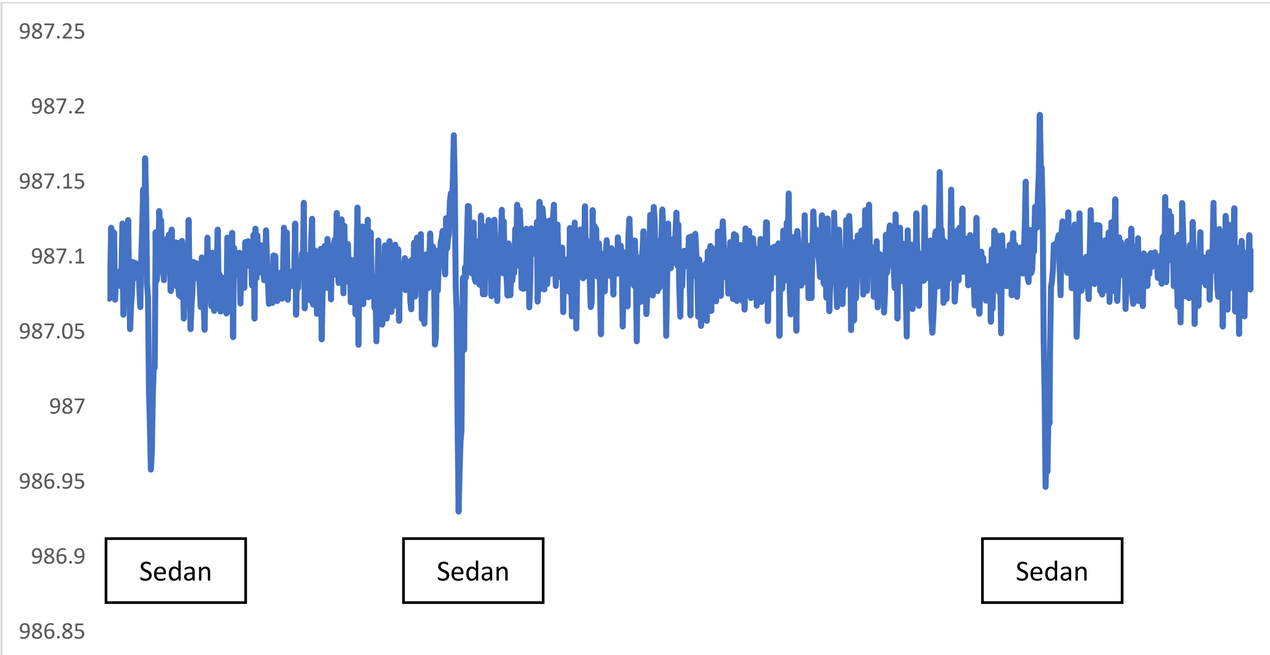

Figure 4.16 Detecting the same type of crossing vehicles. The x-axis is the time as vehicles pass by. The y-axis is the barometer reading in hPa (mbar).

The second run of the experiment demonstrates the impact of crossing the same type of vehicles on the barometric data readings. Even though all three passing vehicles were sedans, the impact of each was different.

The third run of the experiment demonstrates the impact of crossing different types of vehicles on the barometric data readings. The results are shown in Figure 4.17, as the first vehicle in this run is a sedan, and the second is a truck.

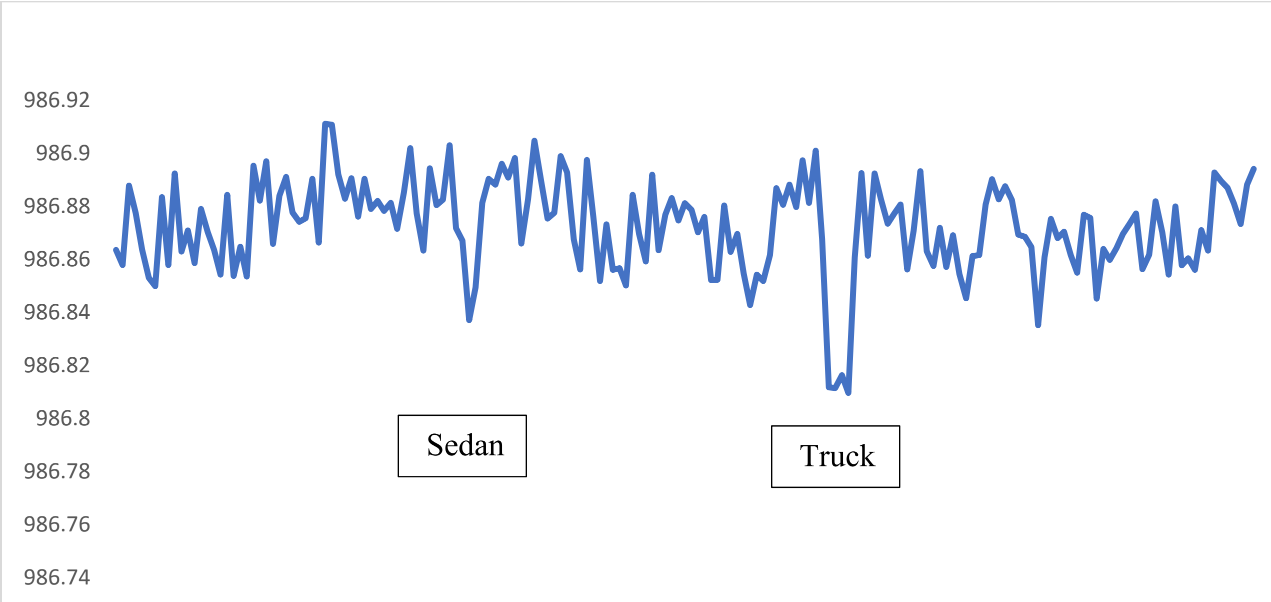

Figure 4.17 Detecting various types of crossing vehicles. The x-axis is the time as vehicles pass by. The y-axis is the barometer reading in hPa (mbar).

This experiment demonstrates the impact of different types of crossing vehicles. As expected, the impact caused by each vehicle is different.

5 Conclusion

This thesis investigated the environment's and smartphone context's impact on commercial smartphone barometric sensor readings. A range of applications, including indoor localization, sound classification, software interaction, and vehicular traffic detection, are explored using only smartphone barometer readings. The results from the various experiments confirm that the smartphone barometer is powerful enough to be used for applications outside of vertical positioning.

References

[1] Ajaykumar Manivannan, Wei Chien Benny Chin, Alain Barrat, Roland Bouffanais. *On the Challenges and Potential of Using Barometric*. Manivannan, Ajaykumar, et al. "On the Challenges and Potential of Using Barometric Sensors to Track Human Activity." Sensors, vol. 20, no. 23, Nov. 2020, p. 6786. Crossref, https://doi.org/10.3390/s20236786. November 2020.

[2] Hafez Alireza. *Information Inference Based on Barometer Sensor in Android Devices.* 2020. https://era.library.ualberta.ca/items/15d8d051-45ab-4b1f-ba8a-005688e92f05. .

[3] Hafez Alireza, Dorsa Nahid, and Majid Khabbazian. *Barometers Can Hear, and Sense Finger Taps.* 2020. arXiv preprint arXiv:2008.03872 .

[4] Haibo Ye, Wenhua Yang, Yunyu Yao, Tao Gu, Zhiqiu Huang. "BTrack: Using Barometer for Energy Efficient Location Tracking on Mountain Roads," in IEEE Access, vol. 6, pp. 66998-67009, 2018, doi: 10.1109/ACCESS.2018.2879311. n.d.

[5] Kartik Muralidharan, Azeem Javed Khan, Archan Misra, Rajesh Krishna Balan, and Sharad Agarwal. *Barometric phone sensors: more hype than hope! In Proceedings of the 15th Workshop on Mobile Computing Systems and Applications (HotMobile '14).Association for Computing Machinery, New York, NY, USA, Article 12, 1–6.* n.d. https://doi.org/10.1145/2565585.2565596.

[6] Oscar. D. Lara and Miguel. A. Labrador, "A Survey on Human Activity Recognition using Wearable Sensors," in IEEE Communications Surveys & Tutorials, vol. 15, no. 3, pp. 1192-1209, Third Quarter 2013, doi: 10.1109/SURV.2012.110112.00192.

[7] Xia H, Wang X, Qiao Y, Jian J, Chang Y. Using multiple barometers to detect the floor location of smart phones with built-in barometric sensors for indoor positioning. Sensors (Basel). 2015 Mar 31 and 15(4):7857-77. doi: 10.3390/s150407857. n.d.

[8] Zhang, Jieying, et al. *"Performance investigation of barometer aided GPS/MEMS-IMU integration,"*. n.d. Proceedings of the 2012 IEEE/ION Position, Location and Navigation Symposium, 2012, pp. 598-604, doi: 10.1109/PLANS.2012.6236933.