Correlation Between User Opinion and Pavement Roughness Measurement Using Smartphones in Dhaka

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The thesis titled **Correlation Between User Opinion and Pavement Roughness Measurement using Smartphones in Dhaka** submitted by Nafis Ahsan (160051034), Md. Imtiaz Howlader (160051050), Prince Adnan (160051067) has been found satisfactory and accepted as partialfulfillment of the requirement for the Degree Bachelor of Science in Civil Engineering.

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We hereby declare that the undergraduate research work reported in this thesis has been performedby us under the supervision of Dr. Nazmus Sakib and this work has not been submitted elsewhere for any purpose.

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DEDICATION

Our combined thesis work is dedicated to our respective parents, family, and friends. We also express our gratitude to our respected supervisor Dr. Nazmus Sakib. It is a small token of appreciation towards all those who supported us throughout our endeavor and encouraged us to continue our work until the end.

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"In the name of Allah, Most Gracious, Most Merciful."

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Abstract

Keywords: *Pavement Roughness, Smartphone, International Roughness Index (IRI), Ride Quality, User Opinion, Acceleration Data.*

Pavement roughness is described as a road surface imperfection that impacts user comfort and safety. Pavement is a vital part because it influences vehicle maintenance costs, vehicle delay costs, and fuel consumption. The ride's quality is also impacted. Roughness influences performance, increasing the contact surface between the tire and the pavement. This will result in less brake friction. Pavement roughness arises because of vehicle axial stress, increased traffic volumes, harsh weather conditions, and the use of low-quality materials while paving roadways. The international roughness index (IRI) is used to categorize roughness measurements. It is an internationally recognized standard for measuring the comfort of a ride. IRI is often measured using inertial profilers. To assess pavement profile, inertial profilers are outfitted with sensitive accelerometers, a height detecting laser, a distance measuring device, and so on. Smartphones have a range of sensors, including a three-axis accelerometer, which was utilized in this study to collect vehicle acceleration data using an Android-based smartphone app. Some research studies have been carried out about the use of smartphones to assess the road surface distress. The purpose is to correlate the road surface distress using a android phone with the public opinion. For preliminary validation, five test sites in Dhaka, Bangladesh, were chosen to collect user feedback as well as acceleration data acquired via the smartphone application. A successful model is being established that demonstrates an appropriate relationship among the pavement roughness assessed by android phone and common public opinions in Bangladesh. As reports and data are scarce in our country then this report can be preserved for future research. This paper can be helpful in any transportation-related project.

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Chapter 1: Introduction

1.1 General:

Pavements are an important element of our society's infrastructure system, and their correct operation is critical for growth. Pavements, like other forms of infrastructure assets, degrade with time. As a result, there is a need to develop strategies to conserve these capital-intensive assets for them to operate as planned. This need led to the creation of periodic and regular maintenance operations carried out by Departments of Transportation around the country. The extent of road repair and rehabilitation is determined by the physical state of the road at a given moment concerning its acceptable and operational condition. As a result, the state of pavements is monitored regularly, which is known as pavement condition monitoring. These condition monitoring surveys are critical in pavement management because they give useful information that serves as the foundation for repair and rehabilitation efforts. The information provided to management personnel is typically in the form of condition ratings of portions or a complete pavement network, which is used to make smart and educated decisions. The durable surface material placed down on an area meant to withstand automotive or foot activity, such as a road or sidewalk, is referred to as the road surface or pavement. Previously, gravel road surfaces, cobblestone, and granite sets were widely utilized, but these surfaces have mostly been replaced by asphalt or concrete. The pavement systems fail largely due to fatigue (in the same way as metals do), and the damage done to the pavement rises with the fourth power of the axle load of the cars moving on it. According to the AASHTO Road Test, Overloaded trucks may cause 10,000 times the damage of a standard passenger car. Pavement roughness affects the quality of riding. To characterize road conditions and quality of riding, road surface roughness is used. It is often quantified using International Roughness Index (IRI). The road surface condition is very important to both citizens and concerned officials. Travelers are concerned about the comfort of their journey as well as the operating costs of their vehicles. Therefore, concerned authorities use pavement roughness as an important indication to undertake optimal pavement maintenance planning, which considerably reduces the maintenance cost. and improves the return period of the road.

Pavement roughness data is collected using two primary methods:

- Physical and
- Automatic

Generally, physical data collection is less expensive but hard to collect data where automatic data collection is expensive to purchase and the operational and maintenance cost is also expensive.

Smartphones have a variety of low-cost sensors, which includes accelerometers, gyroscope, and Global Positioning System sensors. They are normally used sensor in android phone but they may also be used in technical disciplines such as transportation engineering. Smartphones are used for pavement roughness data collection as alternative devices because of their embedded sensors.

1.2 Background:

Dhaka, the capital of Bangladesh, is one of the world's fastest expanding megacities. Continuous population increase is inflicting serious problems like stagnant traffic conditions throughout the city. According to the JICA report, there is about 354,891 km. paved public roads in Bangladesh,[1] and many concerned authorities such as Roads and Highway department, LGED, City corporation utilize pavement management system (PMS) to manage their pavement network efficiently and cost-effectively. Pavement roughness, as well as other distress data, is required by PMSs. For particularly rough surfaces, fuel consumption might rise by as much as 4-5 percent [2]. Most transportation organizations plan maintenance and rehabilitation using International Roughness Index (IRI) measurements. International Roughness Index (IRI) is used by most transportation organizations to plan, maintenance and rehabilitation. Roughness measurements were traditionally taken with manual tools such as a sliding straightedge. Technological advancements have resulted in highly automated pavement condition evaluations that use sophisticated data-gathering vehicles outfitted with sensitive inertial profilers.

In automatic methods of road surface data collection, Road Doctor Laser Scanners (RDLS), profiler machines are used. It is hard for local governments in Bangladesh to gather data using this type of device and assess overall status of the road network regularly. Smartphones may also be used to collect data on pavement roughness. Besides, road users are the most important stakeholders in a road network, we must include their perspectives as well.

1.3 Scope of Study:

Roadway condition surveys are essential because they provide a clear picture of current road conditions, increasing road efficiency and longevity, allowing for more pleasant traffic flow in a specific segment, and allowing for the development of infrastructure. All roads require some sort of maintenance before they reach the end of their life. Some agencies utilize pavement management systems to continuously evaluate road conditions and conduct preventative maintenance treatments as needed to extend the life of their roads. Advanced agencies use sophisticated technology such as laser/inertial profilometers to check the surface condition of the road network. The data found by this instrument is then put into a pavement management system, which advises the optimum maintenance or construction procedure to repair the damage. The management of pavement conditions in our nation is not very good. Roadway maintenance infrastructure and financing are severely lacking. As a result, maintenance tasks become time-consuming and ineffective. There is a possibility that a range of unique obstacles will emerge because of highway structural vulnerability. Pavement roughness measurement plays a vital role in roadway maintenance and management. Roads are developed because of continuous interactions between people and their surroundings. So, the opinion of the road users has also a significant impact on the roadway management system. As a result, a study of the current roughness measurement is necessary to understand and correlate the roughness of the pavement data using a smartphone with the user opinion. In Dhaka, we chose Nilkhet to Gulshan route for the study. Several standard scientific parameters must be considered and noted.

1.4 Objective of the study:

The following are the study's objectives:

- The objective of this study is to correlate the roughness of the pavement data using a smartphone with the opinion of common road users in Bangladesh.
- Use of smartphone application, Roughness Capture, to collect vehicle vertical acceleration data using smartphone accelerometer capabilities.
- Analysis of acceleration data to obtain pavement profile.
- To develop a successful roughness model demonstrating an appropriate relationship among the road surface condition assessed by android phone and common public opinions in Bangladesh.

Chapter 2: Literature review

- Park et al. (2015) collected data using tab mounted on the back of a car. Three-dimensional data of acceleration was captured by the tab, GPS locations, and speed of car. From the study they found that the index could distinguish defective pavement section with a high accuracy. [3]

- Cameron et al. (2014) used 11 different sections in Canada on a 1km length of a minor roadway. They sought to connect pavement roughness collected by phones with a traditional profiler machine and concluded that there was a strong connection between the profiler output and the smartphone. [4]

- Szmechta et al. (2011) assessed road quality by analyzing data from accelerometers installed on four distinct points in an automobile. [5]

- Van Der Zwaag et al. (2014) used S.V.M to detect and categorize the distress of roads. The road irregularity detector could detect about 90% of severe abnormalities. [6]

- Chan et al. (2010) used phones equipped with a 3-axis accelerometer while riding a motorbike to detect road abnormalities and evaluate road condition with a 78.5 percent accuracy. [7]

- Klopfenstein et al. (2014) launched the "Smart Road Sense" technology. The research intends to use phones to monitor road surfaces. In this work, they created a model to generate an index for pavement roughness based on data gathered by the system. Finally, to prioritize pavement repair, they color-coded pavement portions on a map. [8]

- Oneyama et al. (2013, 2014) assessed road conditions by constructing a pavement roughness index using the VIMS component as a guideline. They gathered the data using the Andro-Sensor software, which is loaded on phones and is used to identify pavement surfaces and calculate IRI. [9]

- Buttlar et. al. (2014) statistically double-integrated accelerometer sensor and processed it using Proval computer software. The research was carried out in three separate locations to collect road surface and acceleration data using an android phone mounted on a car and profiler machine. When compared to an inertial profiler, the results showed that smartphone devices could measure IRI with acceptable precision. [10]

- Girod et al. used smartphones to examine road abnormalities. They implemented a technique known as patrolling potholes. Seven rented running taxis were outfitted with phones to assess road surface quality and detect potholes via strong vertical shaking of cars. [11]

- Strazdins et al. (2011) described "THRESH of Z" as boundary for "Axis of Z." data of acceleration. Statistics were classified into several type of dips beyond conditions. A new method was created identifying irregularities "G-ZERO," which denotes condition at which all data of 3-axis accelerometer having value compared to 0 gravity. [12]

- Gan et al. describes a test program that used a crossover technique to evaluate pavement serviceability ratings by automobile and bus rater panels. The findings of the tests indicate that a panel of riding bus is a viable method of assessing road surface serviceability. [13]

- Yeganeh et al. (2019) computed pavement roughness data using smartphone integrated sensors and explored the possibility of using a smartphone to detect pavement surface distress using a road surface profiler to evaluate sensor data. [14]

Chapter 3: Methodology

The research study was carried out in a variety of ways, including data collection, pavement indices measurements, and analysis into the validation and correlation of the indices. The study strategy is depicted schematically in Fig 1.

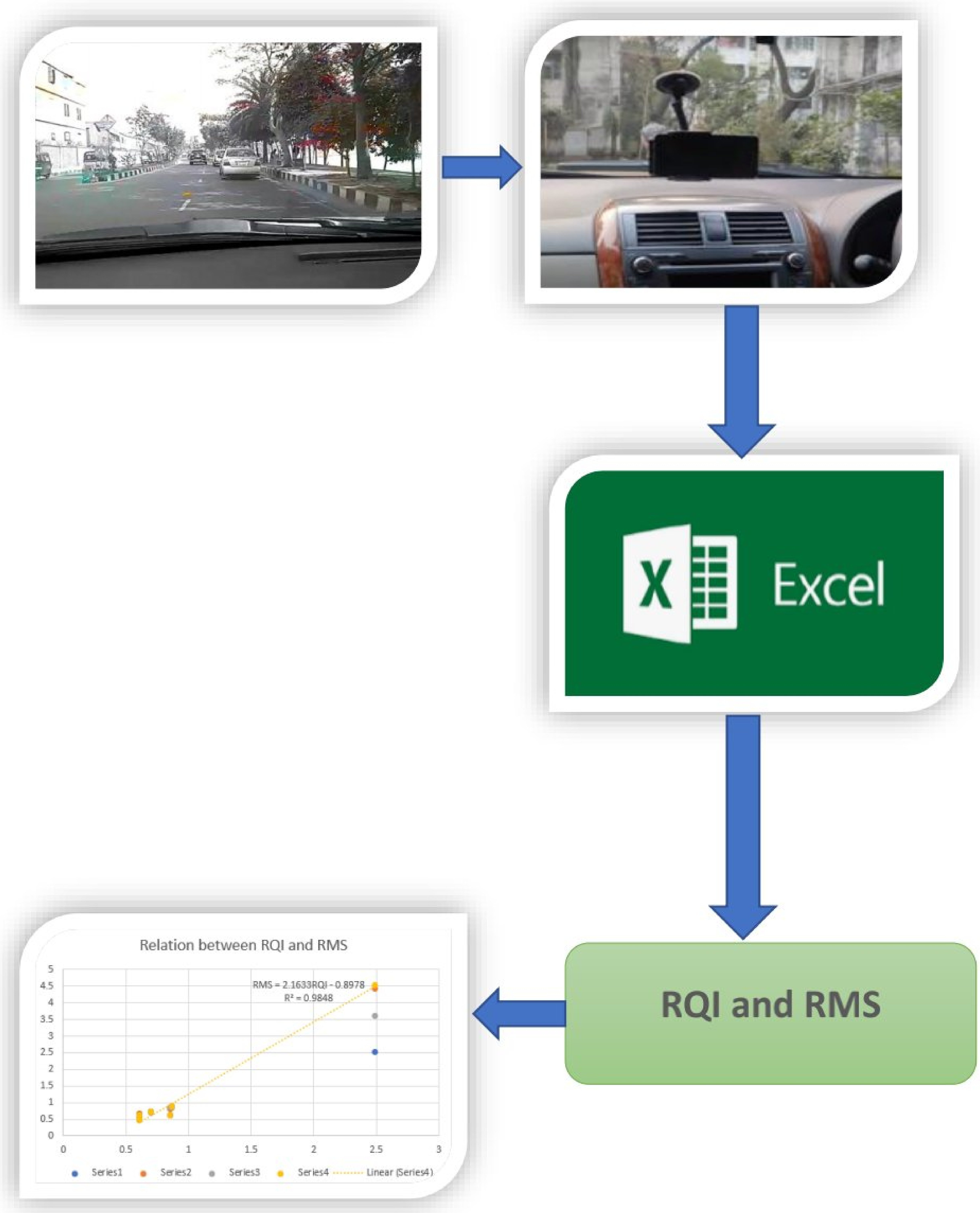


Figure 1: Study Strategy

This research is divided in 3 parts. Initial part was to test the whole study procedure. Because of this, a test study was conducted in purpose of finding out drawbacks. In the next part android phone and public opinion were used to assess the quality of the pavement. Finally, the roughness calculated via smartphones was confirmed in the third part, and the relationship between road surface distress measured by android phone and the public opinion was studied. Figure 2 shows the study's research approach.

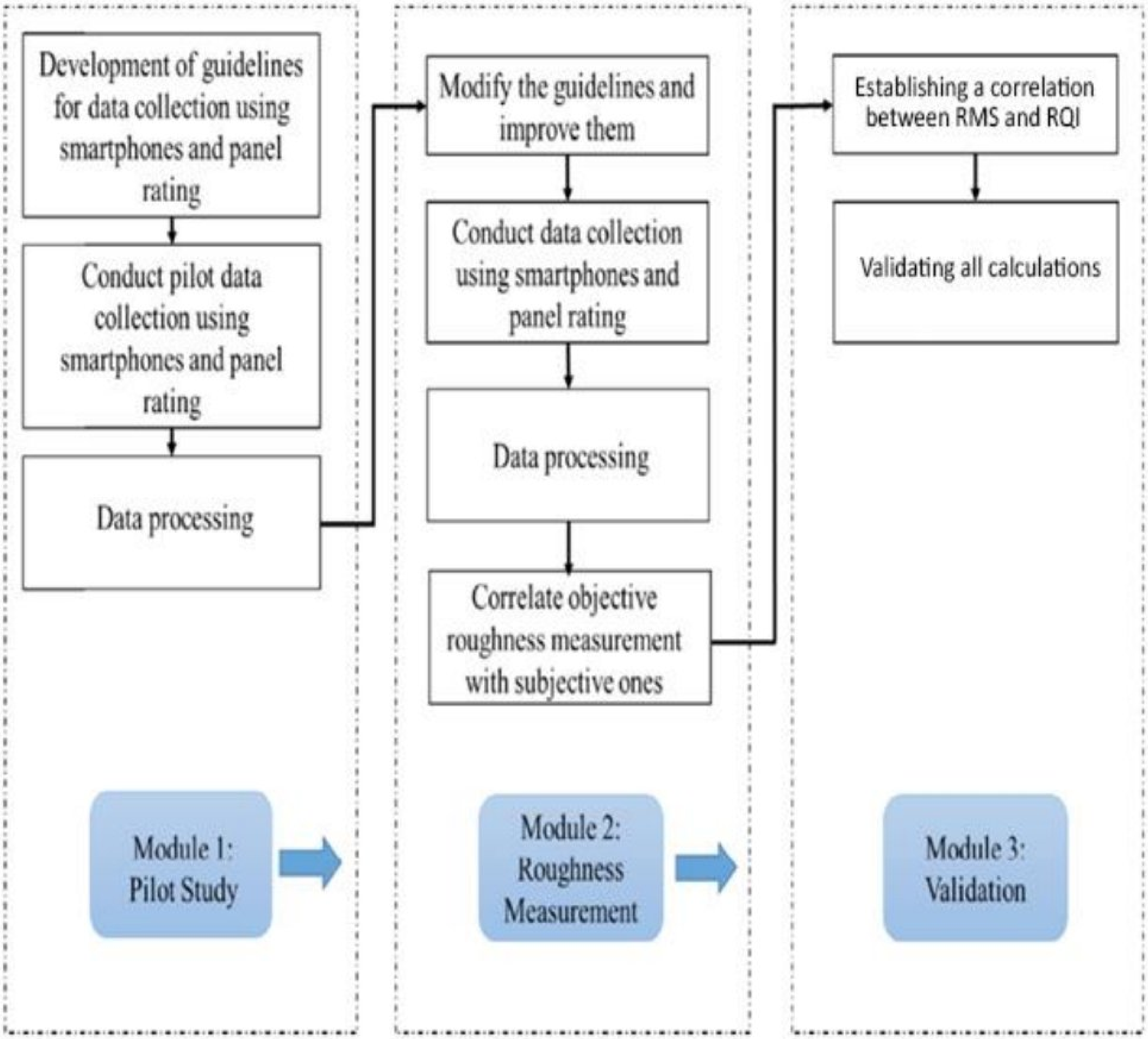


Figure 2: Research Methodology

3.1 Leniency and severity error:

One of the most frequent mistakes in performance assessments is the leniency error. Leniency error is described as an error that leads to greater appraisals than other raters and a valid/reliable propensity for certain raters. According to another definition, leniency error is the case when the raters unjustly give higher scores, appraisal results. These scores are evaluated by the distances of the middle point of the scale to other scores or by their range to an accurate score. In other words, leniency mistakes restrict the given value range, resulting in a statistical reduction in validity.

The severity error, which is the inverse of the leniency mistake, occurs when the rater rates the employee's performance lower than it is. In other words, it is the case when the rater evaluates an employee or a group of employees lower than they are without taking into account their actual success level. This tendency is typically found among raters who are unskilled and unaware of the elements that impact performance, have poor self-confidence, and get bad evaluations.

3.2 Central tendency effect:

A central tendency (or measure of central tendency) is a center or typical value for a probability distribution in statistics. It is also known as a distribution center or location. Averages are a colloquial term for measurements of central tendency.

The arithmetic mean, median, and mode are the most often used measurements of central tendency. A finite set of values or a theoretical distribution, such as the normal distribution, can be used to calculate a middle tendency. Authors will occasionally use the term "central tendency" to refer to "the tendency of quantitative data to cluster around some center value."

A distribution's central tendency is frequently contrasted with its dispersion or variability; dispersion and central tendency are two frequently described characteristics of distributions. Based on the dispersion of the data, analysis can determine if it has a strong or weak central tendency. [15], [16], [17].

3.3 Standard deviation:

The standard deviation is a statistic that measures the degree of variation or dispersion in a set of data. [18] A low standard deviation implies that the values in the set are near to the mean (also known as the expected value), whereas a high standard deviation shows that the data are stretched out over a larger range. The standard deviation of a random variable, sample, statistical population, data collection, or probability distribution is the square root of its variance. It is algebraically easier, but less resilient in practice, than the average absolute deviation. The standard deviation has the advantage of being stated in the same unit as the data, unlike the variance. [19],[20].

3.4 Margin of error:

The margin of error is a statistic that expresses the degree of random sampling error in survey findings. The wider the margin of error, the less sure one should be that a tracking poll properly represents survey results. The percentage errors of estimation, also known as the margin of error, is a measure of an estimate's precision and is defined as one-half the breadth of a confidence interval.

$$s_{\bar{x}} = \frac{s}{\sqrt{N}}$$

Here, $s_{\bar{x}}$=Margin of error (Confidence intervals)

s= Standard deviation

N= Sample count

3.5 ANOVA:

The ANOVA, or Analysis of Variance test, is a statistical method for comparing the means of two groups of data sets and determining how much they differ. ANOVA test is used to determine whether or not survey or experiment outcomes are significant. In other words, they assist in determining whether one should reject the null hypothesis or accept the alternate hypothesis.

3.5.1 Classification of ANOVA test:

There are 2 types of ANOVA tests: one-way and two-way. Two-way tests can be performed with or without replication. Hence ANOVA test will be classified as:

- **One-way ANOVA between groups:** It is used whenever two categories are being tested to see whether there is a difference between them.
- **Two-way ANOVA without replication:** It is utilized when somebody has one group and is testing it twice.
- **Two-way ANOVA with replication:** There is two groups, and the members of those groups are doing many things.

3.5.2 One-way ANOVA:

Using the F-distribution, a one-way ANOVA is used to analyze data collected from 2 separate (unrelated) groups. The test's null hypothesis is that the two means are equal. As a result, a significant result indicates that the two means are unequal. [21]

3.5.3 Limitations of One-way ANOVA:

A one-way ANOVA will show that at least 2 groups differed from one another. It will not, however, reveal which groups were different. If the test yields a significant f-statistic, an ad hoc test (such as the Least Significant Difference test) may be required to determine which groups had a difference in means.

3.5.4 Two-way ANOVA:

Two-Way ANOVA test is a variant of the One-Way ANOVA test. One independent variable influences a dependent variable in a One-Way ANOVA test. There are two independent variables in a Two-Way ANOVA. When there is one measurable variable (i.e., a quantitative variable) and two nominal variables, a two-way ANOVA test is performed.

The significant effects and an indirect impact will be calculated from the results of a Two-Way ANOVA. The main effect is similar to a One-Way ANOVA in that the influence of each component is examined separately. The interaction effect takes into account all elements at the same time. When there is more than one observation in each cell, it is simpler to examine interaction effects between variables. If you place one observation in each cell, two null hypotheses are tested. [21]

3.6 Repeatability test:

The degree of agreement between the results of subsequent measurements of the same measure conducted under the same measuring conditions is referred to as repeatability. In other words, measurements are performed by a single person or device on the same subject, under the same conditions, and in a short period of time.

3.6.1 Condition of Repeatability test:

The following requirements must be met in order for repeatability to be established:

- same experimental equipment
- the same investigator
- the same measurement equipment, used under the same circumstances
- the same place
- repetition over a short time.
- same goals [22],[23].

The repeatability coefficient is a precision indicator that reflects the number below which the absolute difference between two repeated test results is predicted to lie with a 95 percent probability. Precision and accuracy include the standard deviation under repeatable circumstances.

Since the same test is performed twice and each test is parallel with itself, discrepancies between test scores and retest results should be attributable exclusively to measurement error. This type of reasoning is most completely possible for many physical measures.

3.7 Area of the study:

The study area of this research is demonstrated in fig.3 which is in Nilkhet to Gulshan.

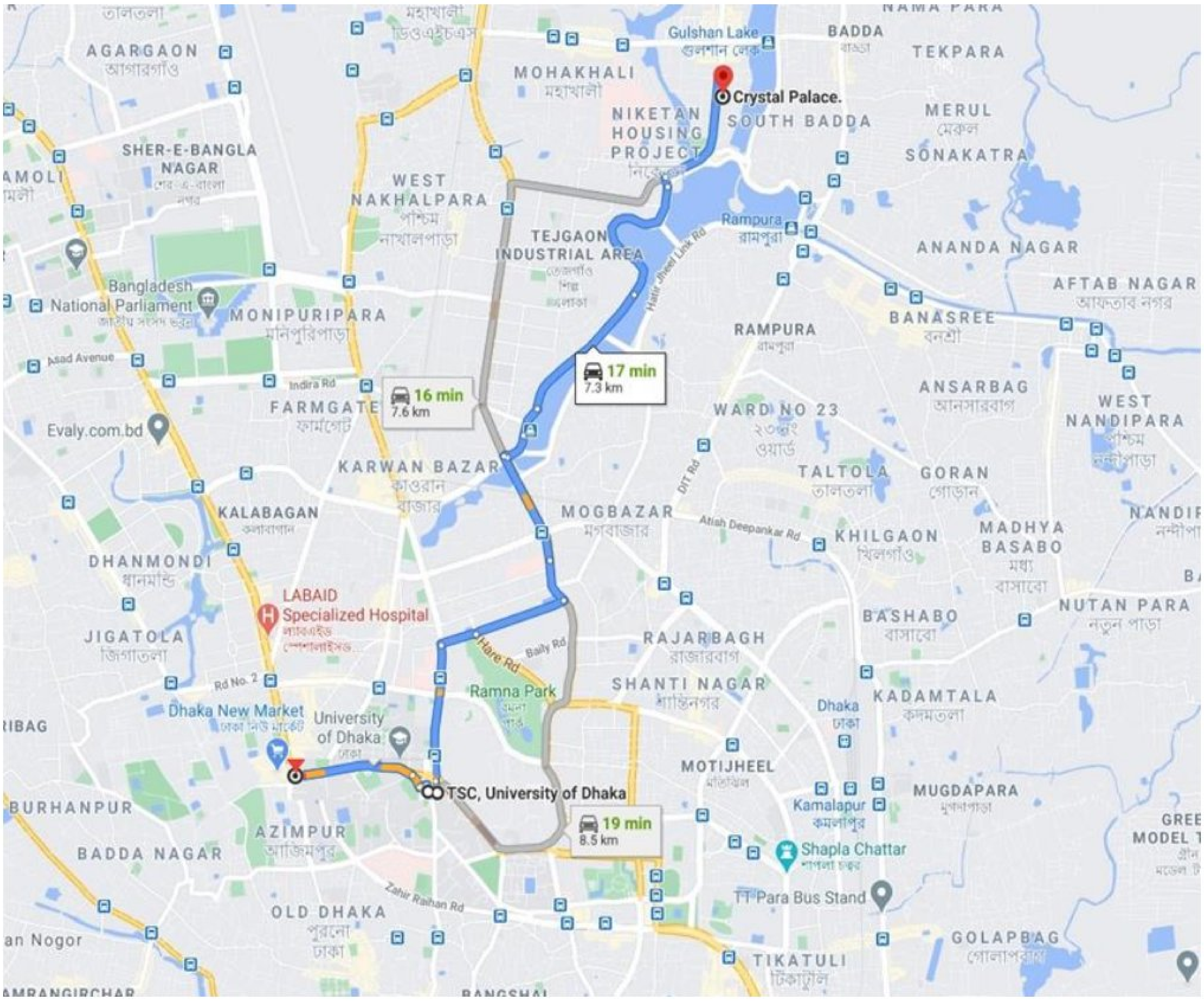


Figure 3: Study Area

The whole study area is divided into five sections. Table 1 shows the sections.

Section-1	
Nilkhet to Shahbag	
Section-2	
Shahbag intersection to Intercontinental Intersection	
Section-3	
Intercontinental intersection to Holy family Hospital	
Section-4	
Holy Family to Mogbazar Hatirjheel Link Road	
Section-5	
Link Road to Gulshan	

Table 1: Sections of Study Area

3.8 Pilot study:

The pilot data was collected via public opinions and android phone application. The study begins with the formation of rules for smartphone data collecting and public opinion assessment. Two guidelines are being developed for the study. The first guideline is regarding android phone data collection. In android phone data collecting guideline, placement of android phone on vehicle dashboard, running the and storage of the data is included. The other guideline was created for public. It includes process like assessing pavement surface defects, containing definitions of asphalt pavement distress categories as well as severity and density categories. The guideline also divided customer feedback on quality of riding into five different level such as:

- Very good.
- Good.
- Moderate.
- Poor.
- Very poor.

For example, “good” indicates whether the driver seems comfortable and does not experience any difficulty when the vehicle goes along the roads, although there is some roughness on the road.

Several applications collect data from smartphones sensors such as accelerometers, gyroscopes, GPS concerning time. In this study, we used open-source free software to collect data that was developed by the Massachusetts Institute of Technology (MIT) for their research purpose.

In the very beginning, we did a short test run from Nilkhet to Shahbag. One of our teammates occupied the seat beside the driver. He oversaw the assessment of the road surface quality and operating the application.

As illustrated in Fig 4, the smartphone was installed on the car dashboard to capture GPS and accelerometer data.

Figure 4: Installation of Smartphone

The ride quality was assessed by the rater who sat in the back seat of the automobile. Furthermore, an android phone was attached to the automobile dashboard illustrated in Fig. 4 to capture visual data to confirm the data of team member and public opinion in terms of RQI. Following that, the test data was effectively processed.

3.9 Roughness Measurement:

Following the completion of the test run, the main study was started in November 2020 to January 2021 on the same segment repeated five times by trained participants. We selected 11 raters from a particular company who travel from Nilkhet to Gulshan on working days via the company's staff vehicle. The smartphone was mounted on the dashboard of this vehicle to record GPS and accelerometer data. We divided the whole route into five sections based on a major intersection. The sections were mentioned in table 1. This procedure was repeated for five consecutive working days. The raw data were used to calculate relevant indices of pavement condition. RQI, RMS, and other indices were used in this study.

The initial indicator was RQI, which described users' perceptions of pavement roughness while riding on roadways. The RQI scale ranges from 0 to 5, with 0 indicating a very bad condition and 5 indicating very good quality. [24]

To train the raters, a guideline with verbal and numerical pavement ratings was created, as previously stated. Based on this criterion, they assessed the pavement's riding quality. Table 2 provides a verbal and numerical explanation of the various condition levels.

Verbal Rating	Numerical Rating
Very Good	4.1-5.0
Good	3.1-4.0
Fair	2.1-3.0
Poor	1.1-2.0
Very Poor	0.0-1.0

Table 2: Ride Quality Index

The second index was RMS, which was used to evaluate vehicle vertical acceleration. The vertical acceleration was recorded using a smartphone application that made use of the accelerometer sensor included in the smartphones. The application recorded and stored acceleration data every 60.67 ms. Equation 1 was employed to calculate RMS [25].

$$RMS = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(a_{z,i} - \mathrm{g}\right)}$$

Here, RMS= Root Mean Square of acceleration data,

N= the total number of acceleration records for each section,

$a_{z,i}$ = the total number of acceleration records for each section,

g= gravity

3.10 Data Collection:

We provided data collection forms to our panel raters. Table 3 provides a sample of the data collection form.

Data Collection Form					
Nilkhet-Gulshan			01		
Location			**Rater No.**		
Dry			Good Asphaltic concrete		
Weather Conditions			**Roadway Surface Condition**		
	Section-1	Section-2	Section-3	Section-4	Section-5
Run-1	3	3	4	4	5
Run-2	2	2	5	3	4
Run-3	3	3	4	3	4
Run-4	3	3	4	3	4
Run-5	3	3	4	3	4
Date:			**Signature**		
19/11/2020			Mr. Kabir Hussain		

Table 3: Data Collection Form

The panel raters give their rating in five different sections. Table 4 to Table 8 provide panel rating data in different sections.

	Rating (Day-1)				
Rater	Section-1	Section-2	Section-3	Section-4	Section-5
1	3	3	4	4	5
2	2	3	5	4	5
3	3	2	4	4	4
4	2	3	5	3	5
5	3	2	4	4	5
6	2	3	4	3	4
7	3	3	5	4	5
8	2	3	4	3	5
9	2	3	5	4	5
10	3	3	4	4	4
11	2	3	4	3	5

Table 4: Data of Panel Rating (Day-1)

	Rating (Day-2)				
Rater	Section-1	Section-2	Section-3	Section-4	Section-5
1	2	2	5	3	4
2	3	2	4	4	5
3	2	3	4	4	5
4	3	2	5	3	5
5	3	3	4	4	5
6	3	3	5	4	4
7	2	2	5	3	5
8	3	3	4	3	4
9	3	3	5	4	5
10	2	2	4	3	4
11	3	2	5	4	5

Table 5: Data of Panel Rating (Day-2)

	Rating (Day-3)				
Rater	Section-1	Section-2	Section-3	Section-4	Section-5
1	3	3	4	3	4
2	3	2	4	4	5
3	2	2	4	4	4
4	3	2	5	3	5
5	2	2	4	3	4
6	3	3	5	4	4
7	2	2	4	3	4
8	3	3	5	4	4
9	2	3	5	4	5
10	2	2	4	4	5
11	2	3	5	4	5

Table 6: Data of Panel Rating (Day-3)

	Rating (Day-4)				
Rater	Section-1	Section-2	Section-3	Section-4	Section-5
1	3	3	4	3	4
2	3	2	4	4	5
3	2	2	4	3	4
4	3	2	5	3	5
5	2	2	3	4	4
6	3	3	5	4	4
7	2	2	4	3	4
8	3	3	5	4	4
9	2	3	5	4	5
10	2	2	4	4	5
11	2	3	5	4	5

Table 7: Data of Panel Rating (Day-4)

	Rating (Day-5)				
Rater	Section-1	Section-2	Section-3	Section-4	Section-5
1	3	3	4	3	4
2	3	2	4	4	5
3	2	2	4	3	4
4	3	2	5	3	5
5	2	2	4	3	4
6	3	3	5	4	4
7	2	2	3	3	4
8	3	3	5	4	4
9	2	3	5	4	5
10	2	2	4	4	5
11	2	3	5	4	5

Table 8: Data of Panel Rating (Day-5)

3.11 Data Collection from Smartphones:

Table 9-Table 11 shows the data collected from smartphone sensors.

Longitude	Latitude	Speed	Distance	Time	Acc X	Acc Y	Acc Z	Heading	gyro_x	gyro_y	gyro_z
90.3908	23.73315	3.25	1.01E+07	9/10/2016	0.199484	0.341479	0.293614	74	0.015503	0.009338	0.00618
90.39103	23.73319	7.7	0	9/10/2016	0.149254	-0.15138	-0.03552	56	0.005905	0.029205	0.02887
90.39103	23.73319	7.7	0	9/10/2016	0.149254	-0.15138	-0.03552	54	0.005905	0.029205	0.02887
90.39103	23.73319	7.7	0	9/10/2016	-0.1167	0.138291	-0.5329	53	-0.04123	0.040497	-0.0047
90.39111	23.7332	8.73	8.072291	9/10/2016	-0.1167	0.138291	-0.5329	56	-0.04123	0.040497	-0.0047
90.39111	23.7332	8.73	8.072291	9/10/2016	-0.17353	0.127445	0.09924	51	-0.01991	-0.01953	0.034927
90.39111	23.7332	8.73	8.072291	9/10/2016	-0.17353	0.127445	0.09924	53	-0.01991	-0.01953	0.034927
90.39111	23.7332	8.73	8.072291	9/10/2016	0.121063	-0.05431	-0.06283	54	-0.01593	0.005661	-0.01689
90.39111	23.7332	8.73	8.072291	9/10/2017	0.121063	-0.05431	-0.06283	55	-0.01593	0.005661	-0.01689
90.39111	23.7332	8.73	8.072291	9/10/2017	-0.39121	0.32332	-0.29929	55	0.023331	-0.00435	0.01741
90.39111	23.7332	8.73	8.072291	9/10/2017	-0.39121	0.32332	-0.29929	56	0.023331	-0.00435	0.01741
90.39111	23.7332	8.73	8.072291	9/10/2017	0.377754	0.087001	-0.13331	48	-0.03394	-0.00606	0.032593
90.39111	23.7332	8.73	8.072291	9/10/2017	0.377754	0.087001	-0.13331	54	-0.03394	-0.00606	0.032593
90.39111	23.7332	8.73	8.072291	9/10/2017	0.259725	-0.22624	0.199467	52	0.021194	5.95E-04	-0.0106
90.3912	23.73322	9.75	17.31761	9/10/2017	0.259725	-0.22624	0.199467	57	0.021194	5.95E-04	-0.0106
90.3912	23.73322	9.75	17.31761	9/10/2017	-0.67111	0.455251	-0.41718	58	0.010498	0.0495	-0.01114
90.3912	23.73322	9.75	17.31761	9/10/2017	-0.67111	0.455251	-0.41718	65	0.010498	0.0495	-0.01114
90.3912	23.73322	9.75	17.31761	9/10/2017	0.325096	0.227182	0.177222	63	0.008469	0.060516	0.052887
90.3912	23.73322	9.75	17.31761	9/10/2018	0.325096	0.227182	0.177222	63	0.008469	0.060516	0.052887
90.3912	23.73322	9.75	17.31761	9/10/2018	-0.28394	-0.08267	0.334117	56	0.012253	-0.04301	-0.06541
90.3912	23.73322	9.75	17.31761	9/10/2018	-0.28394	-0.08267	0.334117	59	0.012253	-0.04301	-0.06541
90.3912	23.73322	9.75	17.31761	9/10/2018	0.270096	0.147839	0.57601	60	6.10E-05	-0.04691	0.01358
90.3912	23.73322	9.75	17.31761	9/10/2018	0.270096	0.147839	0.57601	59	6.10E-05	-0.04691	0.01358
90.3912	23.73322	9.75	17.31761	9/10/2018	0.219293	-0.19056	0.083451	56	0.078079	0.04364	-0.05981
90.39128	23.73323	9.57	25.59797	9/10/2018	0.219293	-0.19056	0.083451	58	0.078079	0.04364	-0.05981
90.39128	23.73323	9.57	25.59797	9/10/2018	-0.59517	1.253837	0.150116	63	-0.03601	5.49E-04	0.078125
90.39128	23.73323	9.57	25.59797	9/10/2018	-0.59517	1.253837	0.150116	69	-0.03601	5.49E-04	0.078125
90.39128	23.73323	9.57	25.59797	9/10/2018	0.063438	-0.19798	-0.07512	69	0.031525	0.081512	0.015015
90.39128	23.73323	9.57	25.59797	9/10/2019	0.063438	-0.19798	-0.07512	69	0.031525	0.081512	0.015015
90.39128	23.73323	9.57	25.59797	9/10/2019	-0.3012	0.167462	0.484439	70	-0.01007	-0.00424	0.02359
90.39128	23.73323	9.57	25.59797	9/10/2019	-0.3012	0.167462	0.484439	70	-0.01007	-0.00424	0.02359
90.39128	23.73323	9.57	25.59797	9/10/2019	0.271243	0.139888	1.033623	70	-0.02776	-0.06358	0.080154
90.39128	23.73323	9.57	25.59797	9/10/2019	0.271243	0.139888	1.033623	69	-0.02776	-0.06358	0.080154

Table 9: Data of Smartphone Sensors

Longitude	Latitude	Speed	Distance	Time	Acc X	Acc Y	Acc Z	Heading	gyro_x	gyro_y	gyro_z
90.39128	23.73323	9.57	25.59797	9/10/2019	0.310198	-0.27079	0.7586	72	0.045532	0.034958	-0.0179
90.39138	23.73324	9.85	35.29076	9/10/2019	0.310198	-0.27079	0.7586	77	0.045532	0.034958	-0.0179
90.39138	23.73324	9.85	35.29076	9/10/2019	-0.15052	0.493067	0.617924	78	-0.04794	0.008438	0.047714
90.39138	23.73324	9.85	35.29076	9/10/2019	-0.15052	0.493067	0.617924	80	-0.04794	0.008438	0.047714
90.39138	23.73324	9.85	35.29076	9/10/2019	0.021976	-0.43805	1.075293	79	0.065781	0.018341	-0.04144
90.39138	23.73324	9.85	35.29076	9/10/2020	0.021976	-0.43805	1.075293	81	0.065781	0.018341	-0.04144
90.39138	23.73324	9.85	35.29076	9/10/2020	-0.05181	0.146819	0.79653	82	-0.03558	0.021851	-0.01955
90.39138	23.73324	9.85	35.29076	9/10/2020	-0.05181	0.146819	0.79653	85	-0.03558	0.021851	-0.01955
90.39138	23.73324	9.85	35.29076	9/10/2020	-0.23136	-0.17699	1.397847	89	-0.00937	-0.02774	-0.00534
90.39138	23.73324	9.85	35.29076	9/10/2020	-0.23136	-0.17699	1.397847	88	-0.00937	-0.02774	-0.00534
90.39138	23.73324	9.85	35.29076	9/10/2020	0.300872	-0.33618	1.125965	90	0.002182	0.031754	-0.02632
90.39147	23.73325	10.07	45.39953	9/10/2020	0.300872	-0.33618	1.125965	94	0.002182	0.031754	-0.02632
90.39147	23.73325	10.07	45.39953	9/10/2020	-0.30656	-0.04994	1.162475	97	-0.06264	-0.00296	0.017197
90.39147	23.73325	10.07	45.39953	9/10/2020	-0.30656	-0.04994	1.162475	96	-0.06264	-0.00296	0.017197
90.39147	23.73325	10.07	45.39953	9/10/2020	0.110039	-0.44475	1.4616	98	-0.02184	4.88E-04	-0.00214
90.39147	23.73325	10.07	45.39953	9/10/2021	0.110039	-0.44475	1.4616	98	-0.02184	4.88E-04	-0.00214
90.39147	23.73325	10.07	45.39953	9/10/2021	0.030311	-0.20082	1.193282	101	0.001328	0.041397	-0.03479
90.39147	23.73325	10.07	45.39953	9/10/2021	0.030311	-0.20082	1.193282	105	0.001328	0.041397	-0.03479
90.39147	23.73325	10.07	45.39953	9/10/2021	-0.42154	0.218284	1.205083	103	-0.06689	-0.03632	0.06311
90.39147	23.73325	10.07	45.39953	9/10/2021	-0.42154	0.218284	1.205083	105	-0.06689	-0.03632	0.06311
90.39147	23.73325	10.07	45.39953	9/10/2021	0.505422	-0.65996	1.026733	109	-0.00171	0.048279	-0.04608
90.39155	23.73327	7.86	53.24521	9/10/2021	0.505422	-0.65996	1.026733	109	-0.00171	0.048279	-0.04608
90.39155	23.73327	7.86	53.24521	9/10/2021	-0.43944	0.243171	1.304796	108	-0.03644	-0.04042	0.029877
90.39155	23.73327	7.86	53.24521	9/10/2021	-0.43944	0.243171	1.304796	110	-0.03644	-0.04042	0.029877
90.39155	23.73327	7.86	53.24521	9/10/2022	0.527733	-0.17261	1.202779	111	-0.02258	0.006241	0.009689
90.39155	23.73327	7.86	53.24521	9/10/2022	0.527733	-0.17261	1.202779	113	-0.02258	0.006241	0.009689
90.39155	23.73327	7.86	53.24521	9/10/2022	-0.0977	0.070702	1.14819	114	-0.00894	0.032028	-0.0137
90.39155	23.73327	7.86	53.24521	9/10/2022	-0.0977	0.070702	1.14819	117	-0.00894	0.032028	-0.0137
90.39155	23.73327	7.86	53.24521	9/10/2022	-0.03081	-0.01299	1.10322	118	-0.02025	0.016418	0.007874
90.39155	23.73327	7.86	53.24521	9/10/2022	-0.03081	-0.01299	1.10322	116	-0.02025	0.016418	0.007874
90.39155	23.73327	7.86	53.24521	9/10/2022	-0.33493	0.274091	1.395041	118	-0.02344	-0.00276	0.035629
90.39163	23.73328	7.06	61.12333	9/10/2022	-0.33493	0.274091	1.395041	119	-0.02344	-0.00276	0.035629
90.39163	23.73328	7.06	61.12333	9/10/2022	0.479511	-0.26448	1.481268	121	-0.00443	-0.00377	-0.00693

Table 10: Data of Smartphone Sensors

Longitude	Latitude	Speed	Distance	Time	Acc X	Acc Y	Acc Z	Heading	gyro_x	gyro_y	gyro_z
90.39163	23.73328	7.06	61.12333	9/10/2022	0.479511	-0.26448	1.481268	122	-0.00443	-0.00377	-0.00693
90.39163	23.73328	7.06	61.12333	9/10/2023	-0.22968	0.28	1.770723	120	-0.02994	-0.02811	0.028488
90.39163	23.73328	7.06	61.12333	9/10/2023	-0.22968	0.28	1.770723	123	-0.02994	-0.02811	0.028488
90.39163	23.73328	7.06	61.12333	9/10/2023	0.204845	-0.14312	1.625127	125	-0.00569	0.024948	-0.02419
90.39163	23.73328	7.06	61.12333	9/10/2023	0.204845	-0.14312	1.625127	125	-0.00569	0.024948	-0.02419
90.39163	23.73328	7.06	61.12333	9/10/2023	-0.04913	0.004517	1.601452	126	-0.01262	-0.02235	0.005859
90.39163	23.73328	7.06	61.12333	9/10/2023	-0.04913	0.004517	1.601452	127	-0.01262	-0.02235	0.005859
90.39163	23.73328	7.06	61.12333	9/10/2023	-0.05815	0.134341	1.456305	127	-0.01805	-0.00249	-0.00757
90.39167	23.73328	4.36	65.96021	9/10/2023	-0.05815	0.134341	1.456305	128	-0.01805	-0.00249	-0.00757
90.39167	23.73328	4.36	65.96021	9/10/2023	-0.07399	-0.13915	1.477459	129	-0.00357	-0.01527	-0.02057
90.39167	23.73328	4.36	65.96021	9/10/2023	-0.07399	-0.13915	1.477459	132	-0.00357	-0.01527	-0.02057
90.39167	23.73328	4.36	65.96021	9/10/2024	-0.02783	0.107632	1.149444	133	-0.00836	0.028244	-0.02658
90.39167	23.73328	4.36	65.96021	9/10/2024	-0.02783	0.107632	1.149444	132	-0.00836	0.028244	-0.02658
90.39167	23.73328	4.36	65.96021	9/10/2024	-0.32353	0.113854	1.111403	133	-0.01028	-0.01671	0.01358
90.39167	23.73328	4.36	65.96021	9/10/2024	-0.32353	0.113854	1.111403	133	-0.01028	-0.01671	0.01358
90.39167	23.73328	4.36	65.96021	9/10/2024	0.534789	0.267127	1.161063	134	-0.02924	0.014389	0.012558
90.39167	23.73328	4.36	65.96021	9/10/2024	0.534789	0.267127	1.161063	135	-0.02924	0.014389	0.012558
90.39167	23.73328	4.36	65.96021	9/10/2024	1.235999	-0.62424	2.237859	134	0.02562	-0.14156	-0.09343
90.39171	23.73328	2.51	69.87122	9/10/2024	1.235999	-0.62424	2.237859	131	0.02562	-0.14156	-0.09343
90.39171	23.73328	2.51	69.87122	9/10/2024	-0.82673	0.604306	1.068958	130	0.004684	-0.07062	0.012405
90.39171	23.73328	2.51	69.87122	9/10/2024	-0.82673	0.604306	1.068958	129	0.004684	-0.07062	0.012405
90.39171	23.73328	2.51	69.87122	9/10/2025	-0.82673	0.604306	1.068958	129	0.004684	-0.07062	0.012405
90.39171	23.73328	2.51	69.87122	9/10/2025	-2.33424	0.305463	-0.94447	134	-0.0278	0.086411	0.035522
90.39171	23.73328	2.51	69.87122	9/10/2025	-2.33424	0.305463	-0.94447	136	-0.0278	0.086411	0.035522
90.39171	23.73328	2.51	69.87122	9/10/2025	-0.16571	-0.196	-1.57798	135	-0.0025	0.094925	-0.01674
90.39171	23.73328	2.51	69.87122	9/10/2025	-0.16571	-0.196	-1.57798	133	-0.0025	0.094925	-0.01674
90.39171	23.73328	2.51	69.87122	9/10/2025	2.312599	0.5724	-0.09041	133	-0.00644	-0.0215	0.026627
90.39171	23.73328	2.51	69.87122	9/10/2025	2.312599	0.5724	-0.09041	138	-0.00644	-0.0215	0.026627
90.39173	23.73328	0.63	71.42393	9/10/2025	-0.15368	0.015259	-1.00141	140	-0.00288	0.138824	-0.01811
90.39173	23.73328	0.63	71.42393	9/10/2025	-0.15368	0.015259	-1.00141	142	-0.00288	0.138824	-0.01811
90.39173	23.73328	0.63	71.42393	9/10/2025	-0.00611	0.134673	-0.65658	141	-0.01407	0.100204	0.023529
90.39173	23.73328	0.63	71.42393	9/10/2026	-0.00611	0.134673	-0.65658	141	-0.01407	0.100204	0.023529
90.39173	23.73328	0.63	71.42393	9/10/2026	-0.333	0.165715	-0.30785	136	0.003036	-0.02432	-0.01443

Table 11: Data of Smartphone Sensors

Chapter 4: Analysis and Result

4.1 Data Processing:

The data was prepared by verifying for a few criteria, including completeness, consistency, systematic errors, accuracy, and repeatability. Following a comprehensive examination of the obtained data, it was determined that the data were full and consistent.

Public opinions are prone to methodological errors like severity errors and leniency errors, as well as the central tendency effect. From Table 12 leniency and severity error were calculated.

Rater	Mean	Standard Deviation	Delta R	Rank
1	3.44	0.76811457	0.021818	4
2	3.64	1.07548439	-0.17818	6
3	3.24	0.96953597	0.381818	2
4	3.6	1.22474487	-0.13818	5
5	3.28	0.9797959	0.461818	1
6	3.68	0.80208063	-0.21818	7
7	3.24	1.09087121	0.381818	2
8	3.64	0.81034972	-0.17818	6
9	3.84	1.14309521	-0.37818	9
10	3.36	1.07548439	0.101818	3
11	3.72	1.17331439	-0.25818	8
Total	3.516364	0.21200343	0	

Table 12: Public opinions variation from mean

In Table 12, we calculated "Delta R". Also, this data is liable to severity error and leniency error. "Rank" means the difference of public opinion in terms of RQI from grand mean.

The calculation for standard deviation was shown below.

Count, N: 11

Sum, Σx: 38.68

Mean, $\bar{x}$: 3.5163636363636

Variance, s^2: 0.044945454545455

Steps

$$s = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \overline{x})^2},$$

$$s^2 = \frac{\Sigma (x_i - \bar{x})^2}{N - 1}$$

$$= \frac{(3.44 - 3.5163636363636)^2 + \ldots + (3.72 - 3.5163636363636)^2}{11 - 1}$$

$$= \frac{0.44945454545455}{10}$$

$$= 0.044945454545455$$

$$s = \sqrt{0.044945454545455}$$

$$= 0.21200343050398$$

4.2 Margin of Error (Confidence Interval)

The sampling means most likely follows a normal distribution. In this case, the standard error of the mean (SEM) can be calculated using the following equation:

$$s_{\bar{x}} = \frac{s}{\sqrt{N}} = 0.063921439386353$$

Based on the SEM, the following are the margins of error (or confidence intervals) at different confidence levels. Depending on the field of study, a confidence level of 95% (or statistical significance of 5%) is typically used for data representation.

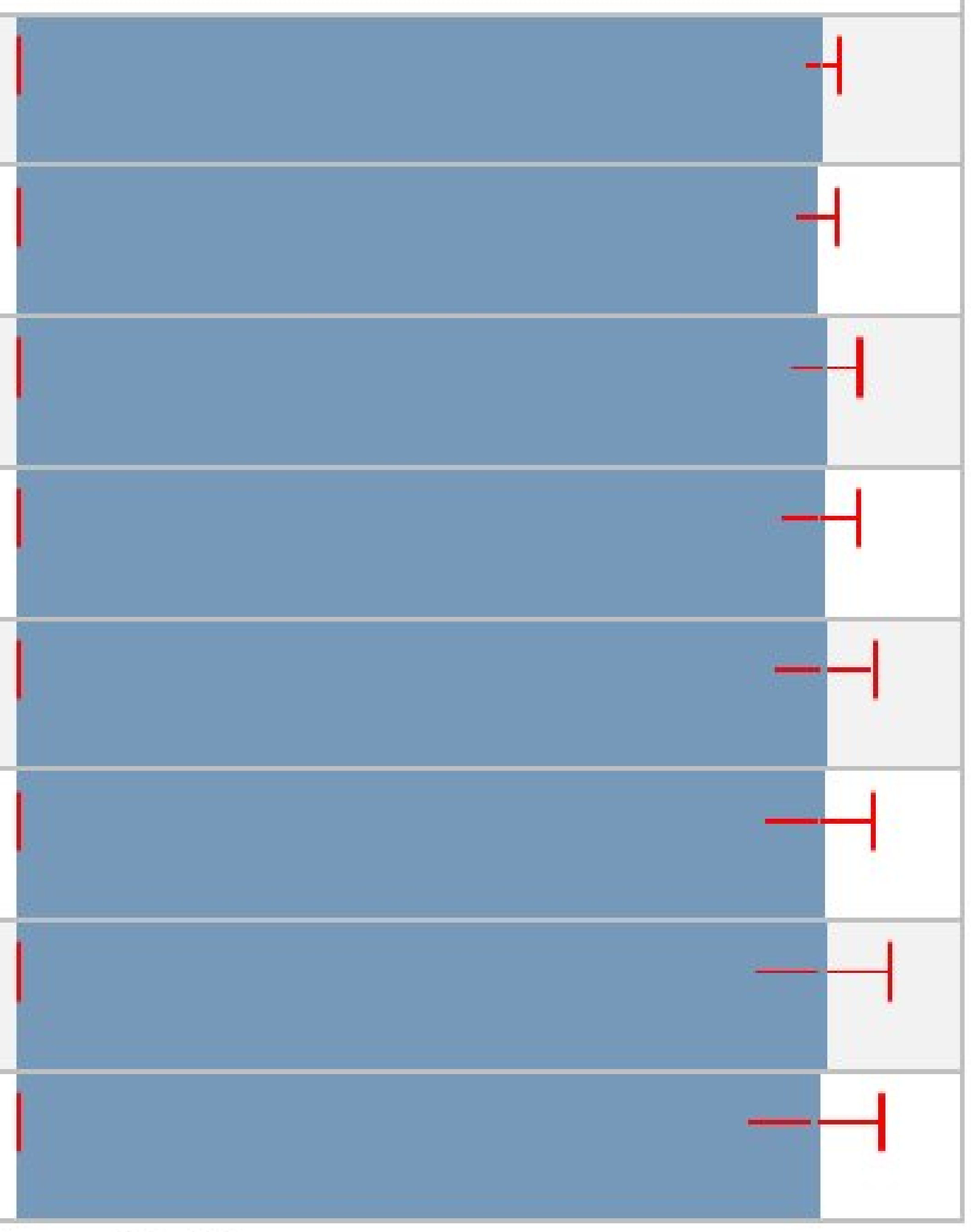
Confidence Level	Margin of Error	Error Bar
68.3%, $s_{\bar{x}}$	3.5164 ±0.0639 (±1.82%)	
90%, $1.645s_{\bar{x}}$	3.5164 ±0.105 (±2.99%)	
95%, $1.960s_{\bar{x}}$	3.5164 ±0.125 (±3.56%)	
99%, $2.576s_{\bar{x}}$	3.5164 ±0.165 (±4.68%)	
99.9%, $3.291s_{\bar{x}}$	3.5164 ±0.21 (±5.98%)	
99.99%, $3.891s_{\bar{x}}$	3.5164 ±0.249 (±7.07%)	
99.999%, $4.417s_{\bar{x}}$	3.5164 ±0.282 (±8.03%)	
99.9999%, $4.892s_{\bar{x}}$	3.5164 ±0.313 (±8.89%)	

Table 13: Leniency and Severity Error

From the calculation above, the amount of severity error and leniency error were insignificant.

4.3 Central tendency effect:

In Table 14 central tendency effect was calculated.

Public	1	2	3	4	5	6	7	8	9	10	11
Range	1.4	2.8	2	2.8	2.2	2	2.2	1.8	2.8	2.4	2.8

Table 14: Central Tendency Effect

A rater's ride quality range = maximum rate - lowest rate.

This range should be high because of varying condition of road segment. As demonstrated in Table 14, the rating ranges are sufficiently High. As a result, no modifications were necessary.

4.4 ANOVA Calculation:

There should be similarity of public opinion in one particular section to find out opinions accurately. There is need of low SD of public opinion, although there is need of high SD of section. ANOVA is a numerical method used to assess if the means of more than 3 groups of trials are equivalent at a particular significance level. In 5% confidence level, ANOVA test was used to assess the variances on public opinion and segments. ANOVA test is showed below. [14].

SUMMARY	*Count*	*Sum*	*Average*	*Variance*
rater1	5	17.2	3.44	0.508
rater2	5	18.2	3.64	1.268
rater3	5	16.2	3.24	0.948
rater4	5	18	3.6	1.72
rater5	5	16.4	3.28	0.892
rater6	5	18.4	3.68	0.652
rater7	5	16.2	3.24	1.108
rater8	5	18.2	3.64	0.588
rater9	5	19.2	3.84	1.528
rater10	5	16.8	3.36	1.208
rater11	5	18.6	3.72	1.492
section1	11	27.4	2.490909	0.090909
section2	11	27.8	2.527273	0.146182
section3	11	48.6	4.418182	0.187636
section4	11	39.6	3.6	0.112
section5	11	50	4.545455	0.152727

Table 15: Calculation for ANOVA

ANOVA						
Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between rater	2.247273	10	0.224727	1.934272	0.068638	2.077248
Between section	43.00073	4	10.75018	92.52895	1.16E-19	2.605975
Error	4.647273	40	0.116182			
Total	49.89527	54				

Table 16: ANOVA test calculation

Table 16 demonstrates that variations in public opinions mean value are not substantial (significance (sig) > 0.05), but in the condition of segment's (significance (sig) < 0.05), as predicted. As a result, raters were able to rate the portions that differed considerably in terms of pavement quality with adequate precision.

4.5 Repeatability of roughness data:

In Table 17 and Table 18, android phone-based road surface and public opinion's repeatability was assessed. Their SD and CV were calculated.

Section Number	**Avg. RQI**	**Standard Deviation(m/s^2)**	**Co-efficient of Variance**
1	2.490909	0.301511	12.10447
2	2.527273	0.382337	15.12845
3	4.418182	0.43317	9.804262
4	3.6	0.334664	9.296223
5	4.545455	0.390803	8.597674

Table 17: Repeatability of Roughness Data

Section Number	**Avg. RMS (m/s^2)**	**Standard Deviation (m/s^2)**	**Co-efficient of Variance**
1	0.712082	0.010829	1.520796
2	0.578807	0.07943	13.72311
3	0.748371	0.128181	9.592704
4	0.588355	0.052723	8.961107
5	0.867249	0.004287	0.494336

Table 18: Roughness Data Repeatability

From the table, value of standard deviation and coefficient of variance are low which is less than 20%. Due to this low percentage value, it demonstrates the repeatability of the test.

Figure 5 illustrates the RMS for each section across five runs.

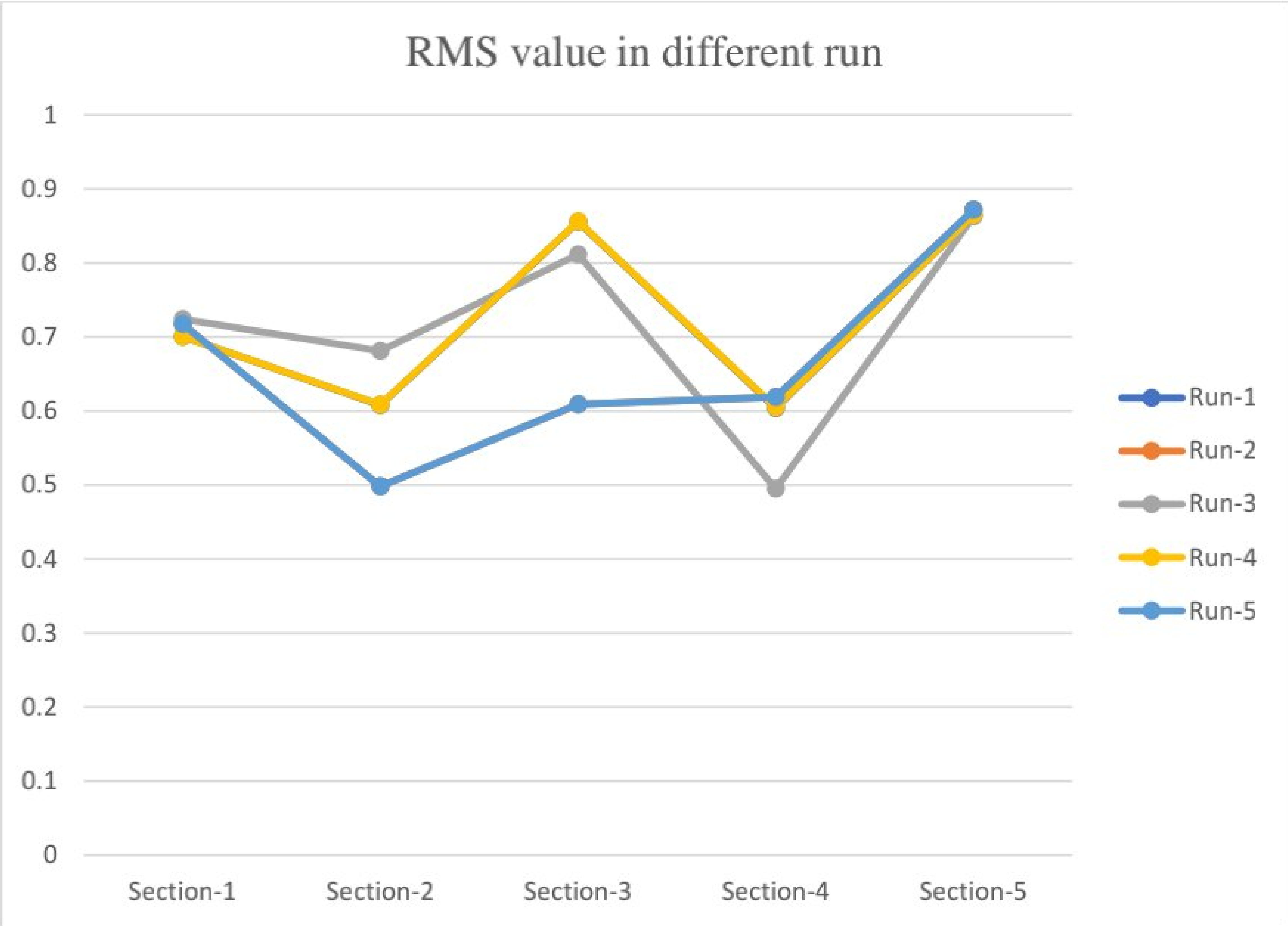


Figure 5: RMS value in different run

This figure shows that the value in different section in different runs are almost identical. A two-way ANOVA test was performed in Table 16, which found no change between various trials at the 95 percent level of confidence. The ANOVA test confirms that there are no significant changes across smartphone replicates, demonstrating the data collection reparability.

Figure 6 to Figure 30 shows acceleration data from a route with various pavement conditions. However, it varied more on the rough road surface and less on the smooth.

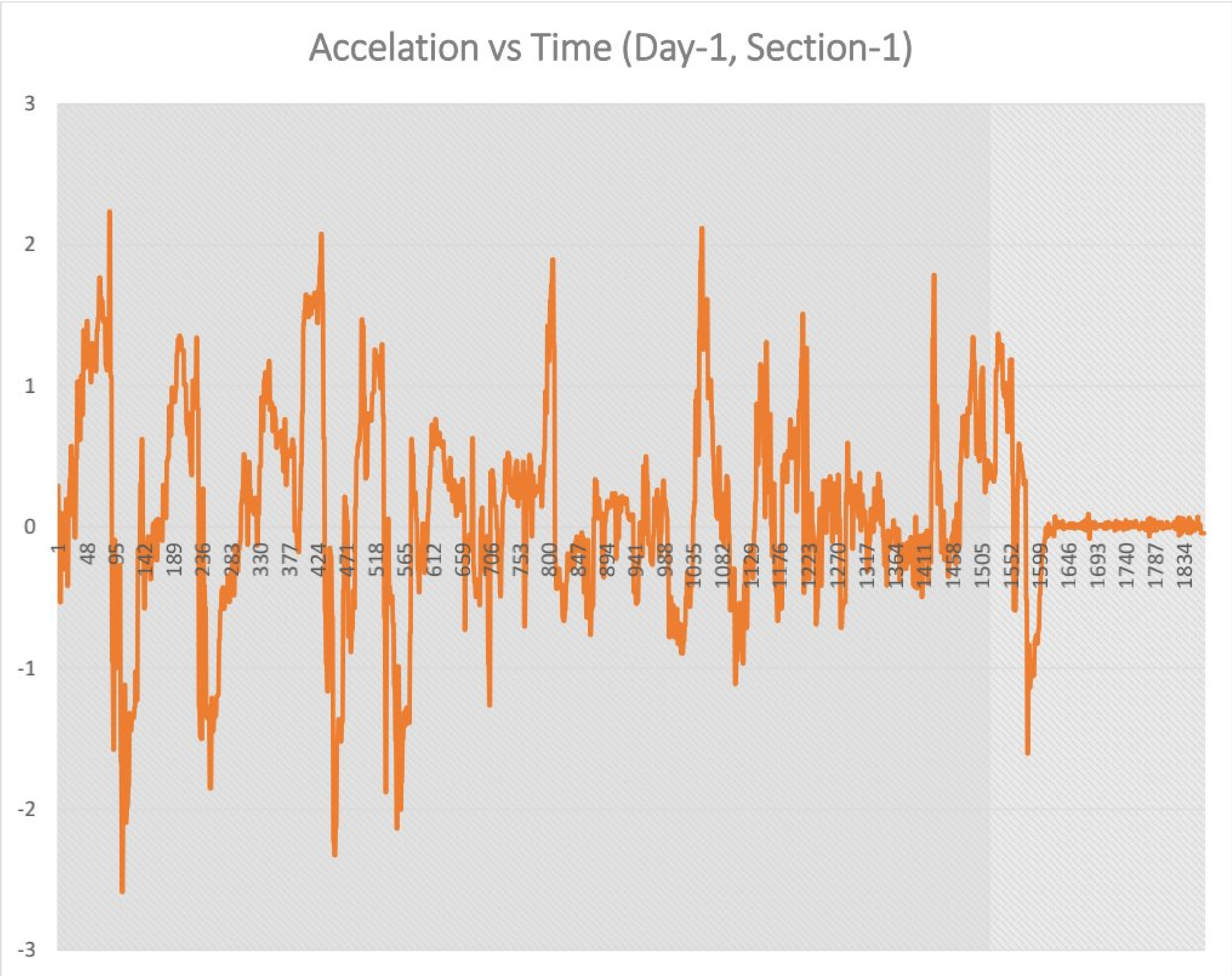


Figure 6: Acceleration Data from Smartphone (Day-1, Section-1)

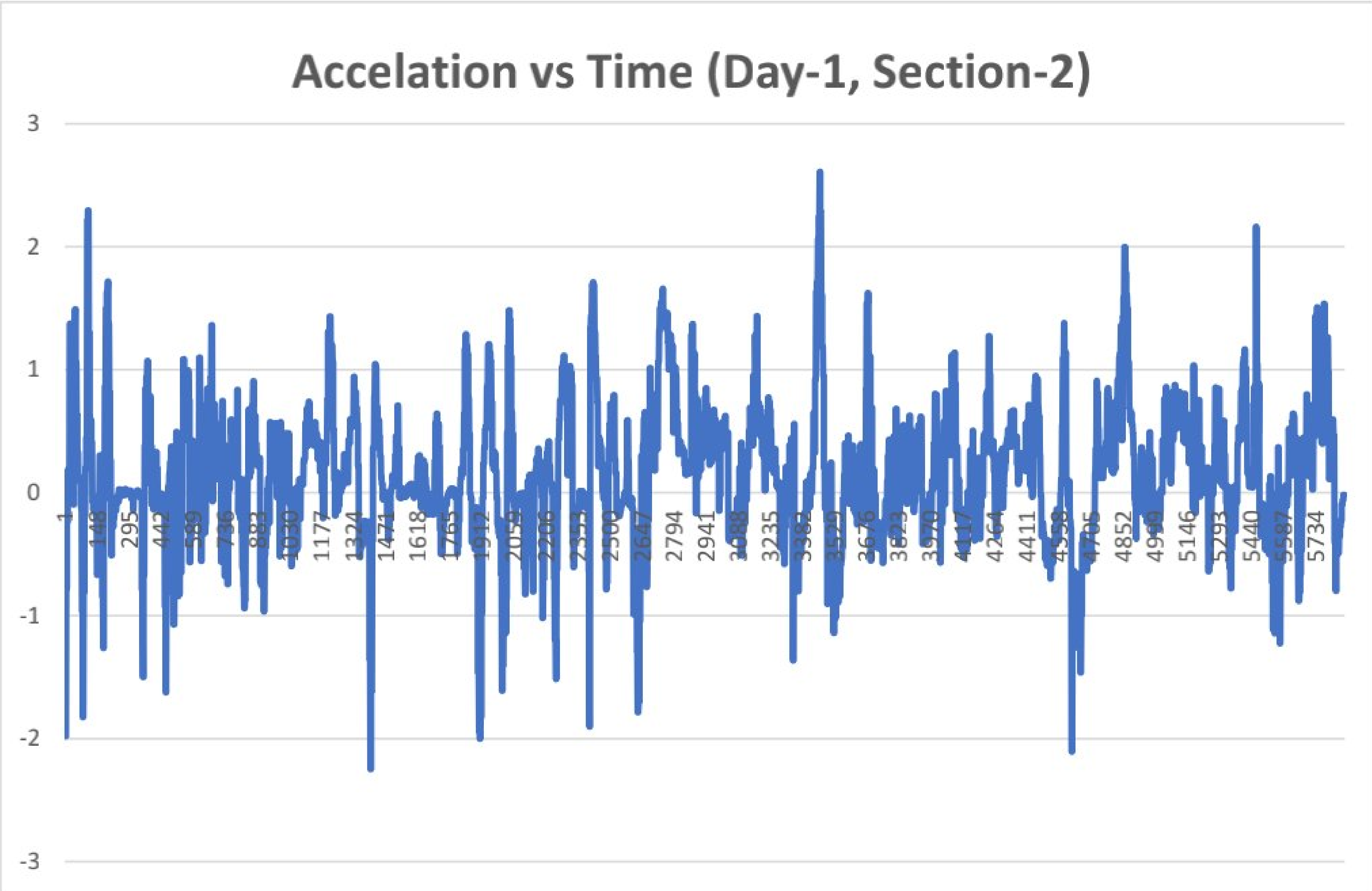


Figure 7: Acceleration Data from Smartphone (Day-1, Section-2)

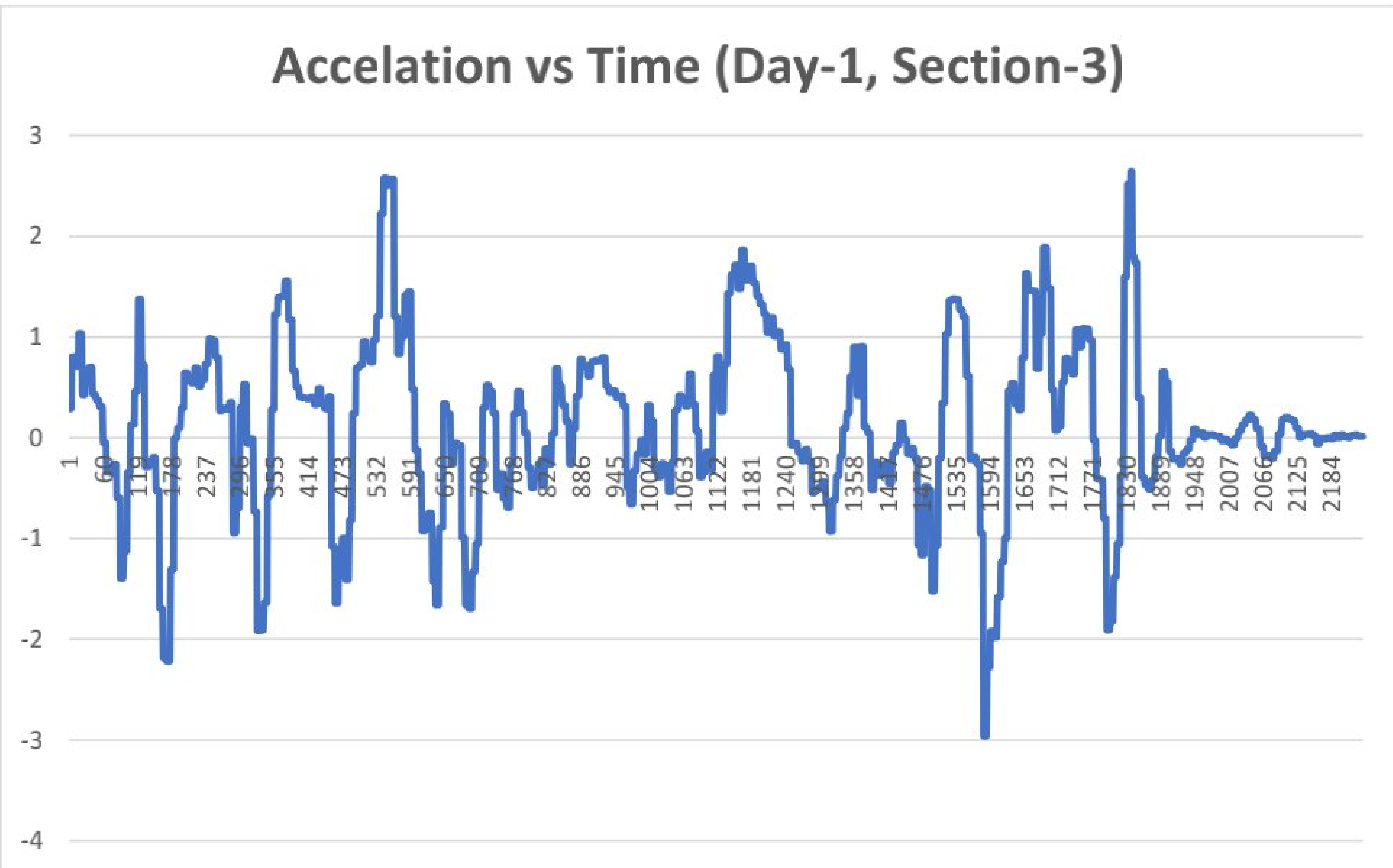


Figure 8: Acceleration Data from Smartphone (Day-1, Section-3)

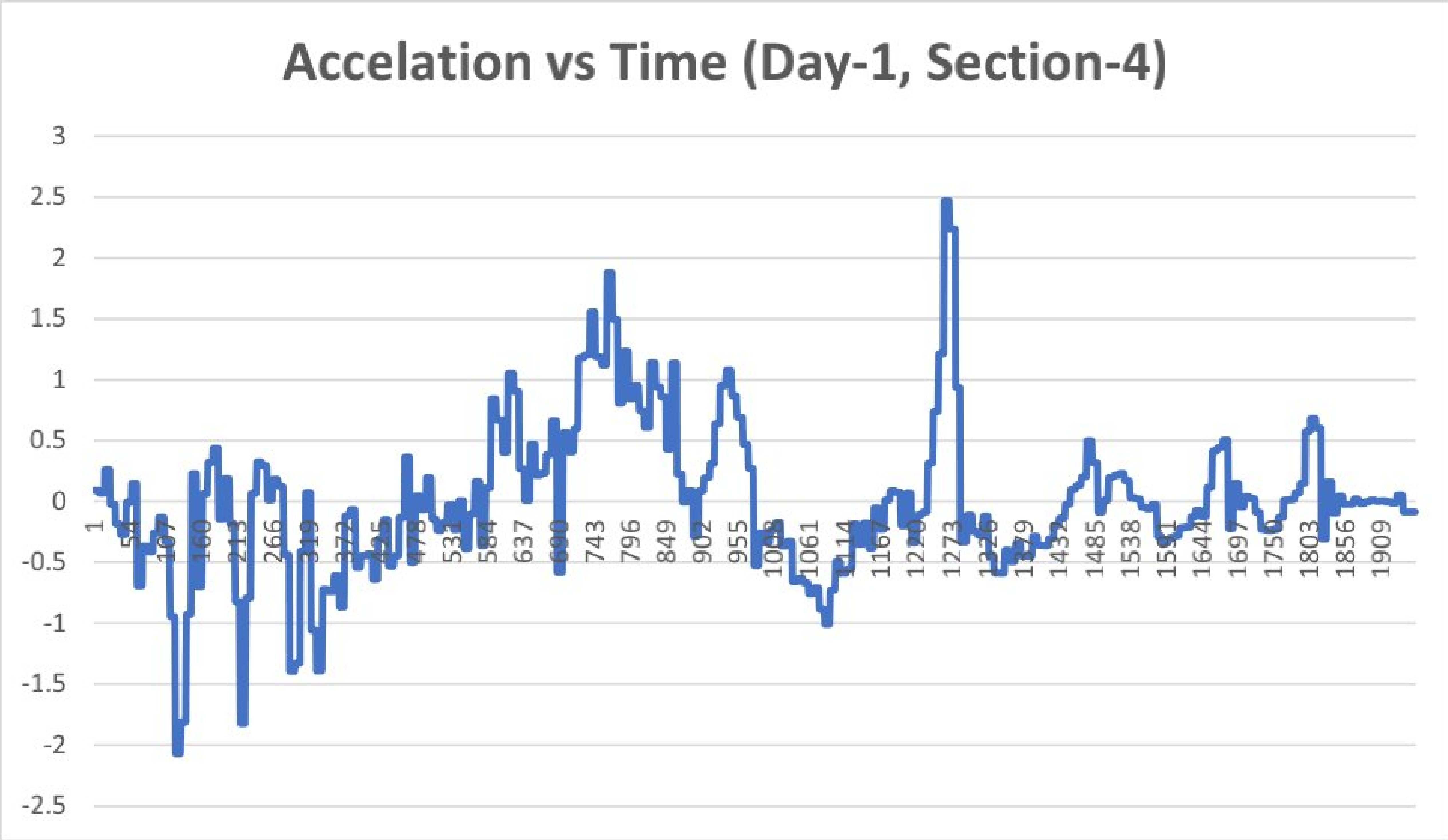


Figure 9: Acceleration Data from Smartphone (Day-1, Section-4)

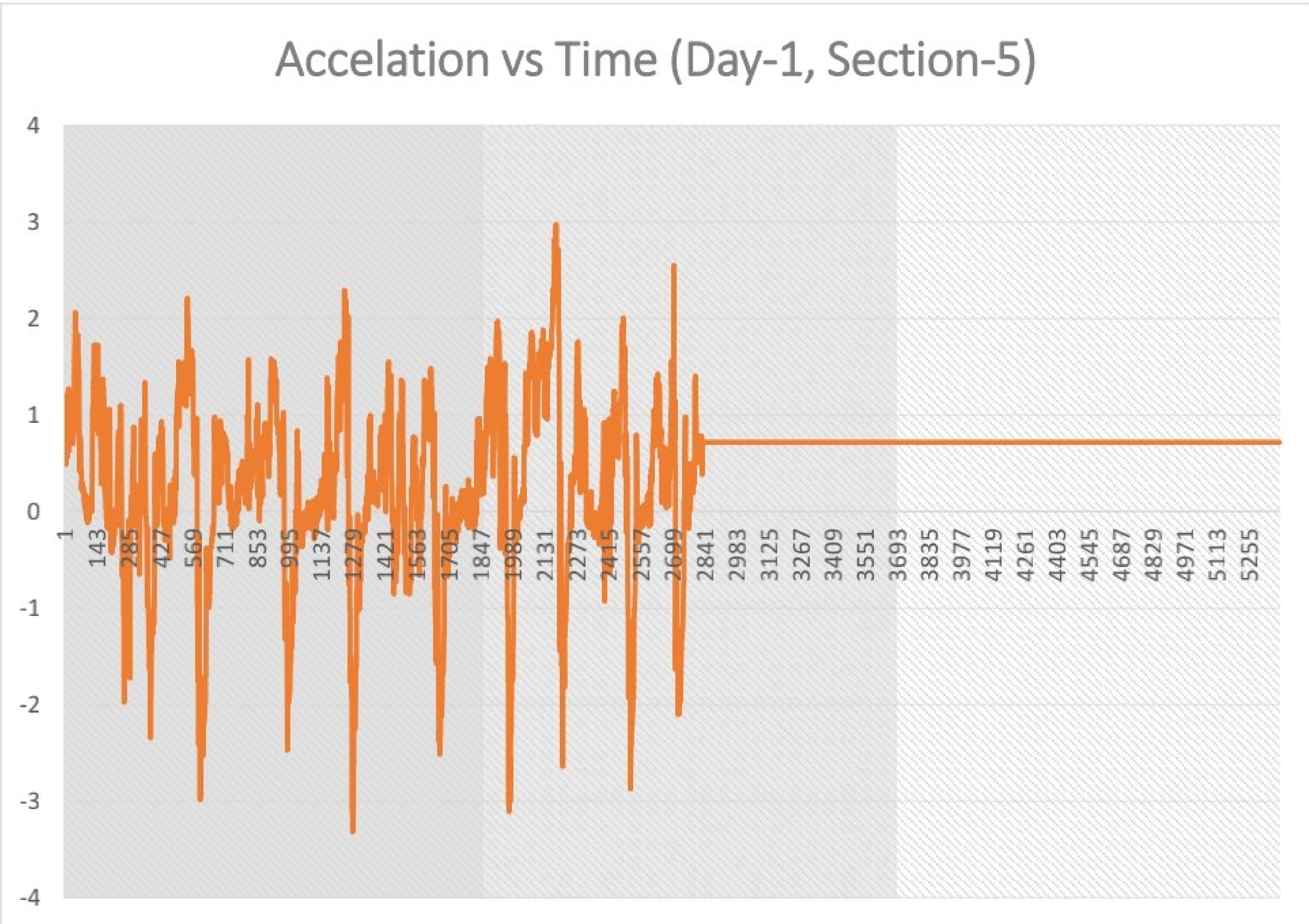


Figure 10: Acceleration Data from Smartphone (Day-1, Section-5)

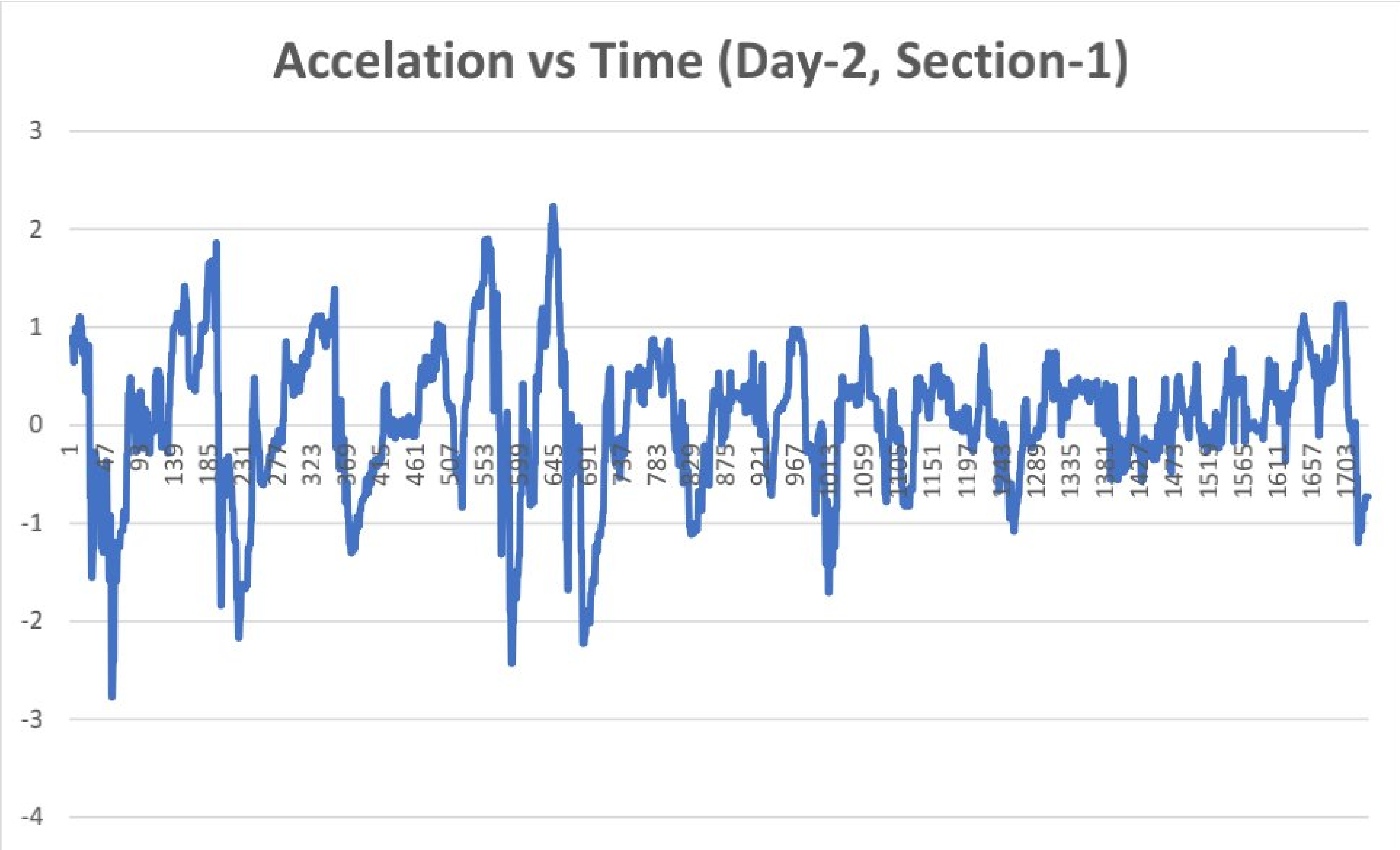


Figure 11: Acceleration Data from Smartphone (Day-2, Section-1)

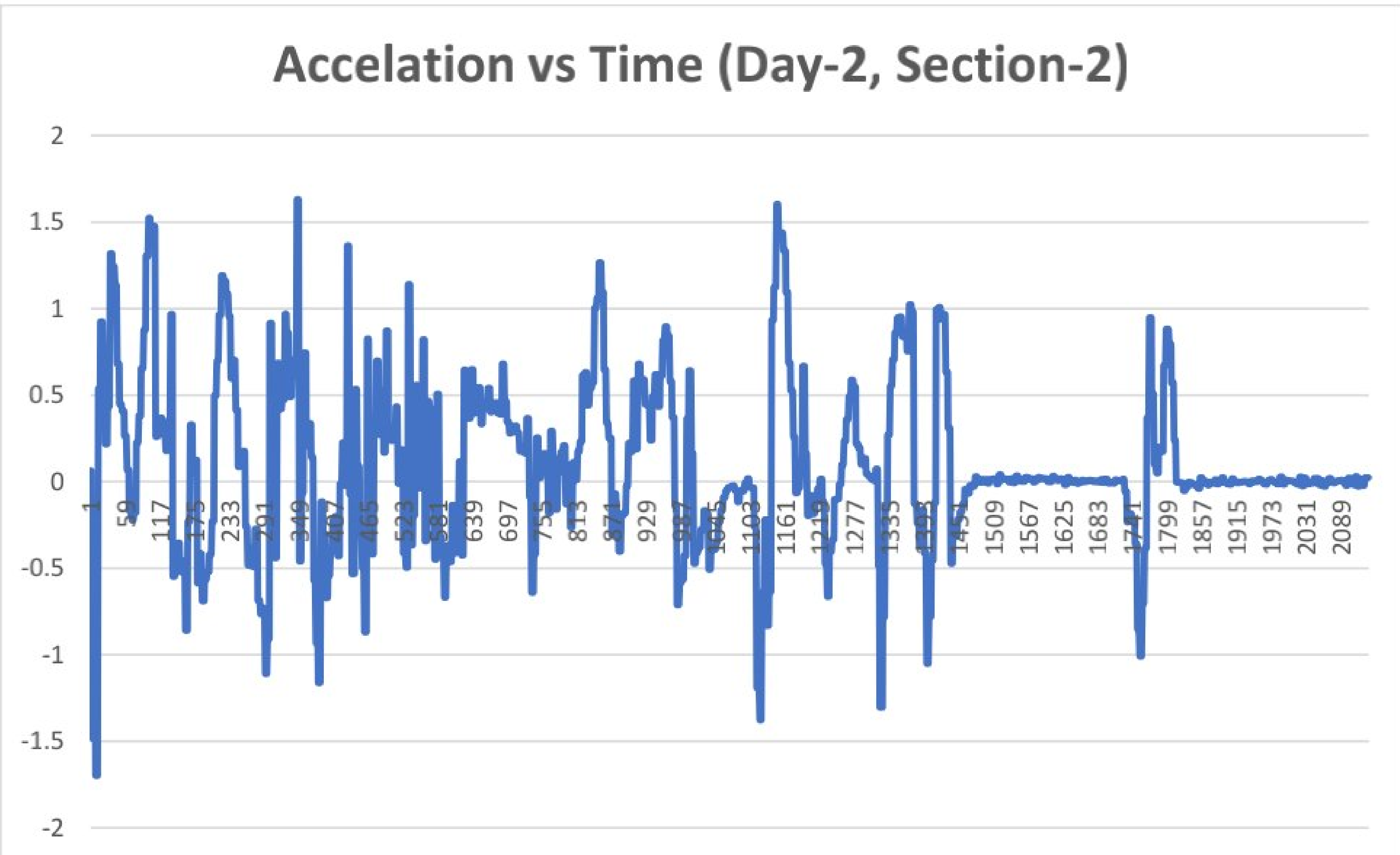


Figure 12: Acceleration Data from Smartphone (Day-2, Section-2)

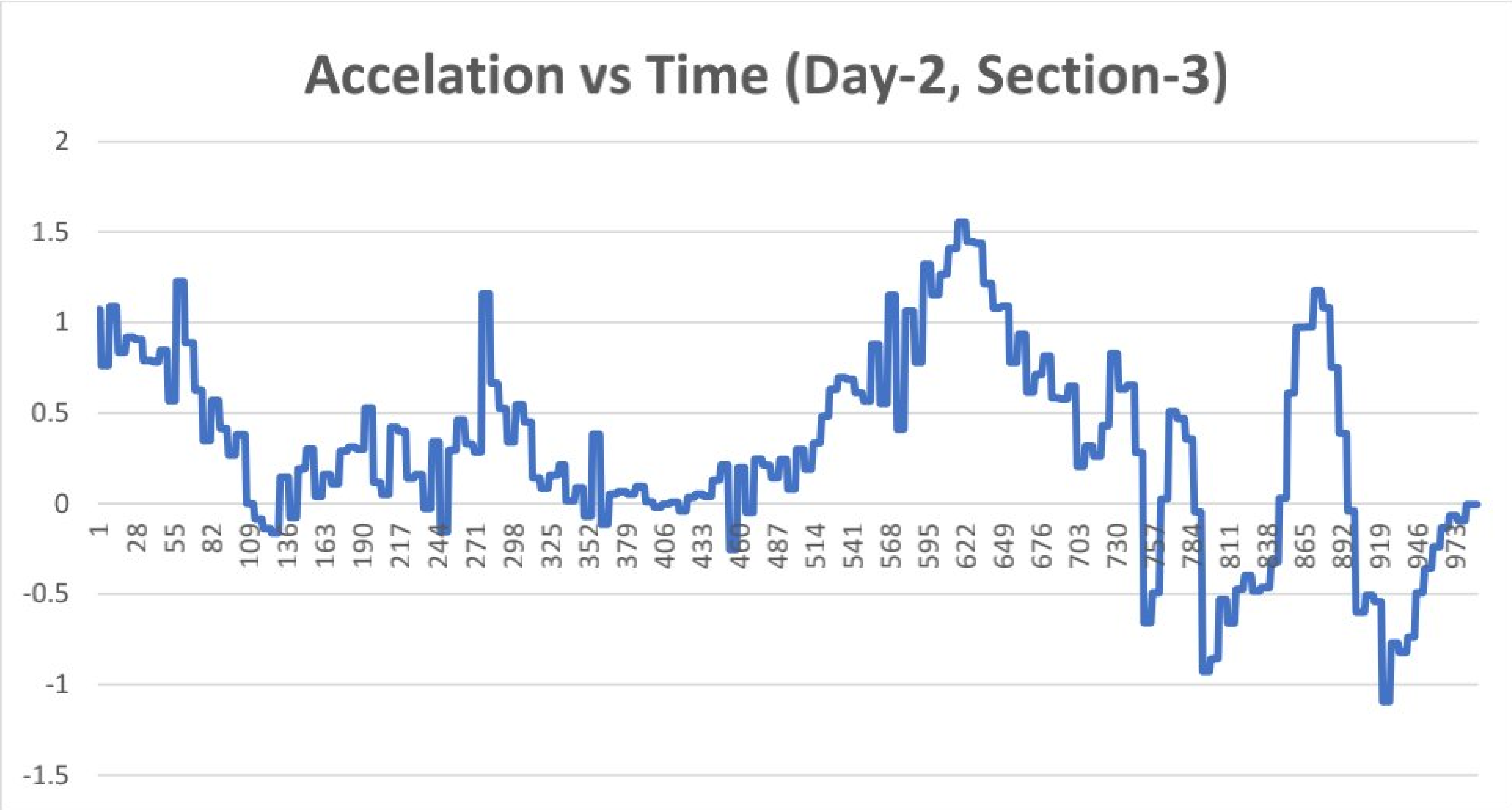


Figure 13: Acceleration Data from Smartphone (Day-2, Section-3)

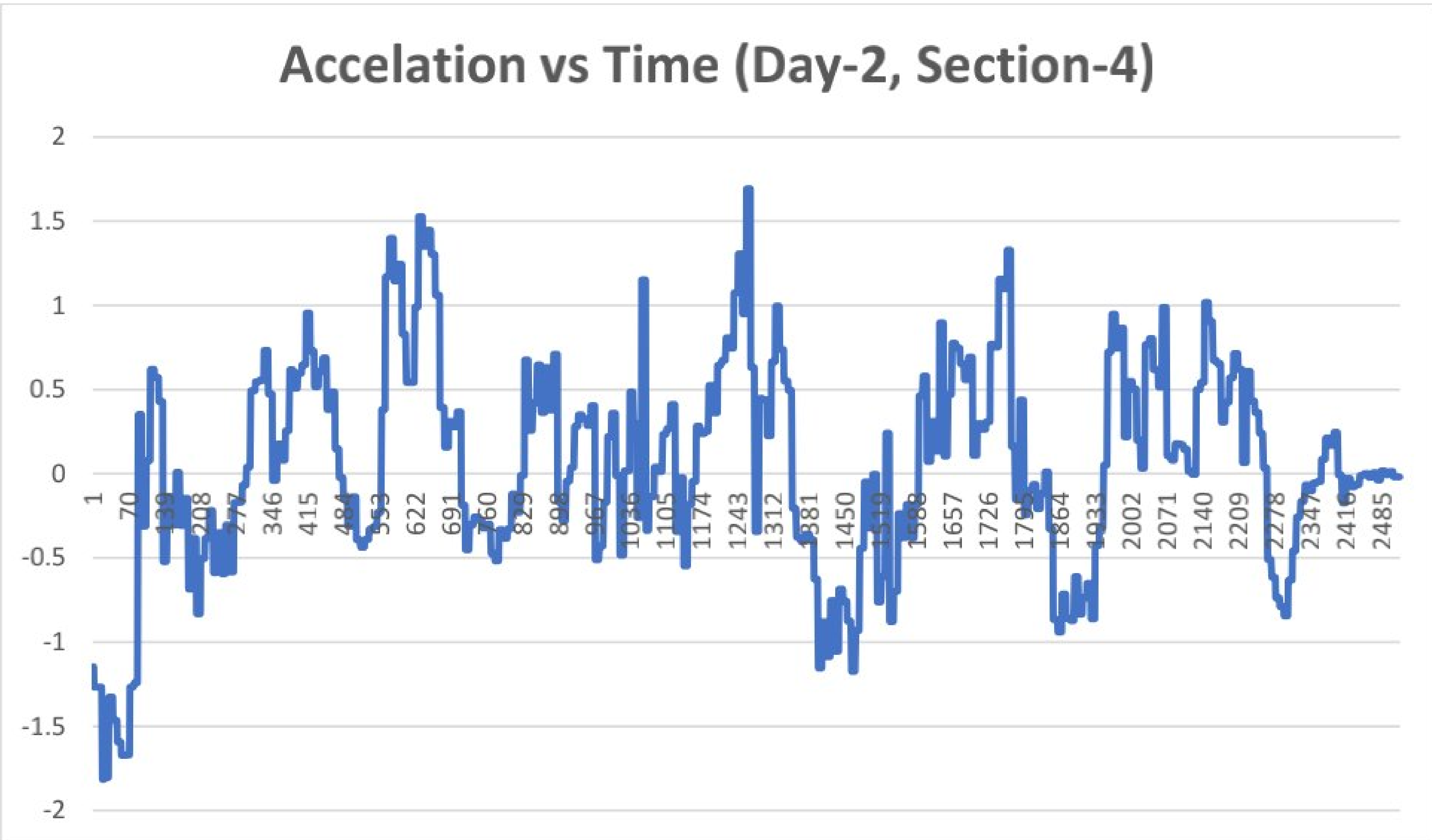


Figure 14: Acceleration Data from Smartphone (Day-2, Section-4)

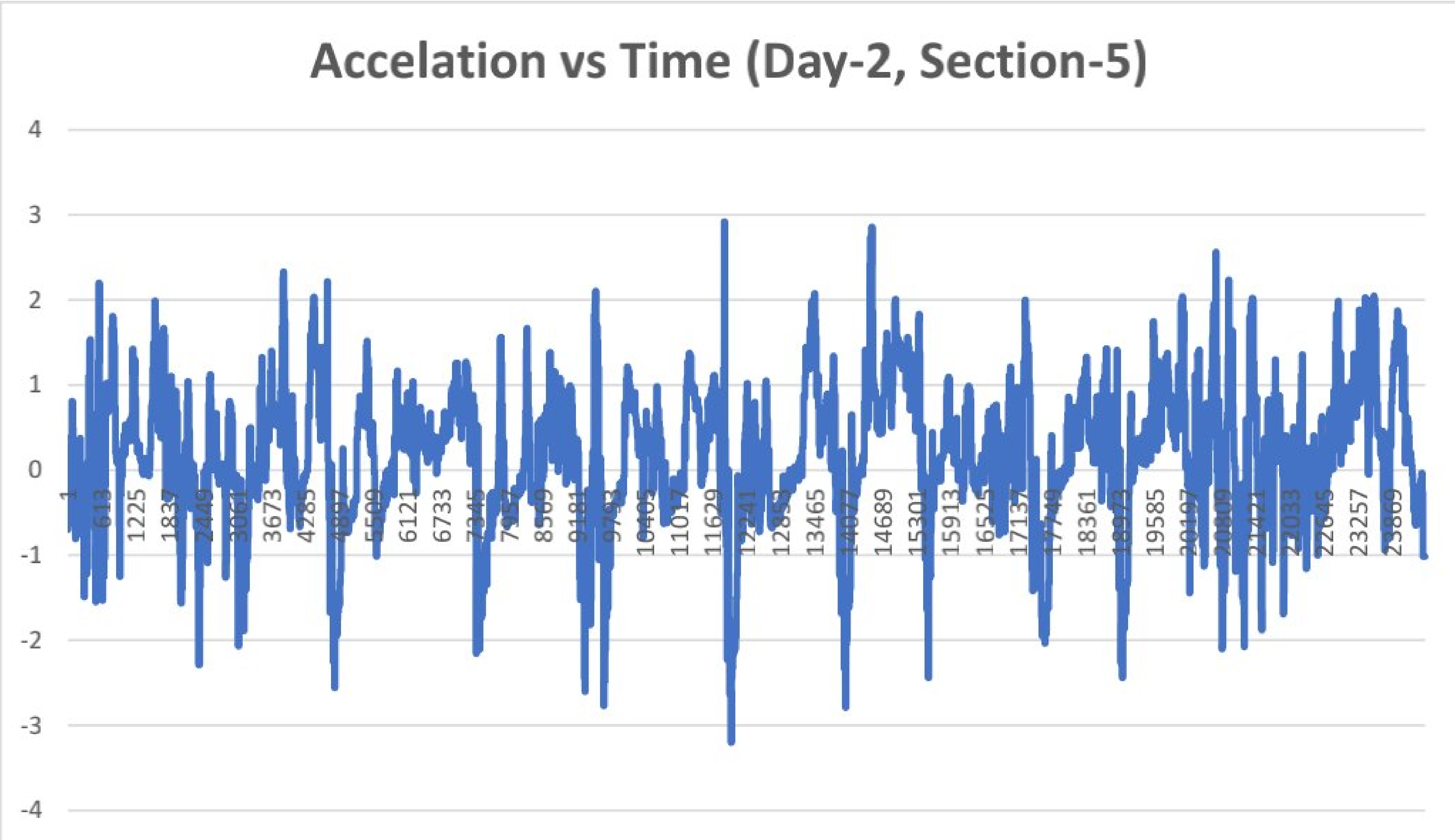


Figure 15: Acceleration Data from Smartphone (Day-2, Section-5)

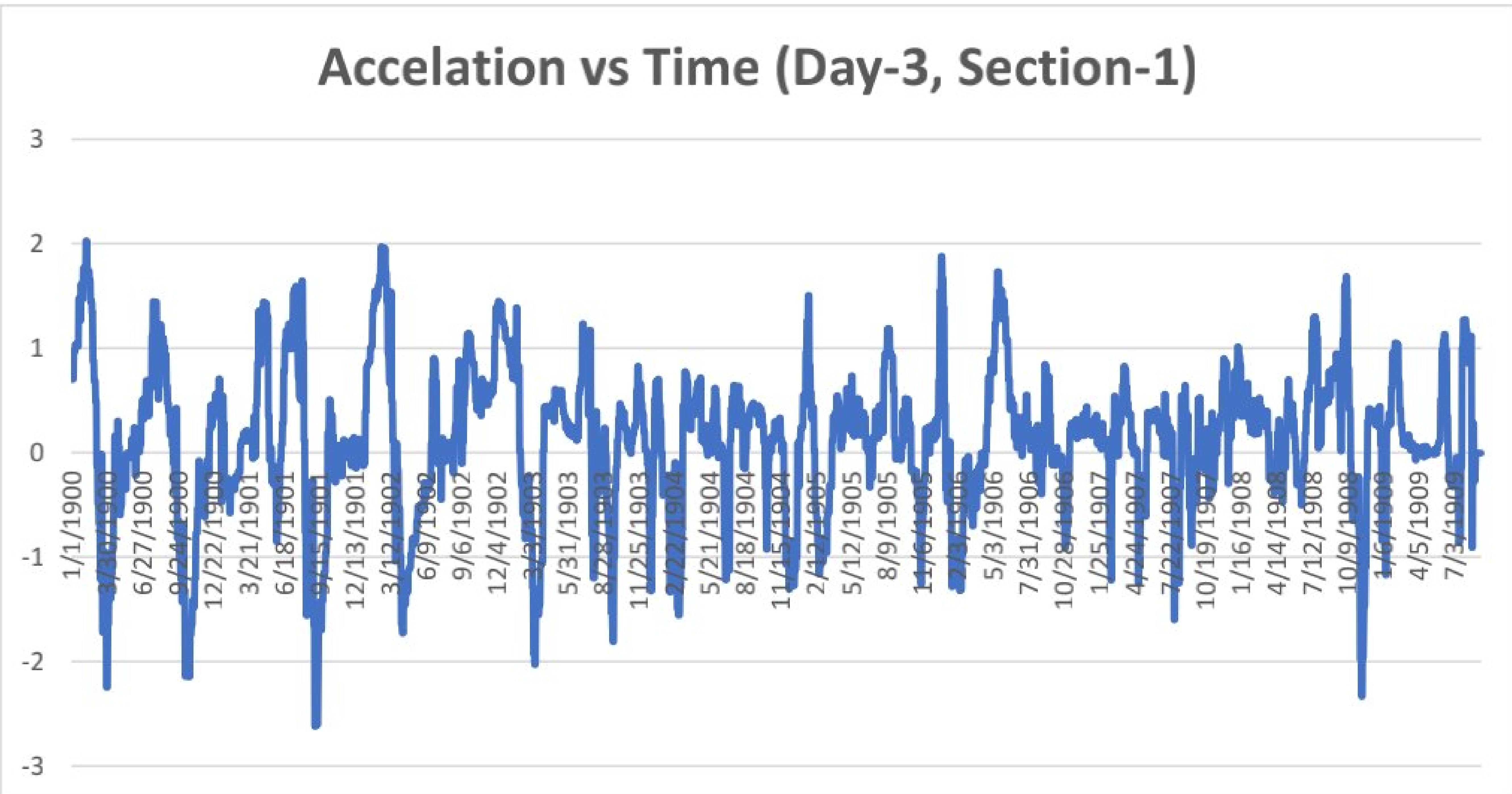


Figure 16: Acceleration Data from Smartphone (Day-3, Section-1)

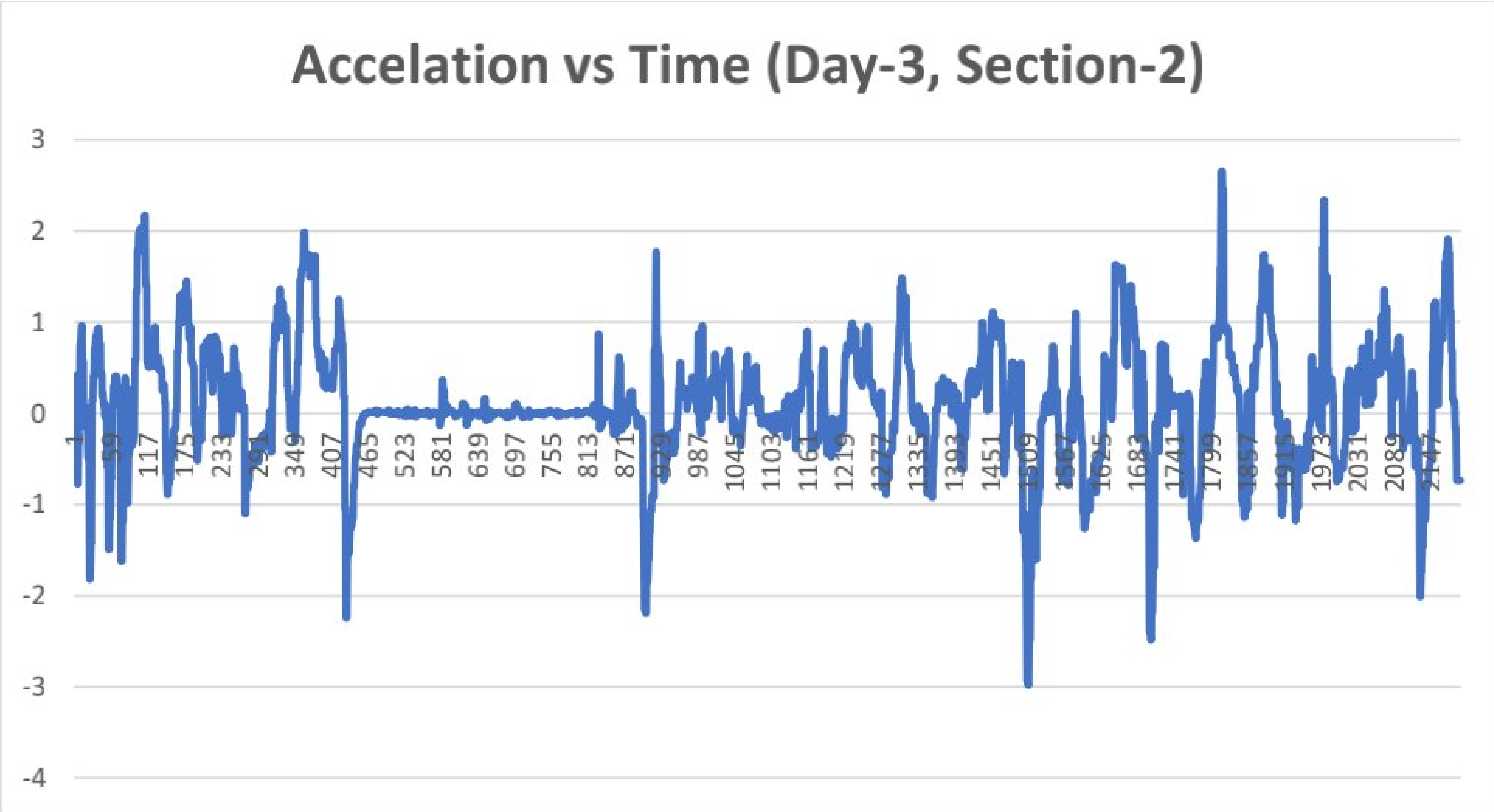


Figure 17: Acceleration Data from Smartphone (Day-3, Section-2)

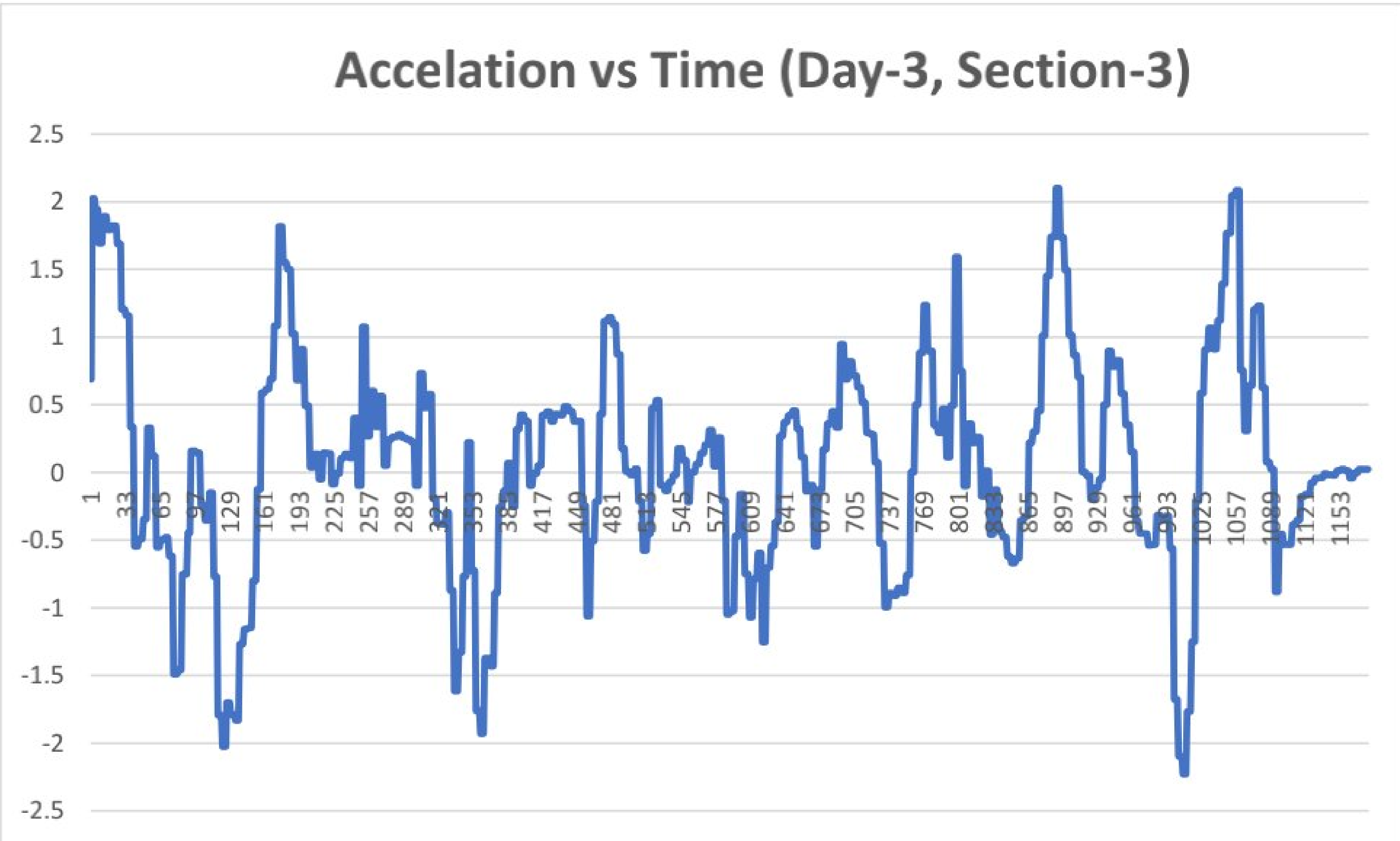


Figure 18: Acceleration Data from Smartphone (Day-3, Section-3)

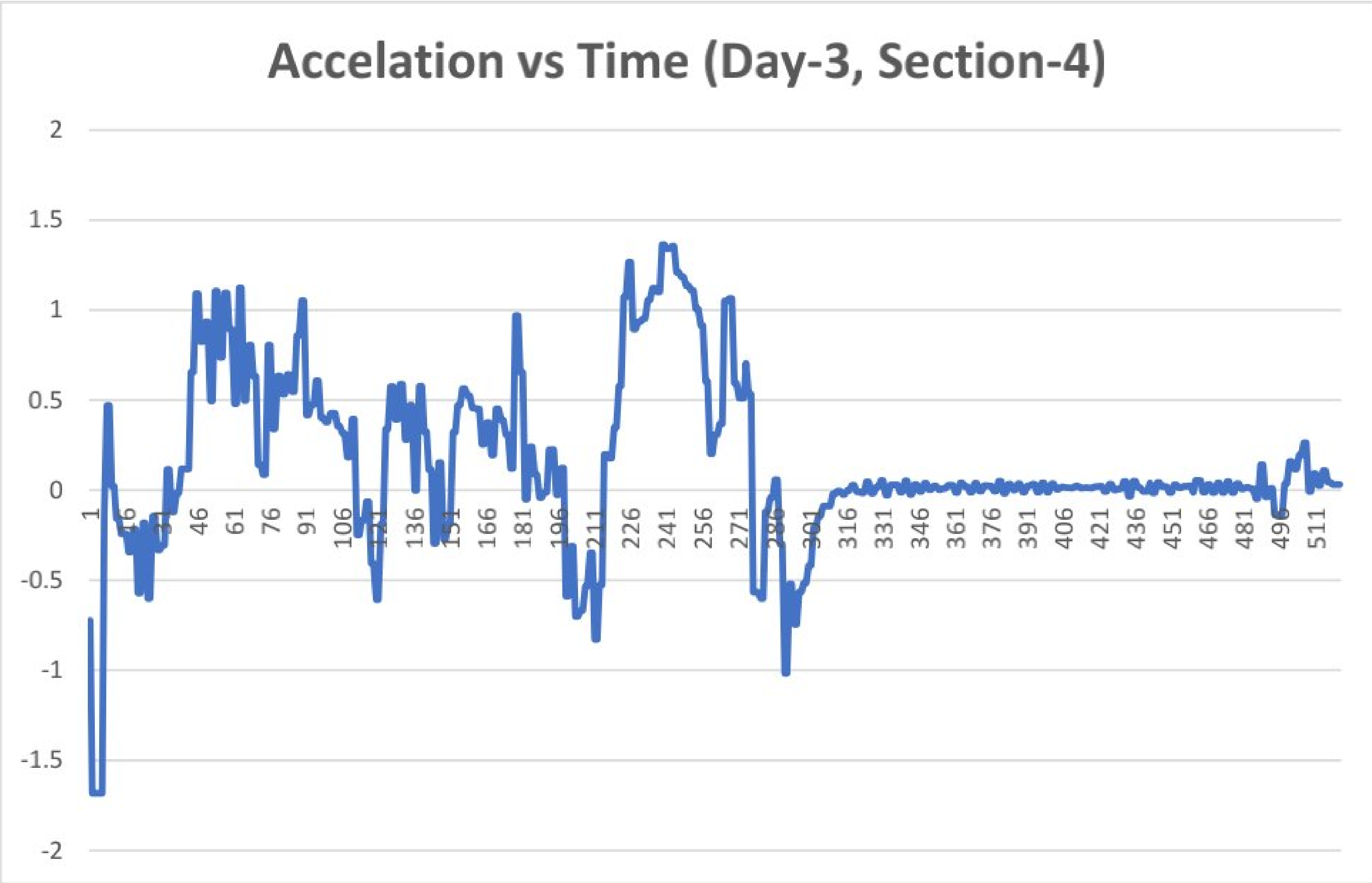


Figure 19: Acceleration Data from Smartphone (Day-3, Section-4)

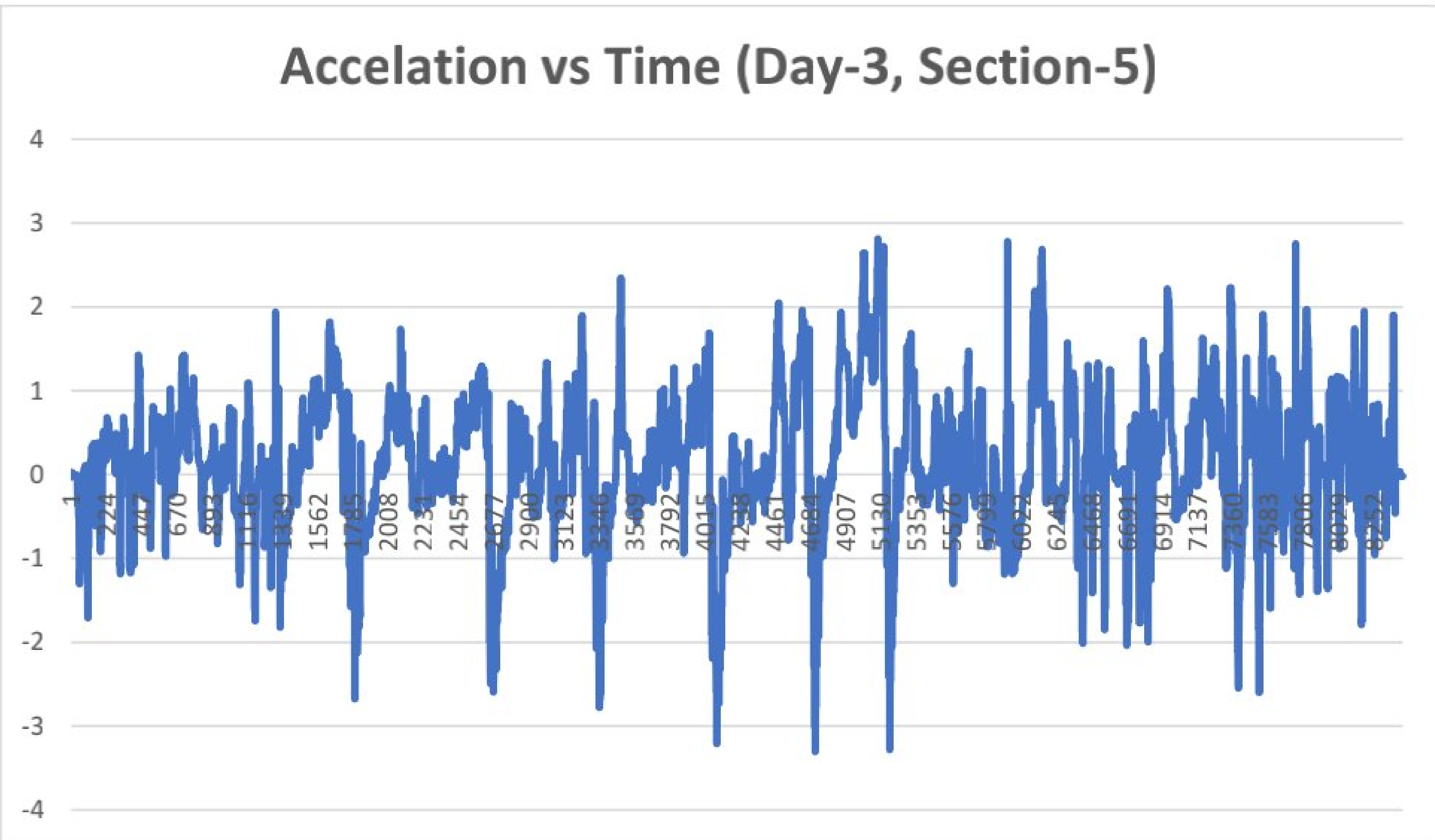


Figure 20: Acceleration Data from Smartphone (Day-3, Section-5)

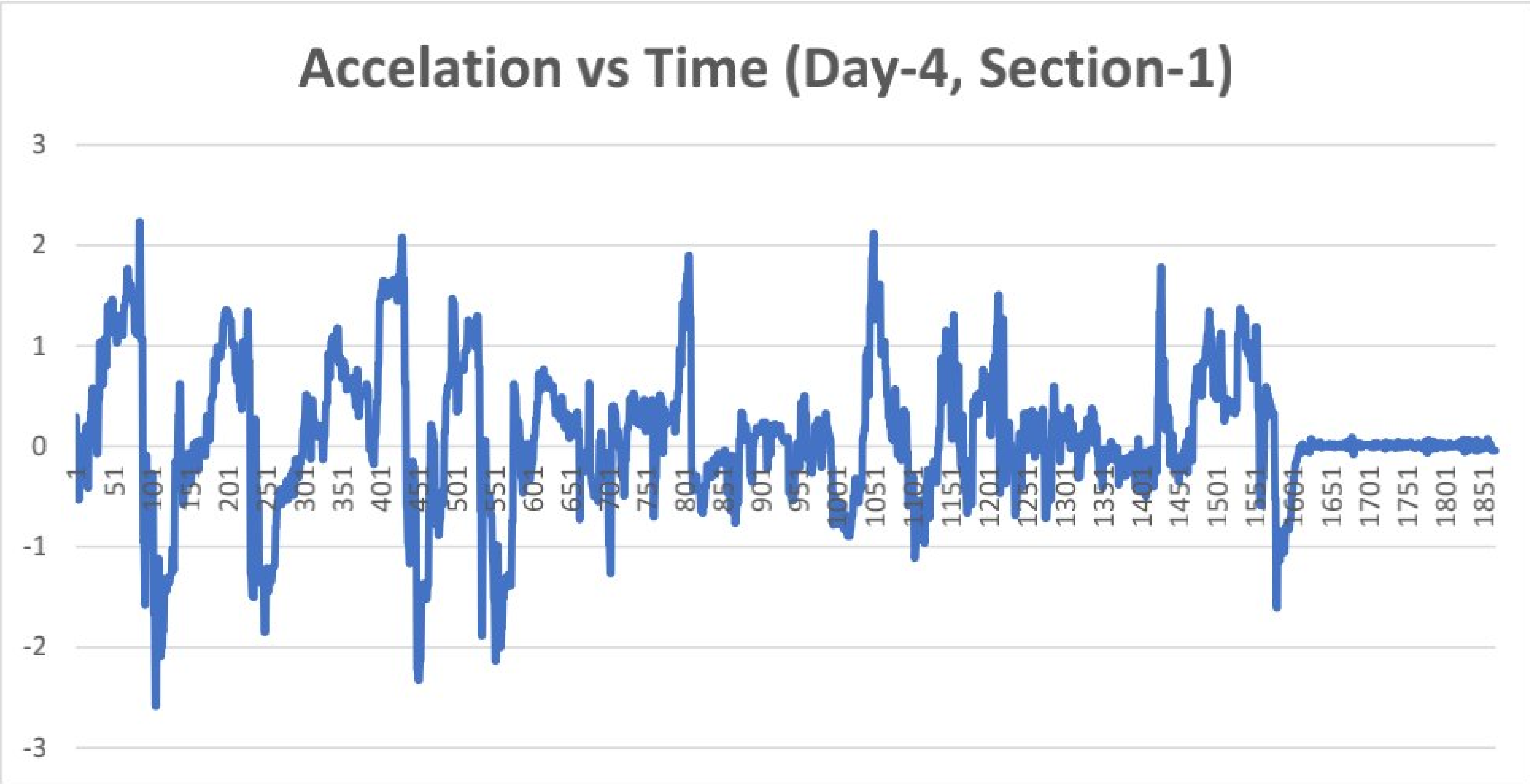


Figure 21: Acceleration Data from Smartphone (Day-4, Section-1)

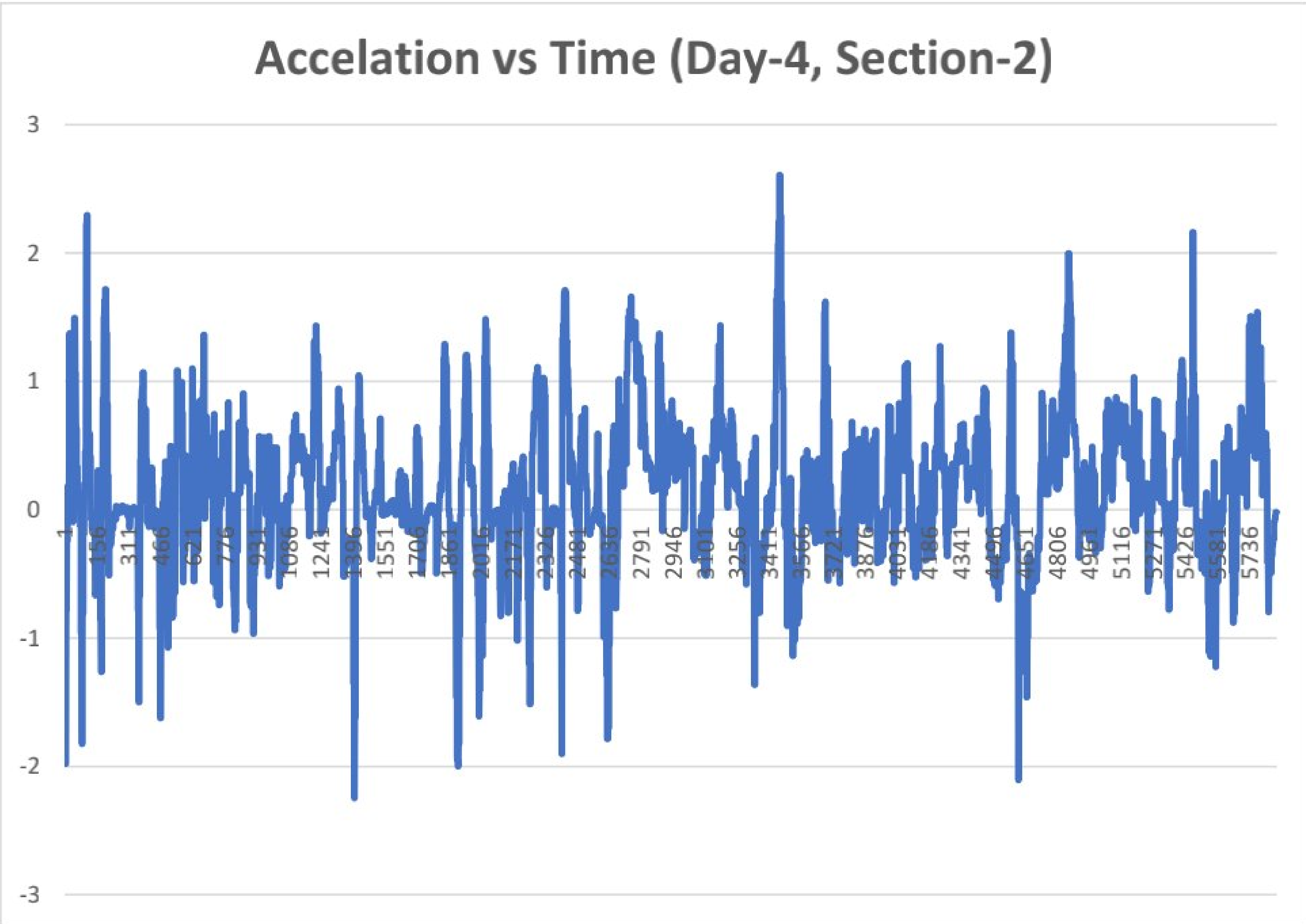


Figure 22: Acceleration Data from Smartphone (Day-4, Section-2)

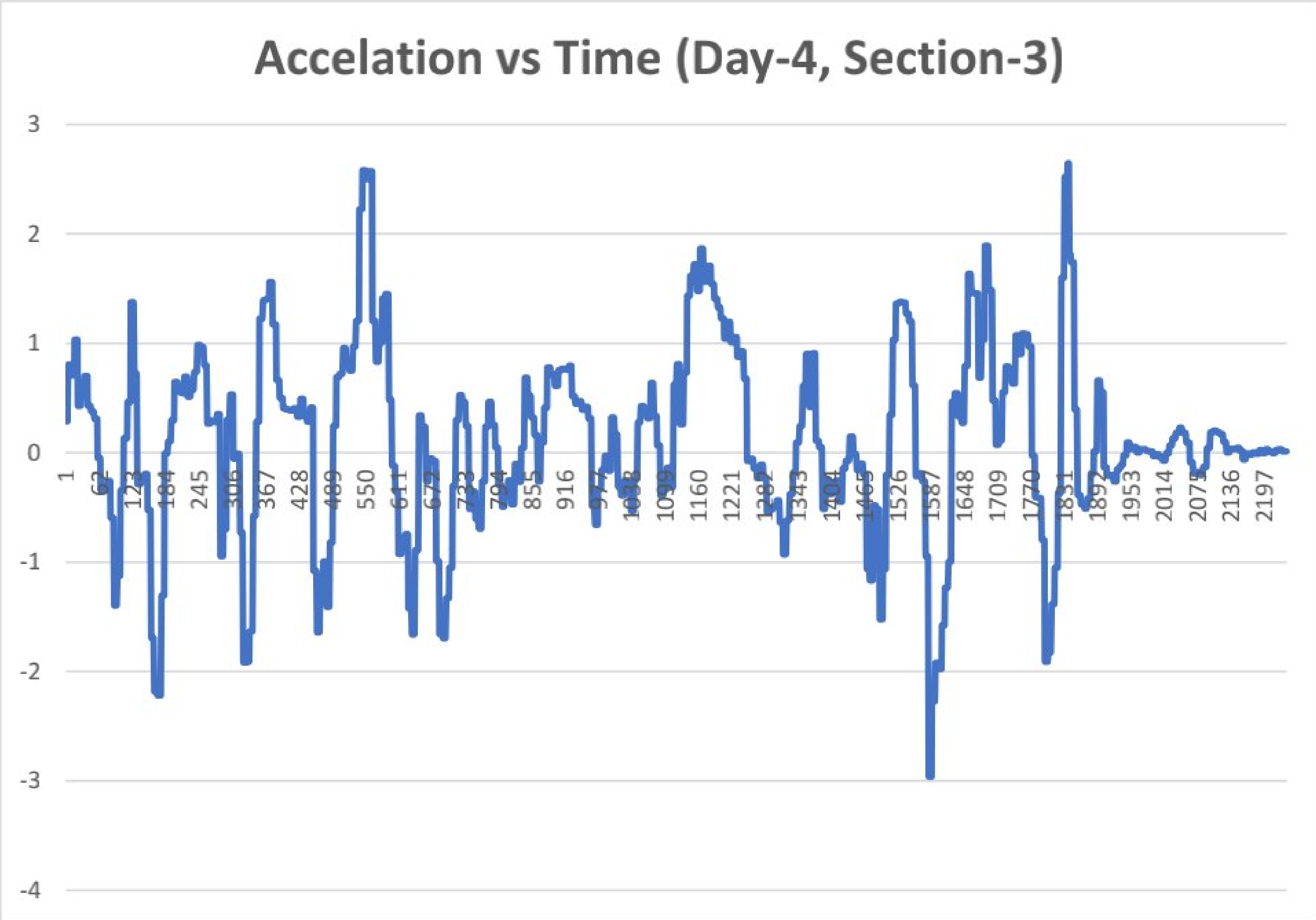


Figure 23: Acceleration Data from Smartphone (Day-4, Section-3)

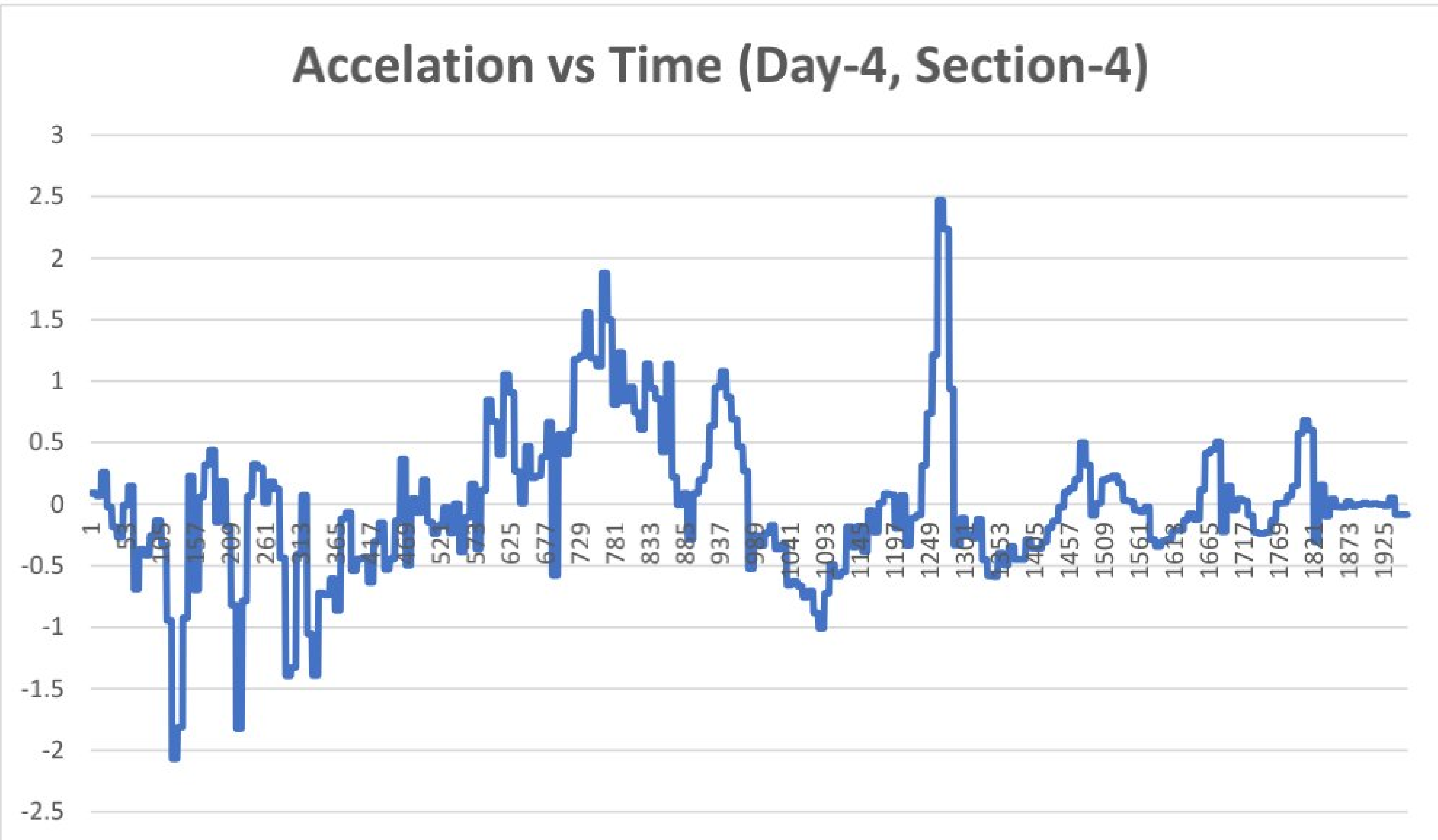


Figure 24: Acceleration Data from Smartphone (Day-4, Section-4)

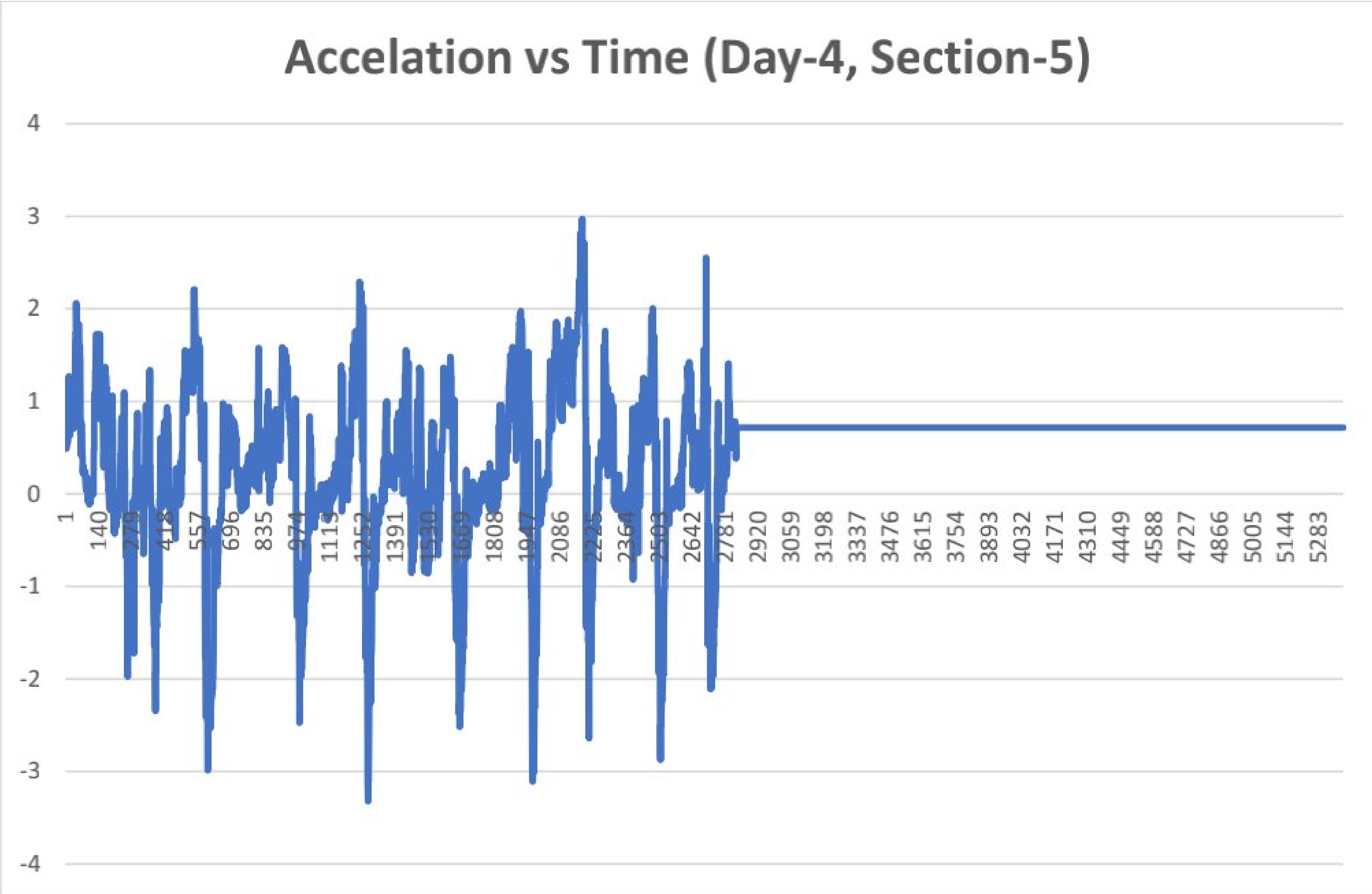


Figure 25: Acceleration Data from Smartphone (Day-4, Section-5)

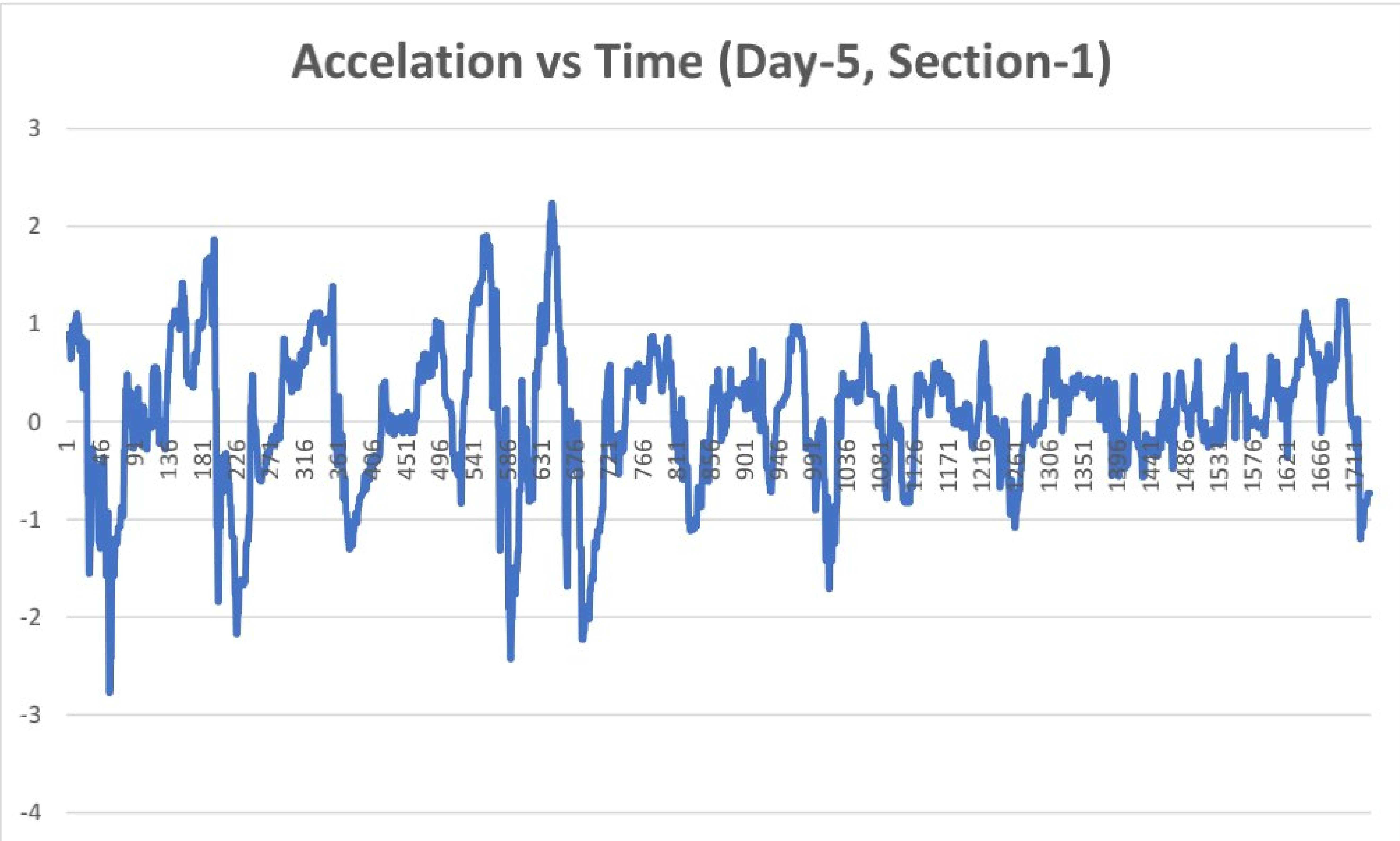


Figure 26: Acceleration Data from Smartphone (Day-5, Section-1)

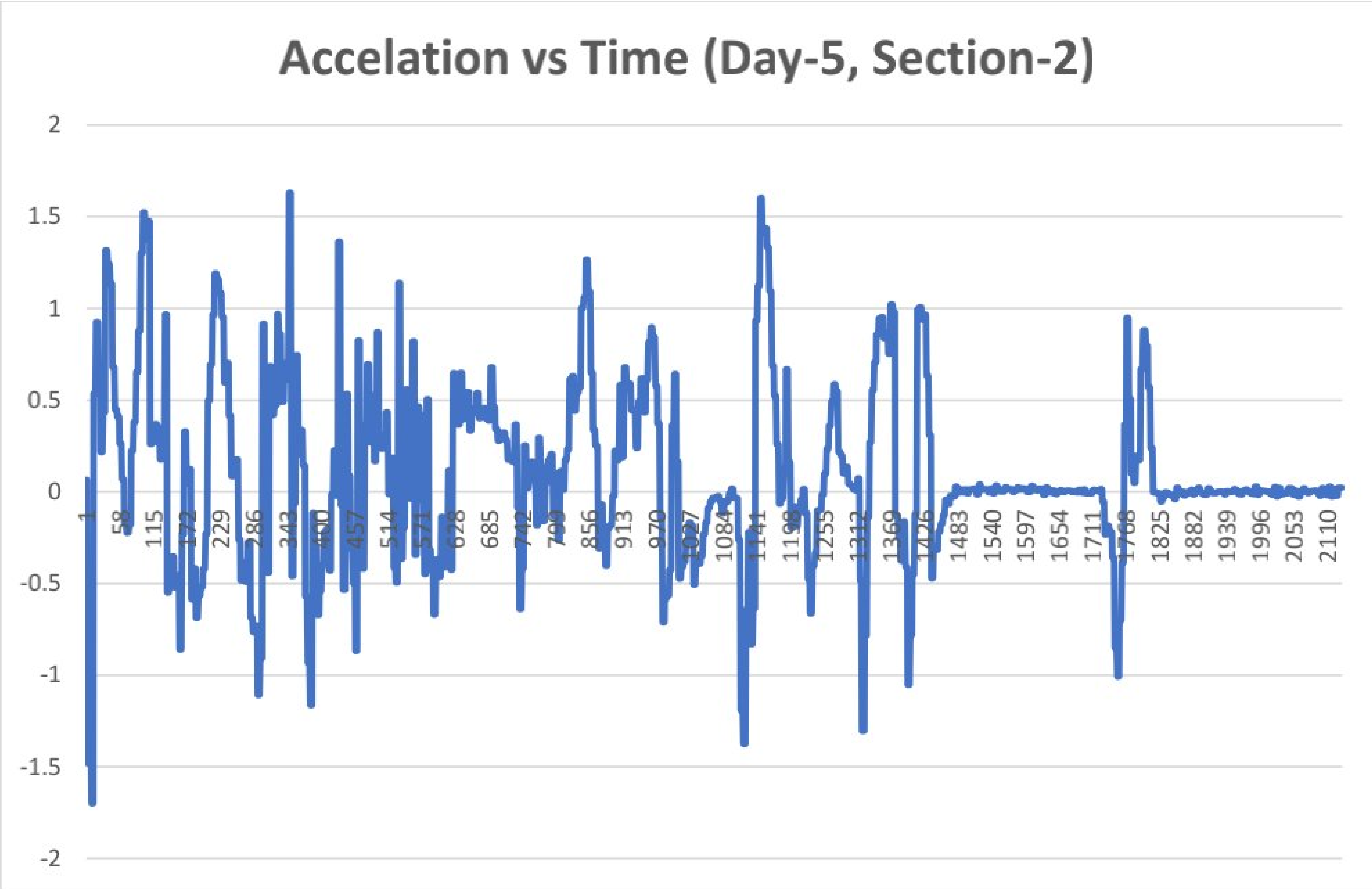


Figure 27: Acceleration Data from Smartphone (Day-5, Section-2)

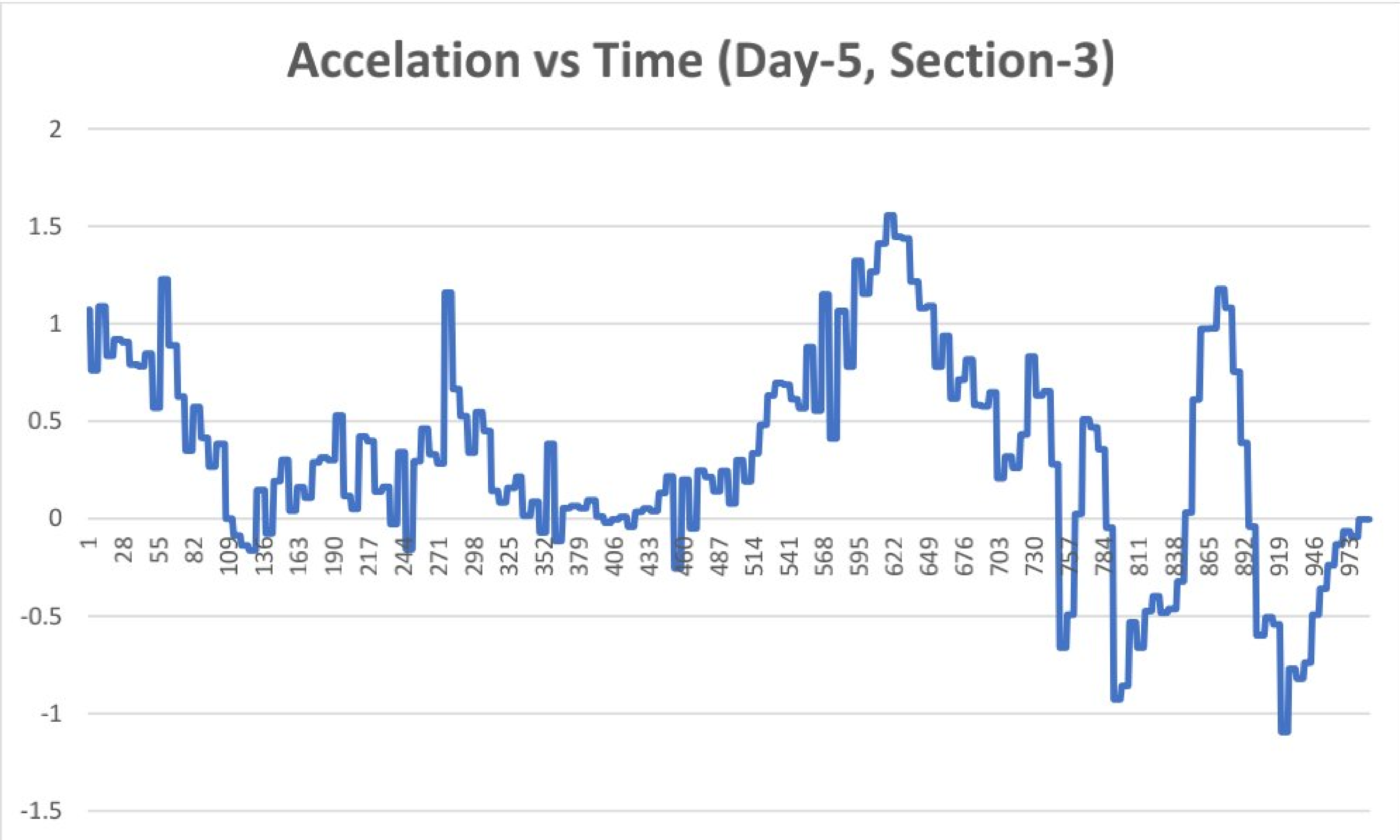


Figure 28: Acceleration Data from Smartphone (Day-5, Section-3)

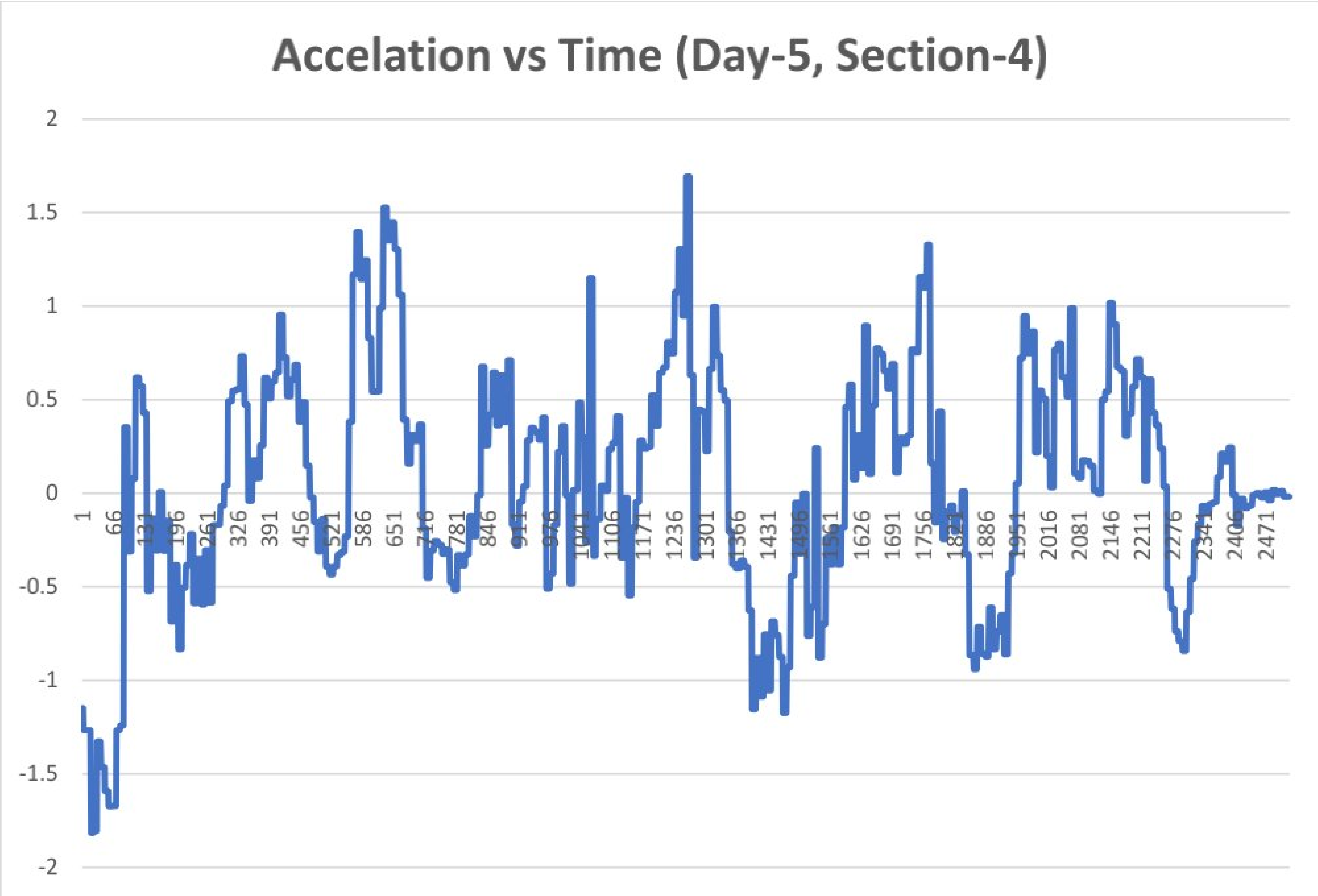


Figure 29: Acceleration Data from Smartphone (Day-5, Section-4)

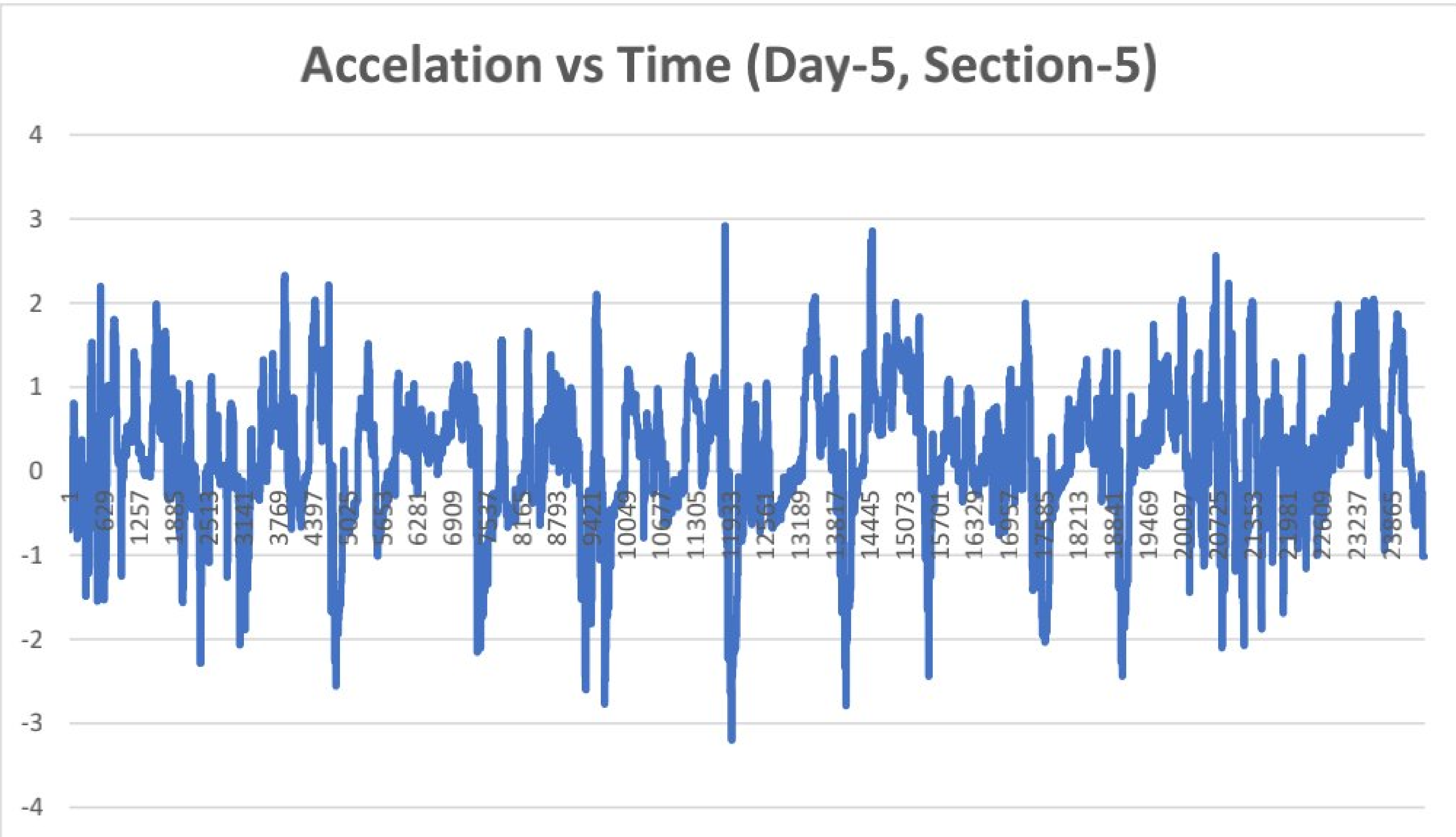


Figure 30: Acceleration Data from Smartphone (Day-5, Section-5)

4.6 Correlation between R.M.S and R.Q.I.:

Furthermore, R.M.S and R.Q.I relationship was investigated. The test's purpose elaborates the android based road distress can accurately reflect the public's comfort, which is referred to as ride quality (expressed by RQI).

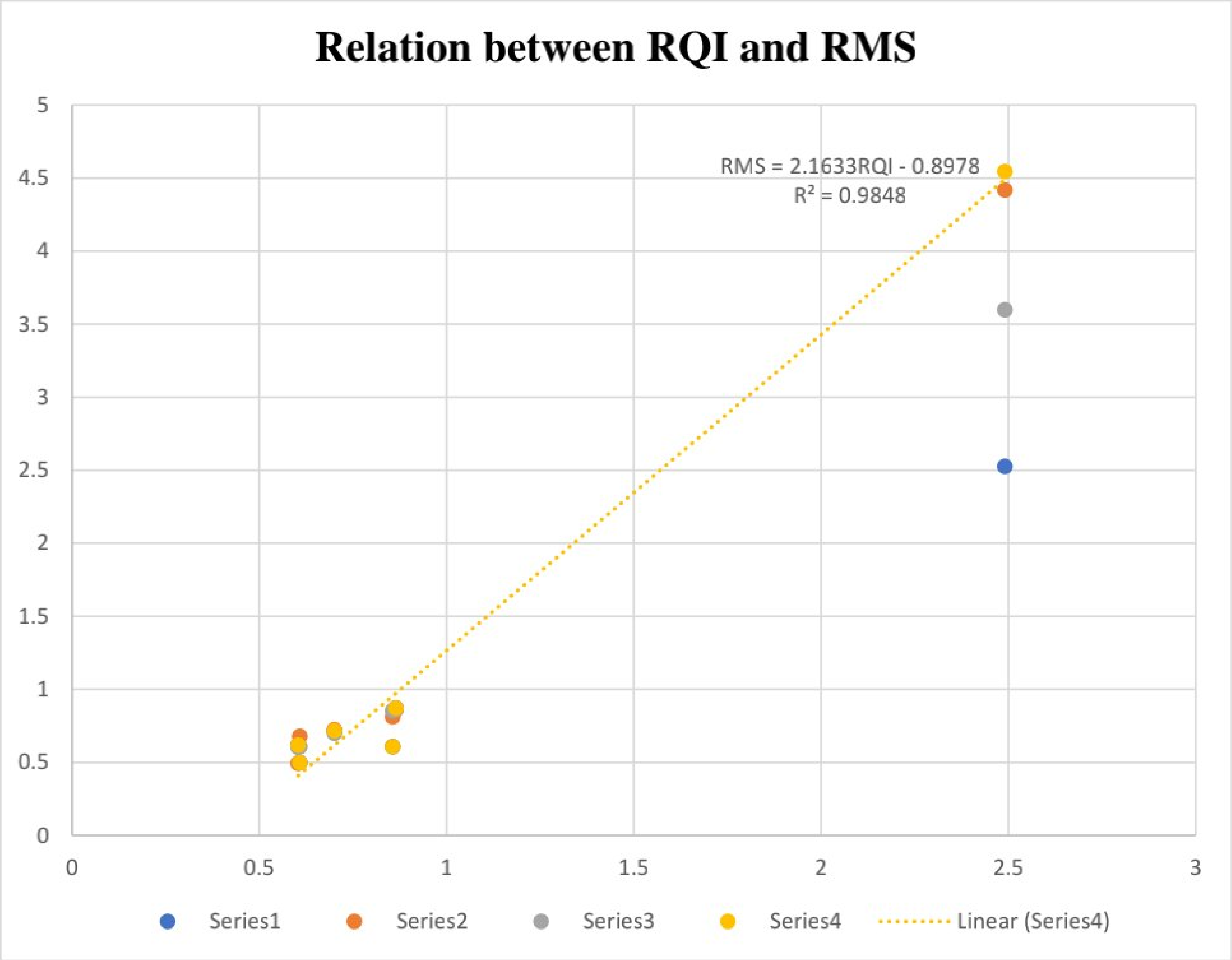


Figure 31: Correlation between RMS and RQI

From Figure 31, RMS has a strong relationship with RQI in the graph, and determination coefficient is 0.98. There is a logical trend of information and equation. The roughness index measured by smartphones is highly compatible with user perceptions of ride quality. That is, RMS may be used as a measure of real-world public opinion.

Android phones can be used to evaluate road surface with sufficient precision and accuracy. Not only are smartphone measurements strongly linked with IRI, but they also have a substantial association with the ride quality stated by travelers. The perception of users on the ride quality is the most important factor in determining the pavement roughness of a route. That is, the results produced from the smartphone accelerometer sensor can properly represent the actual pavement roughness in terms of the users' perception of comfort.

Chapter 5: Conclusion, Future Study and Recommendation

5.1 Conclusion

The analysis of data of pavement is the foundation of the pavement maintenance systems. Specialized automobiles facilitated by a variety of sensors have been generally used to automatically collect data on the roughness of the road surface which is costly to operate. A workable solution is the use of android phone with built-in accelerometer and G.P.S, which are cost-effective in collect the accurate data to calculate the road surface distress.

The main purpose is to establish the relationship between android based road surface distress and opinions of public. Raters' opinions on pavement condition had a good correlation (R^2 = 0.98) with road surface distress measured by android phone. It emphasizes that the road surface condition that is suited with public's comfort can be expressed by android phones. So, the road surface also can be measured by the android phones.

5.2 Future Study and Recommendations:

In Bangladesh, with a massive road network, growing traffic and capacity, and transportation funding limitations, the timing, and prioritization of pavement inspection and repair have been more essential. Pavement roughness data is a key factor for maintenance and rehabilitation planning, as well as overall pavement management, and has historically cost state agencies millions of dollars every year. A smartphone-based application will not only save millions of dollars in taxes but will also make data collection easier and may even allow for real-time International Roughness Index (IRI) evaluation and localized roughness detection in pavement sections.

In the future, the next step will be validating the road surface distress measured by android phones (for example, R.M.S) with accuracy. The road surface profiler (R.S.P), which indicates the International Roughness Index (IRI) of the pavement, may be used to obtain the ground truth.

Moreover, the correlation between RMS and PDI can be investigated. The purpose will be to see relationship between R.M.S and P.D.I.

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