COMPUTER SCIENCE AQA A-LEVEL NEA

EXERCISE DETECTION INVESTIGATIVE PROJECT

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# ANALYSIS

## Introduction

In an age of ever-increasing reliance on technology, with more and more people adopting a sedentary lifestyle, health and fitness have become an aspect that in many cases have become neglected. However, there is now an increasing pressure on governments and on society to change old habits of an unhealthy lifestyle, to a more active one.

Countless studies suggest that exercising not only improves physical health but also has a significant impact on improving mental health and relieving stress. One study suggests that those who exercised had 43.2% fewer days of poor mental health in a month than those who did not. [1]. This shows to us the importance of exercise, especially as one of the leading causes of death in the US and as well as for men in the UK [2] is heart disease, which can be preventable through exercise and a healthy diet.

Despite the majority of the public know the great benefits of exercising, only 63.3% of people aged over 16 consider themselves physically active doing 150 minutes or more of moderately intensive activity in a week, according to a UK government survey. [3] There remains a large portion of the public who do not exercise, for many different and respective reasons. Various reasons may include not having enough time during the day to exercise, finding a gym that is affordable or simply not having enough motivation to work out.

Whilst a large chunk of the population remains unactive, the proportion of the population, especially among young adults, who have access to mobile smartphones continues to increase. One study suggests, that for those aged 16-24 years old, roughly 99% of respondents say they have a smartphone, for those living in the UK [4]. This is a rather stark contrast to society just 10-20 years ago, where smartphones had barely begun to break into the common consumer market. This shows to us the commonality of smartphone nowadays and how much of the UK’s population use smartphones daily, especially younger people.

My objective in this NEA is to investigate how physical activities can be tracked and detected through a device’s onboard sensors. Furthermore, at the end of this project, I aim to have a working app that gives users the interface to access exercise recognition software, to help more young people become active through their mobile phones.

## Sensors Overview

Between devices, the physical hardware and sensors on a given device vary, depending on various factors. Over the past decade, the general progression of these sensors tends to improve over time as computational power increases with more and more devices receiving more and more sensors.

Before motion sensors were widely adopted in mobile phones, they were often used for devices such as Wii remotes, airbag deployment, aircraft, missiles, etc. During the period between about 2005-2012, the adoption of onboard sensors started to break through to mobile phones, most notably within Apple and Samsung phones. The very first phone with 3-dimensional movement recognition was the Samsung SCH-310 [5], with Apple’s first iPhone also using accelerometer technology [6]. Nowadays, it is expected of manufactures to have various sensors, including the gyroscope, accelerometer, and magnetometer.

As I am focusing my project on Android applications, I will mainly be discussing the sensors on a typical Android phone, rather than one on an IOS phone.

Accelerometer Sensor:

As suggested by the title an accelerometer is a part of the phone which measures the acceleration on a device on a three-axis reflecting real-world movement. These axes are in the x, Y, and Z direction.

The data provided by an event from an Android device is given in meters per second squared (unit for acceleration). This provides a force along the X, Y, and Z vectors. [7]

The accelerometer is often used to detect motion within a given axis, especially to measure the translation of a device.

I am in this investigation, to research more on how I can use the accelerometer to track the distance of a given motion exercise, like walking or treadmilling.

Sparkfun Triple Axis Accelerometer https://www.sparkfun.com/products/13926

Gyroscope Sensor:



GK10A MEMS die (oscillating plate) https://www.ifixit.com/Teardown/iPhone+4+Gyroscope+Teardown/3156

A Mechanical Gyroscope https://guide-images.cdn.ifixit.com/igi/nmNv4u3uHqZ5VNIR.large

A gyroscope measures the rate of rotation around the three axes, often known as yaw, pitch, and roll. [7] Early versions of a gyroscope included three spherical axes that span around a rotor, being able to rotate freely in three axes. The gyroscope nowadays in phones is much more compact and consists of a tiny vibrating plate in a chip that is pushed around and is detected by the device processor. [8] can be used for a variety of different applications for a mobile phone. The most common is determining the orientation of a phone, whether it is being held in landscape or portrait mode, which was first well utilized in Apple’s iPhone 4. [9]

To my investigation, I am more interested in how a gyroscope can be used to determine an exercise being done by a user. For example, when a user puts a mobile phone in their pocket and goes for a run, how can I use the data from the gyroscope sensor to determine whether the user is running, based on the rate at which the device rotates in a repeated pattern of harmonic motion.

Magnetometer Sensor:



First Magnetometer https://nationalmaglab.org/education/magnet-academy/history-of-electricity-magnetism/museum/magnetometer

The magnetometer is responsible for measuring the strength and direction of magnetic fields, often used to figure out the spatial position of a device in a given space. They utilize the Earth’s magnetic orientation to calibrate a given device to a specific position. [10]

It is often used as a device in spacecraft measuring magnetic fields and metal detectors. More specifically, mobile phones, it is used to help judge a device’s position, relative to the north pole of the Earth. [9]

In my investigation, I hope to be able to utilize the gyroscope as means to calibrate the device correctly to the north, as a reference to the direction of travel of a device. Furthermore, by using the gyroscope of a device in tandem with the GPS, I hope to be able to show how such data can be used to map out the exact route of an exercise (one which the user travels).

Global Positioning System Receiver:



Source: National Coordination Office for Space-Based Positioning, Navigation, and Timing

GPS is a radio navigation system developed and owned by the US government, which uses radio waves between satellites in space and receivers on a device to triangulate a device’s position on Earth. The original GPS used in earlier mobile phones required multiple satellites to pinpoint the position of a phone, which often took a lot of power and was often very slow as radio waves often became obstructed between satellites and receivers.

However, nowadays most mobile phones use AGPS (Assisted Global Positioning System), which is an improved version of GPS.

AGPS works by introducing data from cellular services and cell towers to “ping” the location of a device. This entirely depends on how many cell towers are near a device, but it is often quite reliable in triangulating a device’s position.

In tandem with the magnetometer, AGPS can be used to track the distance, location, and route of an exercise.

For Androids, this data is available through the Location data class, which has various attributes and methods, such as getSpeed, getLatitude, getLongitude etc. I aim to investigate this further and be able to manipulate such data in my Android app.

Camera Sensor

The camera sensors found within phones is a complex feat of engineering, refined through the decades. We started with cameras using light and physical films, to now being able to use digital cameras in our mobile phones.



Example of camera sensor – Techspot https://www.techspot.com/guides/850-smartphone-camera-hardware/

The sensors found within most mobile phones today works by using CMOS (complementary metal-oxide-semiconductor) technology. Photodetectors separate a given image into individual pixels and measure analogue information to determine a value for each pixel. As there are millions of these photodetectors on the sensor, real-life images can be replicated digitally by stitching up the respective pixels into one single image. The role of the lens is to focus light onto the area of the sensor so that images are crisp and clear. [11]

For my investigation, I will focus on how we can use a camera on a mobile phone to detect patterns in the live image data to determine what exercise is being performed by the user. This will help me to understand the realm of computer vision and how we can make computers become able to recognise patterns within data.

Six degrees of freedom:

In my research of these sensors, one concept that kept being mentioned was the notion of 6 degrees of freedom. This is the idea of combining both translation and rotation in all 3 dimensions, to make a rigid body freely move in a given space. [12]



By GregorDS - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=38429678

It is by using the gyroscope and accelerometer in person, that a mobile phone can fully track the exact movements and rotations that a user makes with a mobile device. Furthermore, I hope to be able to use this idea of 6 degrees of freedom in my investigation, to make exercise detections more accurate and defined.

It is due to all these various sensors, that we can now use algorithms to track and trace various activities and I hope to be able to use them as part of my investigation in exercise detection.

Pedometer Algorithms

A pedometer is a simple device that combines the sensors mentioned above into a single device. A usual pedometer will output a basic user interface, displaying the step count with functions to reset the step count etc. Despite the simplicity, there is much more to a pedometer than meets the eye, especially concerning the algorithms which determine the number of steps.



A digital Omron HJ-112 pedometer

As mentioned before, the accelerometer measures acceleration within 3 dimensions (x, y and z) so to count the steps that a person takes we have to consider whether they are moving in the z-direction, bounces in the y-direction and if the phone maintains orientation throughout the walk. [13]

Furthermore, we can plot the acceleration in the y axis of a typical person walking onto a graph. In a perfect scenario it would look like this:

A graph of acceleration in the y axis over time of someone walking https://www.aosabook.org/en/500L/a-pedometer-in-the-real-world.html

What makes a step a distinct step is whether or not at any point the acceleration in the y-direction reaches a peak. In this case, as we can see three peaks, these are three steps.

Alternatively, we can consider the number of troughs. Similarly, this represents the point at which the person decelerates in the y axis (when their body accelerates downwards towards Earth when taking a step.)

Mathematically, the acceleration graph of a perfect step can be modelled as a sine graph.

Total acceleration consisting of user and gravitational. Figure 16.4 Component Signals - https://www.aosabook.org/en/500L/a-pedometer-in-the-real-world.html

Another thing to note is how the raw data from the accelerometer sensor is a combination of both the user acceleration and the gravitational acceleration of the Earth. To get a more accurate graph of the user acceleration, we must take away the factor of gravitational acceleration from the total acceleration.

In producing a working pedometer algorithm to measure steps, I will need to consider some sort of filtration which can determine the gravitational acceleration and remove this to output the user acceleration for analysis. Furthermore, I will need to research more about 3-D space and vectors, especially on using dot product in comparing the magnitude and direction of the user’s acceleration.



http://datahacker.rs/dot-product-inner-product/

## Exercises and Activities

There are many different exercises and activities out there. From within Google Fit’s activity tracking app alone, there are over 50 different types of activities that can be recorded on their app. Some can be easily tracked, whereas others are harder to detect by Google’s algorithm. For example, Google Fit can easily detect and track someone going for a run, with the specific step count, distance etc. However, when it comes to tracking activity such as rowing, Zumba or even scuba diving, this becomes significantly more complex.



Some Activity types found within Google Fit

For simplicity’s sake, I will split the different types of exercises into two main categories: aerobic exercise, and strength exercises. For aerobic exercises, these are ones in which motion is needed, and the use of the accelerometer, gyroscope and GPS is required.

For strength exercises, these are activities such as push-ups, planks and pull-ups. I aim to use the camera sensor on a mobile device and MLKit Vision Library by Google for computer vision and detection of poses/exercises. As MLKit Vision does not entirely provide exercise detection immediately, I may have to develop a simple computer vision algorithm, geared towards exercises.

## Current Market and Applications

In the current market, various businesses and competitors offer a wide assortment of fitness and exercise apps. Some include activity and exercise tracking, whilst others simply display exercise for people to follow. Here are some of the most noticeable apps:

**Leap Fitness Group / ABISHKKING LIMITED.:**

Currently, as of 2021, one of the most common and prominent companies producing fitness/health apps in Android and IOS platforms is the “Leap Fitness Group”. Their apps have a consistent design, UI, and theming that makes them recognizable, especially amongst the Google Play Store. Furthermore, they do not have a niche market, but produce apps that are wide-ranging with various activities and demographics – there is always an app made by them that covers the wide appeal of the general public. They have millions and millions of downloads.

This incentive of producing as many apps as they can for fitness/health be one of the reasons why they are so successful in the Google Play Store because they can cover so many different aspects of fitness and exercise. From this, they use advertisements and monetization to gain profits.



Apps by Leap Fitness Group on the Google Play Store https://play.google.com/store/apps/developer?id=Leap+Fitness+Group&hl=en\_GB&gl=US

|  |  |
| --- | --- |
| Advantages | Disadvantages |
| Able to cover a wider audience and hitting every part of the market demographic, whether male or female, strength, or fitness etc.  All apps are free to install for users and can run on most Android versions.  Apps normally include a large range of exercises that people can choose from. Includes tracking information such as calorie burn, in each exercise done. Text to speech directions is also included for exercises.  Most of their apps receive 4.4+ out of 5 ratings, so is a reputable fitness app company. | App experience does not feel unique between apps, so it feels like they have been copied and pasted.  Too many apps in production and development mean it may be hard for the company to manage.  Updates and resolving issues in apps may be slow, causing a bad user experience.  Users may get annoyed at ads being featured in their menus unless they purchase a pro version that removes the ads. |

**Google Fit:**



Google Fit App by Google LLC on the Google Play Store https://play.google.com/store/apps/details?id=com.google.android.apps.fitness&hl=en\_GB&gl=US

Google Fit is a widely used tracking app that mainly focuses on detecting what activity you may have done. The app displays to users their step count, their activity history, calorie burnt as well as data from other devices, such as smartwatches.

Google fit is very well integrated with Google Play Services, through Google’s Fitness API. This API is easily accessed by developers who also want to extract and use data from a person’s device for their android app, or certain web applications.

|  |  |
| --- | --- |
| Advantages | Disadvantages |
| Google Fit is well integrated into Android, and especially Google services, so all data is available through the cloud.  Tracking algorithms are surprisingly accurate and may even detect what type of activity you are doing without the user’s input.  Google Fit API can be easily used by other apps to update the user’s activities on their Google account.  Receives regular updates and support from Google’s developers, leading to a generally good user experience. | Only serves as the main storer of data and tracking, rather than giving user’s exercises to follow etc.  Most common for Android users to use this, as Apple users are more likely to use Apple Fitness+ for their fitness tracking. |

## Third-Party Feedback

My third party will be focused on young people who are generally fit and able to do exercises. Here is a list of subjects who have agreed to give me feedback throughout this course:

**Joey Hui, 31 Male**

Joey Hui is currently job-searching for jobs within London. He previously has experience in the fashion sector and worked for a tailor. Now he is looking to enter the IT sector and learn programming languages.

Here is a little background to Joey’s workout routine:

I exercise 5 to 6 times a week at Pure Gym Finchley, however I am flexible if I feel I am too fatigued, I will rest more.

I prefer exercising in a place other than the home because this helps me concentrate during my workout, and the equipment required for a good full body workout would be unfeasible for the home.

I mainly do a bodybuilding style workout and train every muscle. My aim is to grow so I usually choose a light manageable weight and do higher repetitions, focusing on maintaining good technique and a mind-muscle connection. As I become more familiar with an exercise, I gradually increase the weight I use whilst maintaining good technique/form. If the weight is too heavy to maintain good form, then I will reduce the weight until my body has grown to a point that it can handle more.

Joey’s workout routine can be found at appendix 1.

Key takeaways from Joey’s workout routines/fitness:

1. For Joey, exercising is a big part of his daily life and can be considered to be the upper quartile of people, exercising more than the average person.
2. Joey values muscle strength training over cardio.
3. Naturally, fatigue is the biggest hurdle for Joey, especially as he exercises 5 to 6 times a week.



I usually start with running followed by a mix of either upper body or lower body weight training. My workouts include cardio, weights. i.e., running, weights, squats, deadlifts, and leg extensions.

I exercise because since I sit at home majority of the time, it makes me feel mentally/physically better if I exercise. I have felt the health benefits of exercising as I never used to which is why I try to exercise (although not as often now)

I don’t exercise as much as I used to mainly because I don’t commute into the office anymore. Before, there was a gym near my office, so I’d go there before going to work. But since working from home the gym is a bit further for me, so I don’t go as often.

**Keziah Zhou, 28 Female**

Keziah Zhou is a full-time support Engineer at a finance firm. She has over 5 years experience working in the technology and finance sector.

Here is a little background to Keziah’s workout routines:

I exercise 1-2 times a week and usually in the evening at either 6pm or 8pm (normally after dinner). I go to the gym to exercise because there is more space and equipment and I feel more motivated if I’m at the gym compared to at home.

Key takeaways from Keziah’s workout routines/fitness:

1. Keziah values overall fitness over gaining muscle strength, including how exercising helps her mental health.
2. Keziah’s biggest hurdle in exercising is being busy with other things, as well as finding the motivation to exercise.
3. Finding a suitable place to work out is another hurdle, as the home may not be the ideal place to exercise, considering how much space a person has, as well as having the right equipment.

## Prototyping and Spiking

For my investigation, I aim to be able to apply my findings from exercise detection, into a working Android app. To do this, I must first learn how to code an Android app from scratch. Because of the wider documentation, I will aim to use Java in my final project, thus I need to learn Java.

I also aim to include a client-server model to parse data to and from devices, thus I will need to learn SQL and how to implement SQL into a Java program. This will most likely mean I will have to use an API of some sort to do this.

Android Development Spiking:

As I have had no previous experience in programming in Java as well as Android Studio, I will learn all of this from scratch. Thanks to freeCodeCamp.org I followed their comprehensive Android App Development course to learn both Java and the workings of Android.

These are some screenshots of my very first applications which were basic and used basic Java logic as well as basic XML code.



Prototyping with Android Sensors:

As previously mentioned, data from an android device is available through sensor events of each sensor. Depending on the sensor type, there were a few values that can be extracted. For example, the accelerator type has sensor event data as three values within the SensorEvent.values array.



Motion sensors supported by the Android platform https://developer.android.com/guide/topics/sensors/sensors\_motion

However, the SensorEvent.values array for the uncalibrated accelerometer had 6 values, which also held data about drift (Drift is when the gyroscope sensor values change despite being stationary). As I have had no previous experience using these sensors, I thought I should develop a simple app using the gyroscope and the accelerometer sensors to test them out.

Text

Description automatically generated

Firstly, I tested out the gyroscope sensor with the help of a YouTube video. I had to create three main objects, the gyroscope of class Sensor, the sensorManager of class SensorManager and the gyroscopeEventListener of class SensorEventListener.

The sensor manager acts as the main interface between the application and the sensors. It allows an application to access a sensor, controlling the registering and unregistering of a sensor.

The SensorEventListener allows us to detect and manipulate data from a sensor. Whatever motion is detected is stored as a certain event and it is the role of the SensorEventListener to detect this.

In combination with all these three objects, we can override the method onSensorChanged in the event listener to act. In this simple application, I’ve made it so that when the user rotates to the left (in the z-axis) the background will turn blue. When the user rotates to the right (in the z-axis) the background will turn yellow. As an indication of data, I have also made it to print out the float value from the gyroscope sensor to the screen as a TextView.

Interestingly, this data from the gyroscope sensor is recorded as radians per second, which means that I will have to work with radians rather than degrees. Another thing for me to note is that the sensor values for the gyroscope are available in 3 dimensions (SensorEvent.values[0], SensorEvent.values[1], SensorEvent.values[2]), so I will need to grasp the concept of 3-dimension rotation.

Furthermore, if I were to use the uncalibrated gyroscope sensor, I will need to consider drifting and how to counteract that to improve accuracy.

Text

Description automatically generated

I created a similar application to the gyroscope prototype but using the accelerometer. Like before, I had to create three objects and a TextView to help visualise the live data that was coming through the sensor. In the case of the accelerometer, I wanted to just measure the acceleration in the z-axis. When the phone was still on a flat surface, the accelerometer measured roughly 9.8, which is the force of gravity on the phone. Then when I moved the phone up and down, the values quickly shifted in the positive and the negative, reflecting how the phone was accelerating.

Here is a video demonstrating both the simple gyroscope and accelerometer app:

<https://youtu.be/ZrCl8taJ7SY>

An API, stands for application programming interface, to allow a developer access to data without the need for a developer to necessarily know all how this data is formed, etc. API gives way to the abstraction of needing to program everything from scratch.

During my analysis of current fitness applications, Google Fit stood out to me, as they provided developers with their dedicated fitness API, specifically for app developers. As I have not dealt with APIs before, I wanted to learn more about APIs in general, so that I could test out their Fitness API so I could have a rough idea of how to approach developing a fitness app. Furthermore, the method of how Google detected steps and activities intrigued me, because of how easy it seemed for a developer to extract such information from the API.

<https://www.youtube.com/watch?v=GZvSYJDk-us&ab_channel=freeCodeCamp.org>

First use of API through the command line, sending a text message from a phone to another phone via SMS, using Twilio.



By using the curl code provided by Twilio, I was able to send a message from the Twilio phone to my phone, via Twilio’s SMS API, as a POST request.

## Objectives and the Critical Path

**Investigation and Further Research:**

1. Investigate methods in which data from a camera sensor can be used to track and detect exercises. In doing this, I should research more about the MLKitVision library and experiment with basic computer vision.
2. Investigate methods in which data from the accelerometer and gyroscope sensors can be used to detect moving exercises, such as running and walking. I should research more on calorie specifics and how to calculate calories burnt.
3. Investigate more on the different exercises that my third-party users do, that I should include in my detections, i.e. pull-ups, sit-ups, bench presses etc. I should try to find patterns in those exercises as well as research calorie usage, intensity etc.
4. Investigate more on how to implement a GPS tracking system in an Android app, so that when a user tracks an exercise that is not static to one location, the distance and specific route can be tracked.

**Pedometer Algorithm:**

1. Implement and develop a pedometer algorithm in Java, that has at least a 90% accuracy rate in tracking the step count of a mobile phone during a brisk walk.
2. Within this algorithm, it should consist of three main parts: filtering out the raw data into the specific data from the accelerometer, analysing the data to use mathematical comparisons and calculations (such as dot product) and post-processing, to output the data in a streamlined way to the user.

**Android App:**

1. Produce an Android app that applies my findings from exercise detection algorithms, in a way that is user friendly for them to use, whilst also being able to efficiently run on most Android devices.
2. This app should have a modern/minimalistic user design, suited more for young adults. The interfaces should also be simple and easy to use, whilst adhering to Material Design and possibly Material You (Android 12+)
3. Introduce a client-server model for my Android app so that information about exercises can be accessed through a database (i.e. step counts, calories burnt). This will most likely be using SQL, and a JSON file to parse information between the client and the server. Such information should then be displayed within the app within the menu of the app.
4. Within the app, there should be a scrollable menu with different types of exercises that the user can track. Once an exercise is selected, there should be a counter interface to display live information about the exercise and the duration of the exercise.
5. Once an exercise is complete, the information such as duration, calorie burnt, and distance (where applicable) should then be sent as SQL to a database and updated, so that information is not stored on the device itself, but rather on a server.
6. Get proactive feedback from my third party on exercise specific queries as well as eventual user design of the app, to ensure that my investigation remains focused on my objectives and that the project satisfies the needs of my users.

**Critical Path:**

# DESIGN

## Pedometer Algorithm

## GPS Tracking

## Computer Vision and MLKit Library

## Database Design

# TECHNICAL SOLUTION

# TESTING

# EVALUATION

# APPENDIX

#### Joey’s Workout routine

Monday Db shoulder press Military press Lateral raise Reverse peck deck Leg press Pin squats

Tuesday Pull ups Lat pull down Seated row Deadlift Leg curl Lat pull overs

Wednesday Bench press Peck deck Squat Leg extension Adductors machine Ez bar bicep curls

Thursday Deadlift Military press Incline bench press Dumbell chest press Lateral raise Tricep extensions

Friday Bent over rows Lat pull down Lat pull overs Hip thrusts Abductors machine Preacher bench 21s

Saturday Rest day

Sunday Tricep extensions Overhead tricep extensions Seated bicep curls Skull crushers Preacher bench 21s Dumbell bicep curls

# REFERENCES

|  |  |
| --- | --- |
| [1] | “Association between physical exercise and mental health in 1·2 million individuals in the USA between 2011 and 2015: a cross-sectional study,” [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/30099000/. [Accessed 12 August 2021]. |
| [2] | Office for National Statistics, “Leading causes of death, UK: 2001 to 2018,” [Online]. Available: https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/causesofdeath/articles/leadingcausesofdeathuk/2001to2018. [Accessed 30 July 2021]. |
| [3] | GOV.UK, “Physical Activity,” [Online]. Available: https://www.ethnicity-facts-figures.service.gov.uk/health/diet-and-exercise/physical-activity/latest. [Accessed 30 July 2021]. |
| [4] | “staista,” [Online]. Available: https://www.statista.com/statistics/956297/ownership-of-smartphones-uk/. [Accessed 30 July 2021]. |
| [5] | Phys Org, “Samsung Introduces World's First '3-dimensional Movement Recognition Phone',” [Online]. Available: https://phys.org/news/2005-01-samsung-world-dimensional-movement-recognition.html#:~:text=0-,Samsung%20Introduces%20World's%20First%20'3%2Ddimensional%20Movement%20Recognition'%20Phone,%22%20mobile%20phone%20SCH%2DS310.. [Accessed 23 August 2021]. |
| [6] | cnet, “Motion Sensing Comes To Mobile Phones,” [Online]. Available: https://www.cnet.com/tech/mobile/motion-sensing-comes-to-mobile-phones/. [Accessed 23 August 2021]. |
| [7] | Android, “Sensor Types,” [Online]. Available: https://source.android.com/devices/sensors/sensor-types. [Accessed 24 August 2021]. |
| [8] | ifixit, “iPhone 4 Gyroscope Teardown,” [Online]. Available: https://www.ifixit.com/Teardown/iPhone+4+Gyroscope+Teardown/3156. [Accessed 23 August 2021]. |
| [9] | Gizmodo, “All the sensors in your phone and how they work,” [Online]. Available: https://gizmodo.com/all-the-sensors-in-your-smartphone-and-how-they-work-1797121002. [Accessed 24 August 2021]. |
| [10] | Britanica, “Magnetometer,” [Online]. Available: https://www.britannica.com/technology/magnetometer. [Accessed 24 August 2021]. |
| [11] | Techspot, “Know Your Smartphone: A Guide To Camera Hardware,” [Online]. Available: https://www.techspot.com/guides/850-smartphone-camera-hardware/. [Accessed 24 August 2021]. |
| [12] | Techopedia, “Six Degrees of Freedom,” [Online]. Available: https://www.techopedia.com/definition/12702/six-degrees-of-freedom-6dof. [Accessed 25 August 2021]. |
| [13] | aosabork.org, “A Pedometer In the Real World,” [Online]. Available: https://www.aosabook.org/en/500L/a-pedometer-in-the-real-world.html. [Accessed 14 09 2021]. |
| [14] | CDC, “NCHS Data Brief, Number 359, December 2020,” [Online]. Available: https://www.cdc.gov/nchs/data/databriefs/db395-H.pdf. [Accessed 12 August 2021]. |

GitHub repository:

<https://github.com/calebchan1/ALevelNEA>