Skatrixx

Prototyping a sensor system that helps amateur athletes gain insight into their skateboard tricks.

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Preface

The following is the final report for my internship at Urban Sports Performance Centre under the supervision of Fontys University of Applied Science. In this report, the progress of my internship project will be discussed. I will discuss my contribution to the Skatrixx project, a portable sensor system that measures and calculates speed, rotation, and airtime. A communication system was also required, preferably via a Bluetooth connection to a mobile app to be able to send the measured data to be visualized for the skateboarder.

The Urban Sports Performance Centre (USPC) is the knowledge and innovation centre for Urban Sports in Eindhoven. The mission of the USPC is to take urban sports to a higher level and make them more attractive through the use of knowledge, innovation, and technology. In this way, the USPC also contributes to the ambition of the partners in Brabant to organize urban events, structurally professionalize urban sports and make it available for social activities, and help urban athletes and their trainers and coaches with top sport and talent development.

Glossary

Terms list	Definitions
USPC	Urban Sports Performance Centre
IoT	Internet of Things
GPS	Global Positioning System
IMU	Inertial Measurement Unit
MPU	Motion Processing Unit
SDA	The line for the master and slave to send and receive data.
SCL	The line that carries the clock signal, synchronizing master and slave clock.
I2C/I²C	A communication protocol, that transfers data bit by bit through a single wire (SDA)
PCB	Printed Circuit Board
Ollie	A skateboarding trick where the rider and board leap into the air without the use of the rider's hands.
Kickflip	A maneuver in which the rider flips their skateboard 360° along the axis that extends from the nose to the tail of the deck
shove it	A trick where the skateboarder makes the board spin 180 degrees

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Summery

This internship project is accomplished at the Urban Sports Performance Centre, a nonprofitable organization that helps develop and attract people to urban sports, using technology innovation and knowledge.

Currently, the USPC has developed a prototype of the project SenSkate, a skateboard with mounted sensors that helps an embedded scientist or a trainer monitor the urban athlete while doing skateboard tricks. This project has a specific target group, professional skateboarders that can afford to buy the skateboard. Therefore, project Skatrixx started to be a simplified and more affordable version of SenSkate for the normal skateboarders, to help them gain insight into their tricks. Project Skatrixx should be a sensor system that calculates speed, rotation, and airtime; then send the data to a mobile phone application through Bluetooth.

The research before the start of this project concluded that the project is feasible, thus the first step was to create a proof of concept. The investigation and research done throughout this project have resulted positively regarding the research questions ”can a sensor system that obtains data on rotations, speed, airtime and has a way of communicating with a mobile application be developed?”.

Based on the research that took place during the start of this project, the following was concluded and implemented:

- The master controller will be an Arduino nano33 IoT
- The sensor used will be MPU-9250 9-axis IMU
- Calculations of speed took place based on data from accelerometers
- Calculations of rotation took place based on complementary filtered data extracted from accelerometers and gyroscopes
- Calculations of rotation around the Z-axis took place based on data from magnetometers.
- Airtime is calculated based on functions and subfunctions that are alerted to jumping and landing which is determined based on the data from accelerometers.
- The placement of the system will be at the bottom, in the final product placement will be in the form of a riser pad. However, for this prototype, it will be mounted on the bottom with specially designed holders.

Finally, the sensor system was tested multiple times and was proven to accurately calculate different types of rotations. Speed tests took place by mounting the system to a moving car and accurately measuring the speed of the car’s speedometer.

Introduction

As the world advances, the usage of technology becomes common in all daily interactions. Also, technology integrating into sport's practice and competitions are becoming normalized. From athletic monitoring systems to goalball technology in football, the main goal is to enhance the sport by either gaining more information or trying to make the competitions more accurate.
The urban sports community is huge and is growing rapidly. Thus, getting more attention, especially given the fact that some urban sports are now in the Olympics. Organizations like USPC have the sole goal of lifting urban sports to a professional level by helping urban athletes improve their performance and making the sports more attractive. Using knowledge, technology, and innovations, the USPC invests in projects such as injury prevention projects, time registering systems for free runners, and sensor systems for skateboarders, all to support urban sports and athletes in all aspects.

Inspired by projects that include high-tech sensor systems to help athletes improve their tricks, USPC launched the project SenSkate [1]. SenSkate is a skateboarding project, intending to create a skateboard connected to a monitoring system. Using sensors that allow embedded scientists and coaches to gain insight into the athlete's performance throughout the screen of a PC. Thus, allowing professional skateboarders to improve their foot placement, timings, and performance in general guided by their coach's instructions.

Although SenSkate can be used by all skateboarders, it's not popularly priced and it requires an embedded scientist or a coach to monitor the movement of the athletes, therefore not affordable to non-professional athletes. In the spirit of making skateboarding more attractive and making SenSkate more reachable, a simpler version of SenSkate is to be developed, thus the birth of the project Skatrixx. The first step in the Skatrixx project was in collaboration with Capetech in Belgium, a feasibility research was done to decide whether or not the project was feasible. Once the research was done with the positive conclusion that the project is feasible. USPC started looking for interns to develop a proof of concept and a working prototype for project Skatrixx.

The company

Urban Sports Performance Centre (USPC)

The Urban Sports Performance Centre (USPC) is an independent knowledge and innovation centre for urban sports and has the mission to lift urban sports to a higher level and make them more attractive by using knowledge, innovation, and technology.

The USPC helps professionalize urban sports by:

- Helping clubs, teams, federations, trainers, coaches, and athletes with elite sports and talent development.
- Offering various types of training.~~,~~ for athletes, technical staff, and policymakers.
- Making urban sports structurally deployable for social activities.
- Developing innovative products for use in urban sports (both in elite level and recreational sports).
- Contributing to innovations that strengthen urban sports events.

The strength of the USPC is the combination of its network and knowledge about urban sports, technology, and sports support (from elite sports to physical activity). The USPC works together with several sports associations, knowledge institutions, companies, municipalities, and other social organizations. The USPC is an innovation partner of BrabantSport and TeamNL Centre South (accredited by the Dutch Olympic Committee).

The USPC is an integral part of the foundation InnoSportLab Sport & Beweeg and is located in Area51, the recently completely renovated multi-urban indoor sports park in Eindhoven, also home of the TeamNL BMX freestyle team. The mission of InnoSportLab Sport & Beweeg is to realize innovations that make sport and exercise common for everyone. Within that objective, the USPC focuses on urban sports.

The core of the USPC team consists of a lab manager/business developer, an embedded scientist (movement scientist), and a communication professional. The project also utilizes project leaders/researchers of InnoSportLab and structurally several students (10+) of various disciplines (HBO+) are involved.

Harmen Bijsterbosch
lab manager

Raymund ten Broek
Embedded Scientist

Maureen Pennings
Communication employee

Project overview

User requirements

User requirements	MoSCoW Status
A first prototype	Must
Sensor system	Must
Reading acceleration	Must
Reading rotation	Must
Calculates average speed	Must
Communication to a phone app	must
User-friendly placement	Must
Calculate airtime	Must
The sensor attached to the bottom face of the skateboard	Must
Communication via Bluetooth	Should
height of jump	Should
Calculate skating time	Could
Creating phone app	Won't
Creating final product	Won't

System requirements

System requirements	MoSCoW Status
IMU sensor	Must
A power source (battery)	Must
Master controller	Must
Calculating rotation	Must
Measure airtime	Must
Calculating speed	Must
Easily placed on a skateboard	Should
Bluetooth module	Should

Research question

The main research question of this project is “can a sensor system that obtains data on rotations, speed, airtime and has a way of communicating with a mobile application be developed?” Throughout the research phase, the research question was broken down into more detailed oriented sub-questions, that If researched well enough, the main research question shall be answered.

Sub-questions

- What type of sensors should be used?
- What 9 axis sensor should be used?
- What microcontroller should be used?
- What is the way of communication between the system and the user's phone app?
- How to calculate the rotation around the 3 separate axes?
- What is the best placement of the components?
- What type of power supply should be used?

Project's approach

V-model:

The v-model Figure 1 is an iterative design method for software development (SDLC), that will be used only for the creation of the proof of concept.

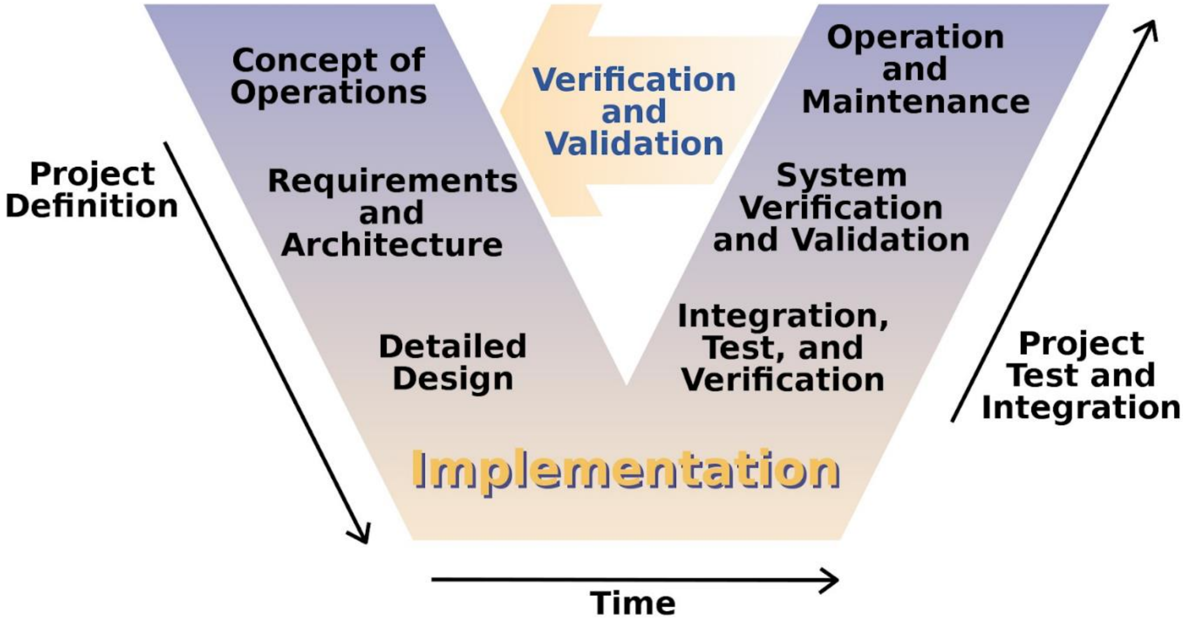


Figure 1

Agile Scrum:

Agile Scrum Figure 2 methodology is a project management system that relies on incremental development. Each iteration consists of two- to four-week sprints, where each sprint's goal is to build the most important features first and come out with a potentially deliverable product.

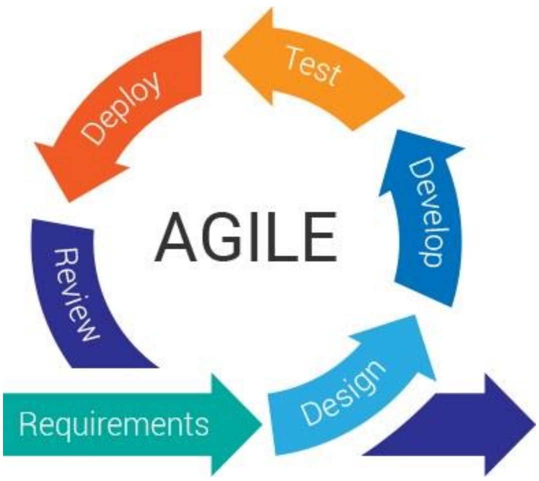


Figure 2

Research and Testing

Research subjects

Type of sensors

At the beginning of the research phase, research took place on types of sensors that can give intel on speed, rotation, and Bluetooth modules. In the following chapter, the choosing and ordering of the sensors will be discussed.

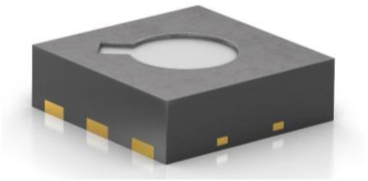


Figure 3

Throughout the process of researching gyroscopes, accelerometers, and GPS components; an inertial measurement unit (IMU) Figure 3 was decided upon, for the following reasons. An inertial measurement unit (IMU) is a combination of gyroscope, accelerometer, and in some cases magnetometers. IMU chips are commonly used in robotic rovers and drones. Thus, while developing a sensor system for a skateboard, an IMU fits all the requirements of the project (speed and rotation). It was decided to use a 9 axis IMU. 3-Axis accelerometer, 3-Axis gyroscope, and 3-Axis magnetometer. This means that the chip has an acceleration sensation on the X, Y, and Z-axis. It measures angular speed around the 3 axes. In addition to 3 magnetometers that sense the magnetic field of earth on the three axes. Although it wasn't 100% clear what could be the applications of the magnetometer, it's another variable that might be useful to stabilize signals of rotation around the Z-axis.

Choosing a 9-axis sensor

Before the assembling phase, while choosing the components to be ordered, it was hard to determine which specific 9 axis sensor should be ordered. Taking into consideration this is not a final product and that a proof of concept was required for this phase. In addition to taking into consideration all the risks of delay due to covid-19 restrictions. An investigation took place on which products were available in Dutch online stores and how long the expected delivery time would be. After gathering the information needed on what is available in stores. More research was performed on the available 9 axis sensors to find out if the sensors had enough available online materials. Online materials and good documentation for every sensor are crucial. Datasheets, libraries, and examples on how to use the sensors help to understand and save a lot of time.
Research led to the conclusion that most of the sensors had online material and enough information with almost no difference between one product and another. Therefore, the decision was to order the MPU-9250 Figure 4 module through Tiny-Tronices in Eindhoven due to contactless pickups within 24 hours of ordering. Which was the safest fastest option during a pandemic.

The mpu-9250

The mpu-9250 Figure 5 is the sensor chip containing all the accelerometers, magnetometers, and gyroscope. However, what was ordered and used in the process of creating the prototype, is the module in Figure 4, which is a board that has a sensor (mpu-9250) mounted on the board among other components. such as a voltage regulator, some resistors, and capacitors. Those types of boards are easier in connecting and sending data to a microcontroller. By connecting the pins SDA and SCL to the right pins on the master controller you have already established an I2C communication protocol.

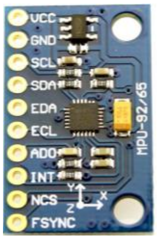


Figure 4

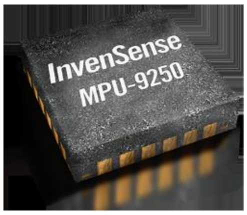


Figure 5

Master-Controllers and boards

Introduction

In the process of researching and brainstorming, a lot of options were considered for what device should be used as a master controller. All the controllers will have the same goal: to communicate with the sensor to record the data, do some simple calculations, and send the data to the phone app. The three main options considered were Arduino products, raspberry pi products, and a self-developed microcontroller on a PCB.

Raspberry-pi

Throughout the process, it was considered to use a Raspberry-pi product. Raspberry-pi Figure 6 is a miniature computer, which unlike a microcontroller can do multiple tasks at the same time just like a normal computer. Raspberry-pi supports multiple programming languages such as python, java, JavaScript, and C/C++. The Raspberry pi that could fit the project's description size-wise is the Raspberry-pi PICO with dimensions of (21mm x 51.3mm x 3.9).

Figure 6

Self-developed board

A master microcontroller was considered to be built in a PCB with other components to develop a tailored board for the Skatrixx project. Developing a board for the specific reason of the project Skatrixx helps in minimizing the size of the board to almost a final product size. Since there will be zero unneeded components on the board. Reducing the number of unneeded components will also reduce battery usage. For the master microcontroller, ATMega328 is an Arduino product that was considered but other options could be any other microcontroller. In addition to the microcontroller on the board will be other components such as voltage regulators, 16 Hz crystal, capacitors, resistors, Bluetooth module, and an IMU sensor. Although this is the approach that would be taken in developing the final product of Skatrixx, for a prototype while creating and testing ways of measuring and calculating the requirements of Skatrixx, a device that is already developed and tested with specific standards by a big company is more reliable and time-saving.

Arduino

An easy, reasonable, and effective option for testing and creating the first prototype is an Arduino board since the boards are created for this reason. Arduino boards Figure 7 are easily connected to components that are programmed and controlled with one microcontroller. Arduino products also come in various sizes and shapes to help quickly assemble prototypes. Just like the raspberry pi products Arduino has a lot of varieties in size and performance. However, unlike the raspberry-pi, Arduino is not a miniature computer, it doesn't have RAM or can-do multiple tasks at the same time. The Arduino that was mostly considered during the research phase was a relatively newly developed Arduino (Arduino nano 33 IoT).

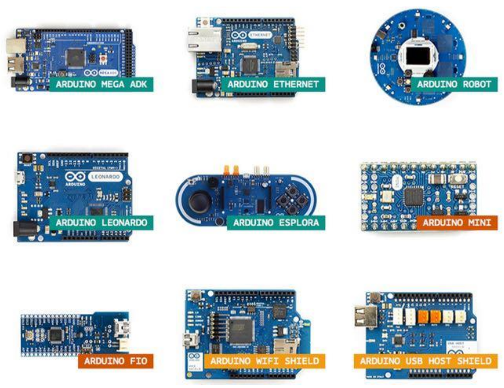


Figure 7

The Arduino

Arduino nano 33 IoT Figure 8 was specifically considered for multiple reasons. As a starter, programming an Arduino is relatively easy, especially given the fact that USPC mostly relies on interns and students for projects. So, engineering students or interns will find it easy to take over this project for the second phase. The Arduino nano 33 IoT also has multiple communication options that are already embedded in the board (Bluetooth low energy and Wi-Fi). In addition to having a 6 axis IMU. This means that the board can be the only component needed or at least might give more information in the testing phase with another IMU Since it's always better to have readings of 2 points (a line segment) than one point. For example, if a sensor is to read and send data of a point. That means that insight is provided on one single point, with it a lot could be assumed and simulated. But with reading on 2 separate points, provided by the sensor and the IMU embedded in the Arduino, more insight is provided. With the reading of two points and knowing the position of each point and their positions relative to each other, an imaginary line is formed in which the start and the end of this line are known.

Figure 8

Conclusion

By the end of the research phase, it was concluded that the project would 100% work with any of the options mentioned in this chapter. since all the products and ideas have different advantages and disadvantages based on which phase the project is in. A decision was made that the project starts with an Arduino nano 33 IoT, because it’s the perfect fit for testing and the one specific needed task. Later in the final product, the implementation can be in a self-created board, to save space and energy consumption. And last but not least if the project is to be taken on a higher level and multiple tasks need to be executed at the same time, the final product can be connected to a Raspberry-pi, or replaced with it.

Communication between the system and the user's phone app

Research and planning

The user requirement for the final product is to have a Bluetooth connection, however, that is beyond the scope of this project. Therefore, the plan was to start developing the system and use a Bluetooth connection to a laptop receiving the data and saving it in an excel sheet. As plan B, it was planned to use wi-fi in case of failing to create an app that can receive data through Bluetooth. Since the laptop that was used has SSD memory, no harm would be done by running and moving around with the laptop. Plan C would be carried on with a USB cable connected to the Arduino board receiving the data through the wire.

Testing

A Bluetooth communication system was developed to advertise and send the data but creating a receiving app on the computer wasn't successfully done. Although creating a receiving app wasn't successful, sending data was tested on a pre-existing app Figure 9. The app was found online as an example of using Bluetooth. The app was used for testing to ensure a working emitter for the team coming later to create the mobile app for Skatrixx. Plane B approaching WIFI wasn't any easier or achieved any higher point. Problems again occurred while creating the receiving app. Thus, moved on to plan C to avoid any more lost time and move on faster toward testing and analysing data.

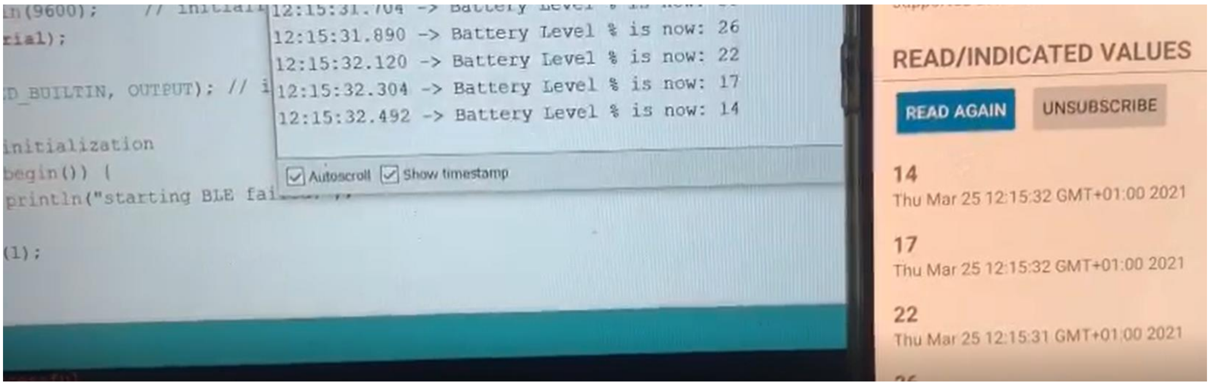


Figure 9

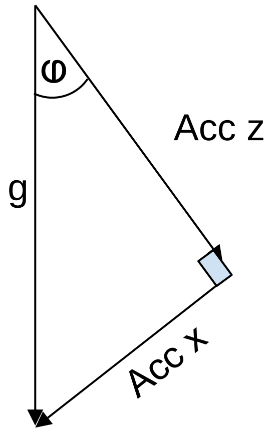
Rotation around an axis calculations

Introduction

Different rotation calculations could be made, each with its advantages and disadvantages. The following chapter will be explaining the different ways of calculating the rotation. Rotations could be calculated based on the readings of the accelerometer in relation to gravity, gyroscope's readings of rotational speed, or with a magnetometer's readings in some cases.

Acceleration

Using the accelerometers and the direction of gravity we can determine the angle of theta.



Equation

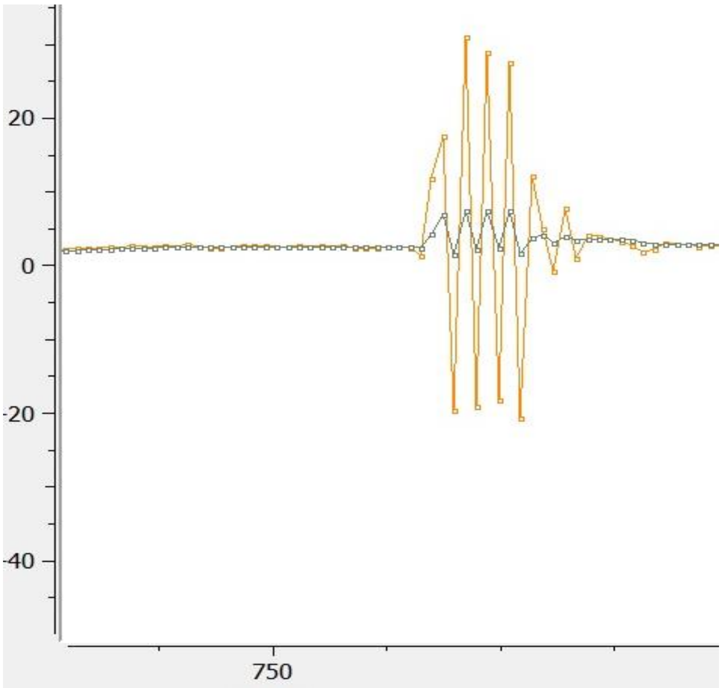
$$tan(\theta) = acc\ x \div acc\ z$$
$$\theta_{acc} = tan^{-1}\left(\frac{acc\ x}{acc\ z}\right)$$

Pros and cons:

This calculation works well on low-speed rotations however it misses a lot of degrees on high-speed rotations and is highly affected by vibration. For example, if the skateboard rotates around an axis 45 degrees up and stops on this position then the reading will be accurate. However, in a '360 degrees' flip which like most of the skateboarding tricks, is done with a very high speed, the position changes from zero degrees to 180/ -180 and works its way back to zero. Since the time frame is too small and the final position is the same as the initial position the result could lack accuracy in such tricks.

Graph:

In the plot shown Graph 1 the Y-axis represents the degrees, and the X-axis represents time.
The yellow line represents the rotation and should be changing based on rotations. However, in this test, there was no rotation around any of the axes, the sensor was only subjected to vibration. And that shows how much the vibration affects the change of degrees using this way of calculation.



Graph 1

Acceleration low pass filtered

To solve the vibration errors a low pass filter can be used to neglect the change of theta due to vibrations. The low pass filter relies on the old data that represents the last position, more than the new read data that represents the new position.

Equation:

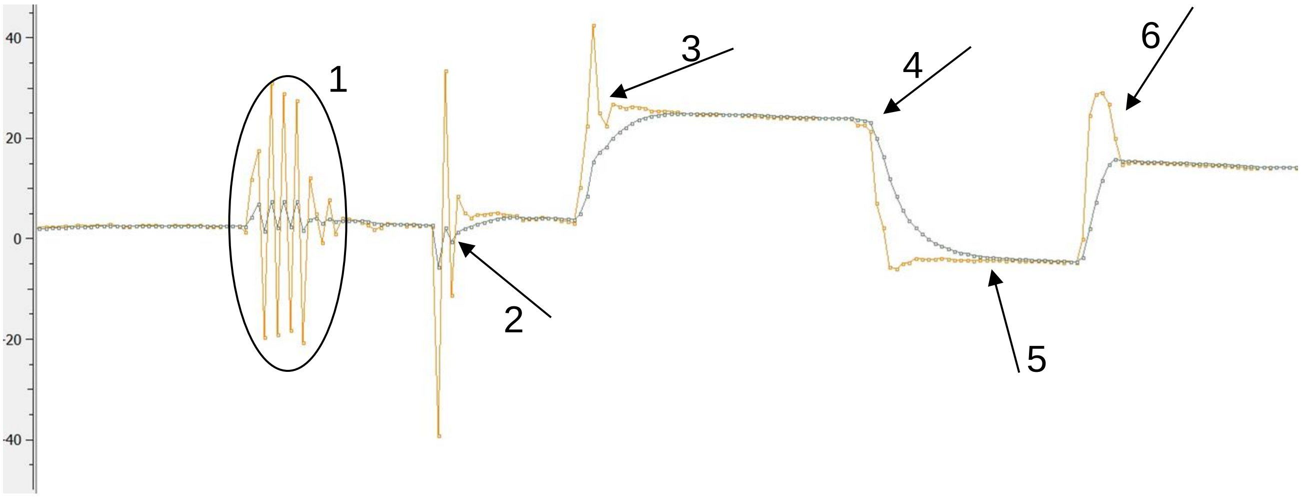
$$\theta_{accf_{new}} = (\theta_{accf_{old}} * 0.9) + (\theta_{acc} * 0.1)$$

Pros and cons:

Using a low pass filter, if the newly read data suddenly increases, it gets filtered into the old position plus a fraction of the change. This allows the value to change while limiting how fast this change is happening. Using this filter minimizes all the high amplitude data and vibration. However, this filter also results in a slower response.

Graph:

This plot Graph 2 represents a comparison between theta and theta filtered. The green line represents filtered angels while yellow represents an angel unfiltered. This plot represents a comparison between theta and theta filtered. At point one Graph 2 under intensive vibration, the filter minimizes the vibration from approximately reading 45 degrees to reading 5-8 degrees approximately. At point two Graph 2 a slight change of angle happens after vibration and the filter minimizes the vibration while going then goes to the new angle. At point three Graph 2 a decent change of angle is happening with an overshot due to impact, the filter ignores the overshot and with a bit of slow response goes to the new angle. However, with a quick angle changing at point 6 Graph 2 the filter cancels the peak although it's not an overshot it's an actual change of angle.



Graph 2

Gyroscope

Gyro sensors measure the angular speed around an axis, Using the angular speed and the difference in time we can calculate the change in angle. Adding the change of angle to the current angle gives an accurate angle of rotation.

Equation

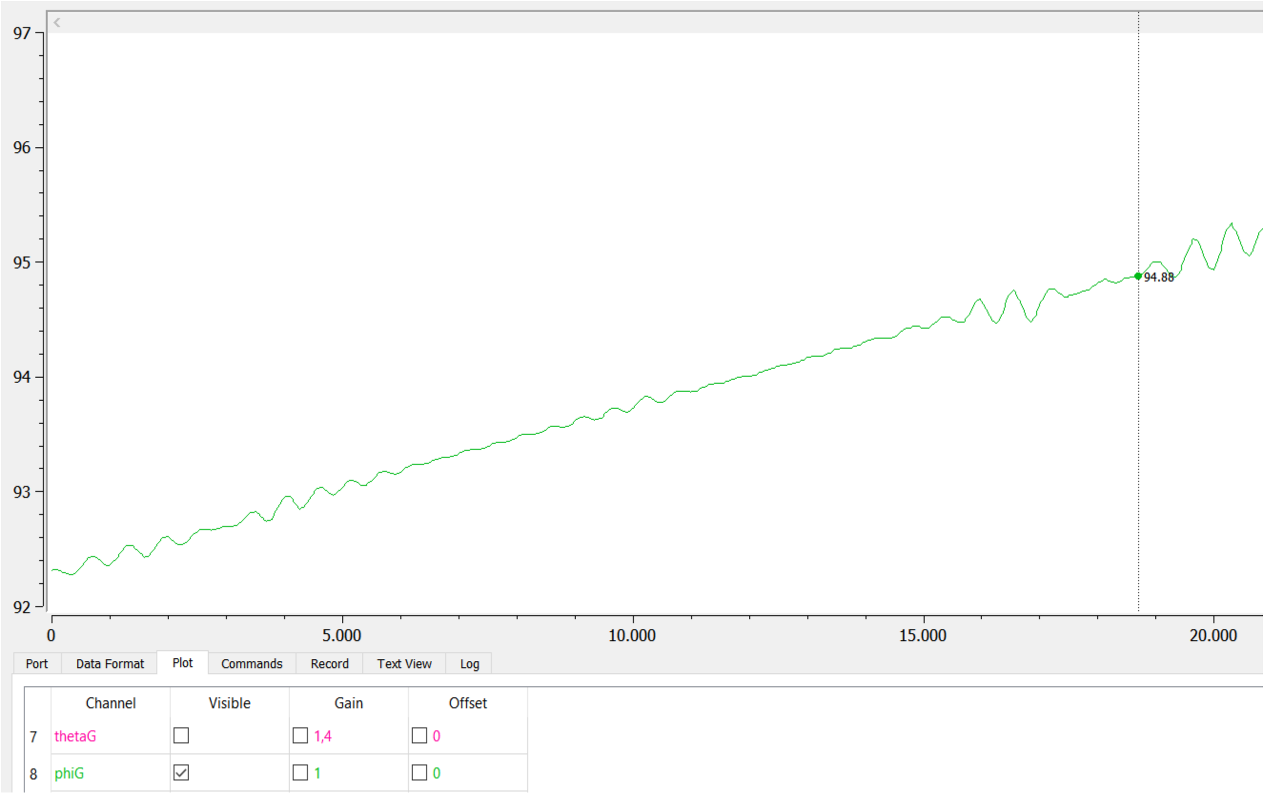
$$\theta_G = (\theta_G + \omega_y * \Delta t)$$

Pros and cons:

The theta calculated is accurate in low and high-speed rotation. However, when no rotations are happening the gyro has a drift that occurs over time due to noise that acts as a small change of angle. in a very slow rotation or while standing still the gyro drift highly affects the calculated angle.

Graph:

In this plot Graph 3, the green line represents the change of angle calculated using the data of the gyro. Over time there is a big change of angle while the sensor was left sitting on a table. With simple calculations to determine the slope of the plot, the change of angle is approximately (8.108108E-5) and the angle of incline is approximately (0.0046456).



Graph 3

Complementary filters

After some research and consulting some professors, I was told that there is no simple way of getting rid of the giro drift but there are multiple ways to use the giro without having to worry about the drift. For a prototype I thought avoiding using algorithms and highly complicated measures like the Mahony Orientation Filter, a complementary filter is the best option. A complimentary filter is a way of combining 2 signals. I used a couple of ways and signals to try and get the most pros and least cons out of all the previous signals representing rotation calculations.

Equation

- Theta Acceleration with Theta gyro

$$\theta_{new} = (\theta_{old} + (\omega_y * \Delta t) * Gain) * 0.95 + (\theta_{acc} * 0.05)$$

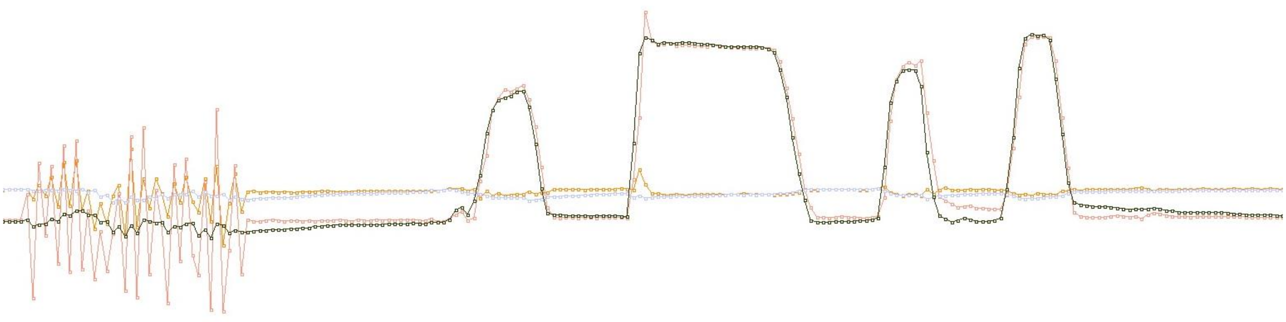
- Theta Low pass acceleration with Theta gyro

$$\theta_{new} = (\theta_{old} + (\omega_y * \Delta t) * Gain) * 0.95 + (\theta_{accf_{old}} * 0.05)$$

Pros and cons:

On the short term and high-speed, the calculation is more tentative to follow the giro, and while no movement the gyro drift is constantly corrected by the theta calculated using acceleration. In high-speed rotation, a fraction of the angle is lost and that could be compensated for with the gain.

Graph:

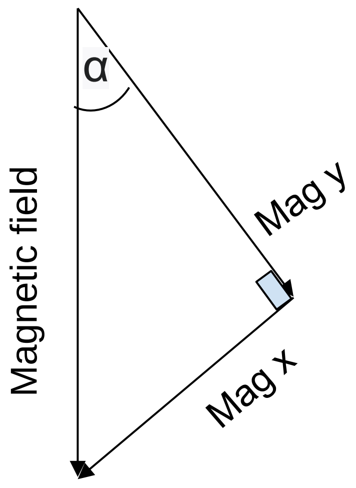


Graph 4

Plotted Graph 4 is the comparison between theta calculated using accelerometers in orange, and theta calculated using complementary filters in black, vibration is minimized angel calculation is accurate, the response is even quicker than the response of acceleration. because it's based on the gyroscope's data, and overshooting during a turn is fully cancelled.

Magnetometers

Using the magnetometer's readings and the north direction based on the earth's magnetic field we can determine the angle alpha. Alpha represents the angle between the readings of magnetometer Y and the north direction.



Equation

$$tan(\alpha) = \frac{mag_x}{mag_y}$$

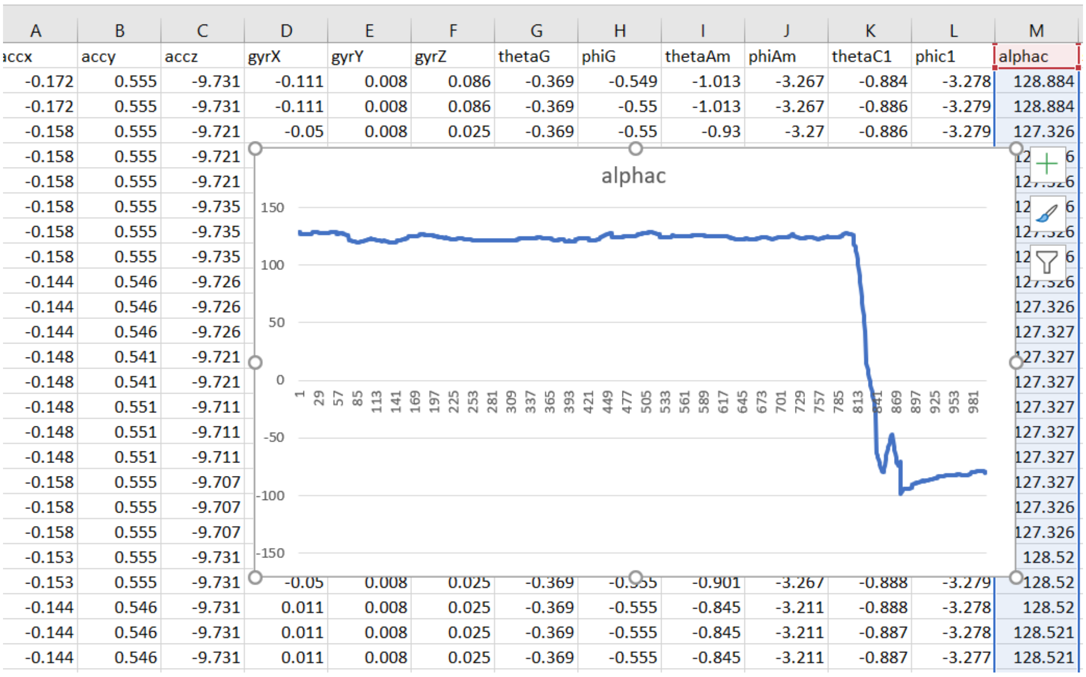
$$\alpha_{mag} = tan^{-1}(\frac{mag\ x}{mag\ y})$$

Pros and cons:

The calculation is accurate, but it doesn't calculate the change of angle instead it gives the absolute position. unlike the accelerometers. this way of measuring angles is not affected by vibration. However, if the sensor is close to a magnet the readings will be highly affected.

Graph:

Plotted Graph 5 is the representation of the trick "shove it" using the absolute position, it shows that the board flipped from the position of approximately 125 degrees to the position of approximately -70 making the angel change around 197.



A	B	C	D	E	F	G	H	I	J	K	L	M
accx	accy	accz	gyrX	gyrY	gyrZ	thetaG	phiG	thetaAm	phiAm	thetaC1	phic1	alphac
-0.172	0.555	-9.731	-0.111	0.008	0.086	-0.369	-0.549	-1.013	-3.267	-0.884	-3.278	128.884
-0.172	0.555	-9.731	-0.111	0.008	0.086	-0.369	-0.55	-1.013	-3.267	-0.886	-3.279	128.884
-0.158	0.555	-9.721	-0.05	0.008	0.025	-0.369	-0.55	-0.93	-3.27	-0.886	-3.279	127.326
-0.158	0.555	-9.721										[illegible]
-0.158	0.555	-9.721										[illegible]
-0.158	0.555	-9.735										[illegible]
-0.158	0.555	-9.735										[illegible]
-0.158	0.555	-9.735										[illegible]
-0.144	0.546	-9.726										[illegible]
-0.144	0.546	-9.726										127.326
-0.144	0.546	-9.726										127.327
-0.148	0.541	-9.721										127.327
-0.148	0.541	-9.721										127.327
-0.148	0.551	-9.711										127.327
-0.148	0.551	-9.711										127.327
-0.148	0.551	-9.711										127.327
-0.158	0.555	-9.707										127.327
-0.158	0.555	-9.707										127.326
-0.158	0.555	-9.707										127.326
-0.153	0.555	-9.731										128.52
-0.153	0.555	-9.731	-0.05	0.008	0.025	-0.369	[illegible]	-0.901	-3.267	-0.888	-3.279	128.52
-0.144	0.546	-9.731	0.011	0.008	0.025	-0.369	-0.555	-0.845	-3.211	-0.888	-3.278	128.52
-0.144	0.546	-9.731	0.011	0.008	0.025	-0.369	-0.555	-0.845	-3.211	-0.887	-3.278	128.521
-0.144	0.546	-9.731	0.011	0.008	0.025	-0.369	-0.555	-0.845	-3.211	-0.887	-3.277	128.521

Graph 5

Air-time calculation

The function that calculates airtime relies on other sub-functions that continuously check the new data received from the sensor. In the block diagram Diagram 1 the program first checks the status of the skateboard between the two options of, if the skateboard started flying or not. The program then decides between continuously checking for landing or continuously checking for a jump and in both cases saves the timing of the beginning of the jump or the beginning of freefall to be subtracted later from the time of the landing, resulting in airtime.

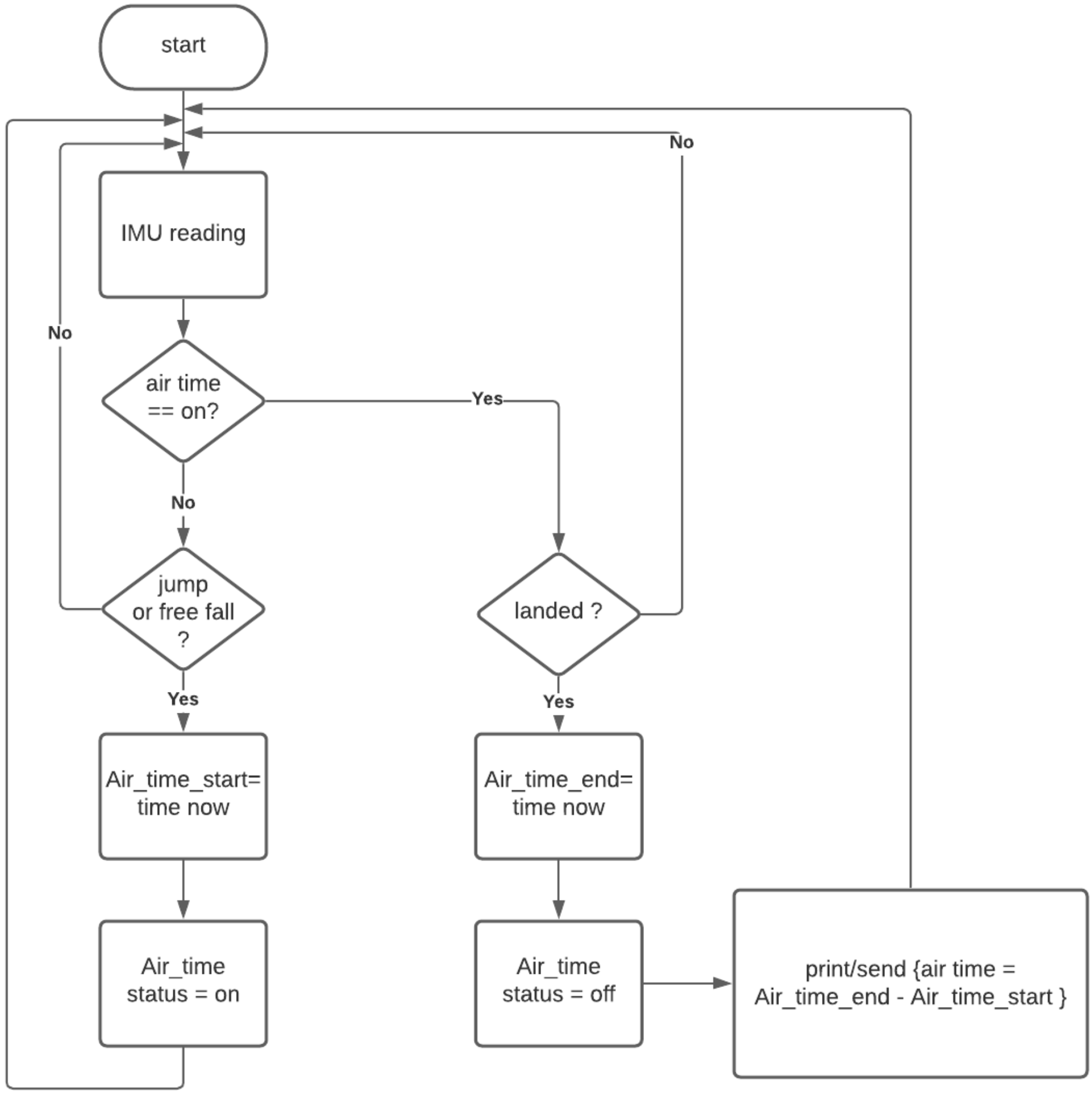


Diagram 1

What is the best placement of the components?

As per the requirements of the final product of the project Skatrixx; the placement should be similar to placing riser pads and shock pads. The placement of that equipment is shown in the Figure 10 This is a high-stress point since this is the area where all the forces are transferred. However, skateboarders usually use all surfaces on the skateboard, which makes the placement of anything complicated.

Figure 10

As per the feasibility research [2] that took place before the beginning of this project and as per the research done throughout this project the placement of the components can also be under the wheels Figure 11. While placing the product under the wheels, it has to be centred away from where the wheel bites take place Figure 12. A wheel bite is when the surface of the board touches the wheels, resulting in biting and sanding off parts of the wood. As required by the project management the placement should be relatively easy for the customer. Thus, the goal is to sell the final product as a pad equally big to the average raiser pad or a shock pad.

Figure 11

Two holders Figure 13 were designed to be attached to the skateboard one for the battery and the other for the PCB. For this phase, the holders will be 3D printing with 100% infill. However, in the future other materials like carbon-fiber or metal can be used.

Figure 12

Figure 13

Power supply

Such a project with a lot of restrictions regarding size needs a small flat battery to power up the system. In the current state of the project where the battery is powering up the Arduino and the sensor is powered up by the Arduino. The required voltage input from the battery is between (4.5V - 21V). Researching the types of flat batteries, it was concluded that there are no flat batteries with a higher voltage than 3.7V. Thus, two flat batteries could be connected in parallel however this will cost space. The only reason a 3.7V is not sufficient is that Arduino requires a voltage higher than 4.5V. However, the master microcontroller, sensor, and all the other components require 3.3V or less. Given all the facts above in addition to using a USB cable for testing. The decision was made to work with AAA lithium batteries in the phase that requires using the Arduino. To avoid wasting money and resources on flat batteries that won't be sufficient to use in the final product due to difference in capacity needed.

Power consumption

Input	Voltage	Sleep	BareMinimum	Blink	Shake detector (IMU)	Basic Scan Networks (Wifi)	HTTPS GET (Wifi)	BLE usage
USB	5V	OK	OK	OK	OK	OK	OK	OK
3.3V pin	3.3V	6mA	18mA	22mA	19mA	112mA	110mA	47mA
Vin	4.5V	10mA	18mA	21mA	19mA	88mA	92mA	41mA
Vin	5V	16mA	25mA	26mA	25mA	82mA	84mA	39mA
Vin	6V	13mA	20mA	21mA	20mA	72mA	66mA	37mA
Vin	9V	<1mA	5mA	7mA	6mA	50mA	40mA	20mA
Vin	12V	<1mA	4mA	5mA	4mA	42mA	37mA	16mA
Vin	18V	<1mA	1mA	2mA	1mA	28mA	30mA	10mA

Calculations of power consumption @V=4.5V

- Simple code running on the Arduino consumes [3]= 21mA
- Bluetooth usage = 41mA [3]
- IMU consumption datasheet = 3.7mA

The system's total consumption is 65.7mA

Implementation and verification

In the upcoming chapter, the implementation and testing will be discussed.

Assembling

Assembling the project was implemented in two main phases. The first was assembling the project for the proof of concept and the second phase was the implementation and assembling a working prototype.

In the assembly of the proof of concept, the determination was to get the system to work as intended. Thus size, placement, the safety of components, and wiring the components weren't the priority. For the testing of the PoC. The Arduino nano 33 IoT and the sensor board mpu-9250 were mounted on a breadboard and connected using jumper cables. The breadboard is designed with double tape on the back however for extra security measures duct tape was used to avoid breaking any components. While testing, jumper cables were challenging and getting in the way, so It was immediately replaced with short single core solid wires.

In the second phase, a PCB was to be designed for a final working prototype. Unlike the first phase, in this phase size of the board and wiring are the most important. All iterations of the final working prototype's PCBs were designed using EasyEDA software, then manufactured in Fontys labs using the UV PCB exposure method. Figure 15 is the design for the first iteration of Skatrixx PCB. Figure 14 is the third and last iteration of the final working prototype PCB

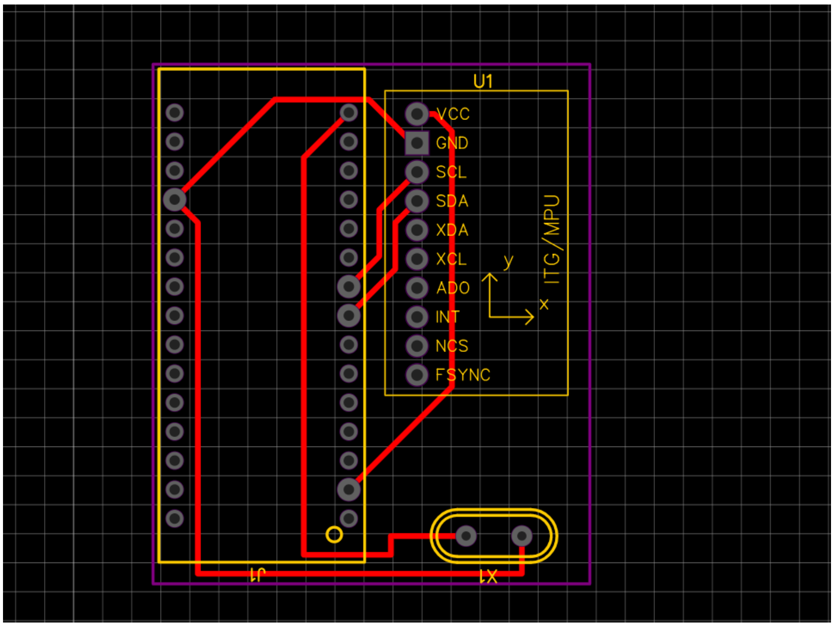


Figure 14

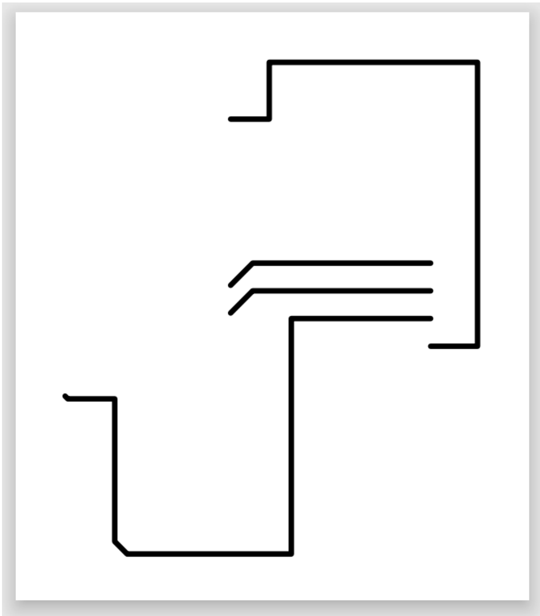


Figure 15

Implementation of software

In the following chapter and block diagram Diagram 2, the software and communication system will be explained. The system starts by establishing communication between the Arduino 33 IoT and mpu-9250, the system then starts advertising the Bluetooth service. As soon as all communications are established the Arduino starts receiving data from IMU to do some calculations and filtering before sending it to the phone through Bluetooth. Since the Bluetooth receiving app on the laptop was never established, in the testing phase the part in the block diagram where Bluetooth is used, gets replaced by sending data through the USB cable.

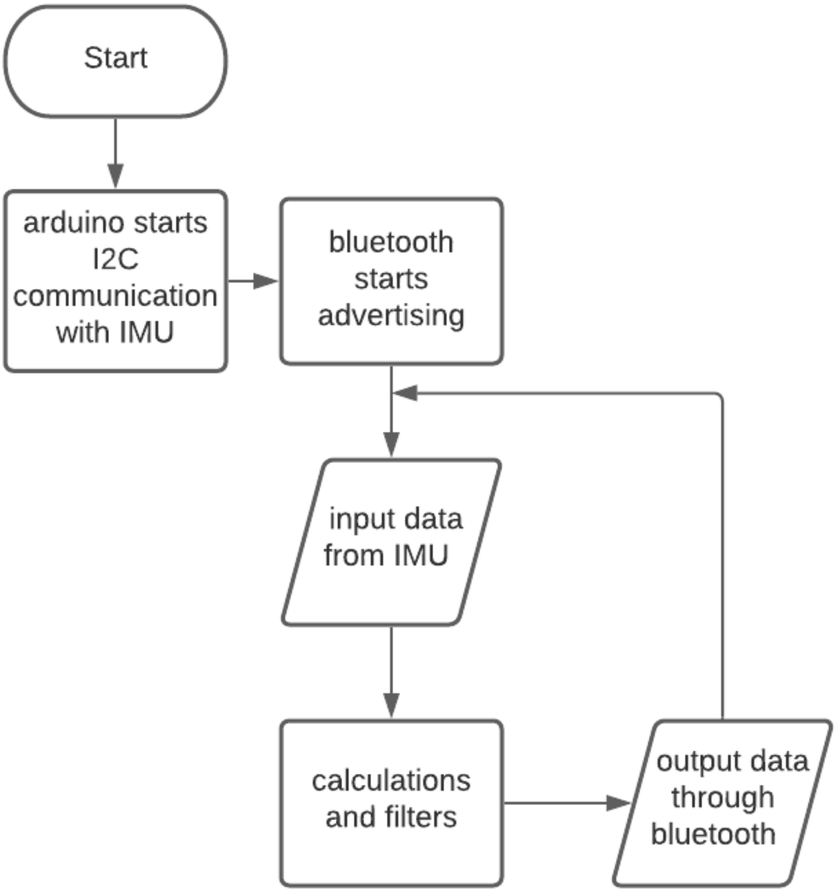


Diagram 2

Testing and verification of the system

After researching and implementing site testing began. with the components mounted onto the skateboard and with the help of Raymund, testing and verification took place twice. Raymond is an embedded scientist and a professional skateboarder with 20+ years of experience. Some of the testing took place during and after the research phase. For example, testing how accurate the rotation calculations are in comparison to a protractor, testing airtime, or testing the Bluetooth connection. However, in the following chapter site testing with a skateboard will be discussed.

The first testing day with Raymond was in the 11th week. Testing took place in an open-air space with a concrete foundation next to the area51 skatepark, since area 51 was unavailable due to construction work. The skateboarder, athlete, and embedded scientist performed several tricks while the sensor system was attached to the skateboard to compare the expected results with the output saved and plotted on the excel sheets Figure 17. During the first testing day, the “ollie” trick was performed 5 times; the “shove it” trick was performed 3 times; the speed test was performed 3 times; the Kickflip trick was performed 3 times.

In the process of analysing the data gathered, there were two main discoveries in need of improvement, speed testing, and rotation angle calculation. Speed testing was the most challenging since it was hard to test the function measuring speed while working from home. Also, there was no reference to speed check on the testing day but measuring distance, and calculating speed manually which was inaccurate. In addition, it was physically the hardest [4] to test since the testing took place using a USB cable as the only communication system. The second most challenging was data loss in high-speed rotation calculation, thus more research and testing were required. One more problem that was discovered while analysing data, was that the data was being saved under the wrong columns, Which was fixed before the second testing.

For speed testing, after debugging the code some adjustments were made and the second testing for the speed function took place without a skateboard. During the second and final speed function testing, the sensor system was mounted to a moving car to have a reference speedometer for comparisons. Regarding the rotation more research and testing were needed to determine the problem, some adjustments were done to the gyroscope’s sensitivity, and a Gain was determined to overcome the loss of data.

The second and final testing took place again with Raymond in an open-air space with a concrete foundation in Eindhoven CityCenter next to the city hall. During the testing day, the focus was mainly on the kickflip trick. Although all the following tests took place, the “ollie” trick was performed 3 times; the “shove it” trick was performed 2 times since it was already a success during the first testing day; the speed test was performed 2 times on that day although no further tests were needed for it was already tested on its own; the Kickflip trick [5] was performed 15 times to be able to analyse as much data as possible with different variations and different variables (gain) in the equations. Even though analysing all the data was a huge challenge and there is still a margin of error in calculating the rotation angles Figure 18, in general, the final testing was successful.

Conclusion and recommendation

SenSkate project, focused mainly on professional Urban athletes with a complicated un user-friendly design. The monitoring system offered the trainers information on foot position, angles of rotations, and a lot more. On the other hand, the Skatrixx project is more focused on creating a simpler, more affordable version. To allow amateur skateboarders to improve their skills by gaining insight as well as a more widely marketable product.

In conclusion, it is possible to create a sensor system that measures and calculates speed, rotation, and airtime with one IMU sensor. Based on the data that is being extracted and used at this phase of the project, it's also possible to add more features such as, the height of jumps and a compass system on the skateboard. The sensor used is MPU-9250 9-axis however the usage of a magnetometer in the future might not be necessary. The master controller being used is Arduino nano 33IoT. However, in the final product, a microcontroller alone with the right components on the PCB will be enough. Bluetooth communication can be established even with Bluetooth low-energy components to save battery consumption. This prototype is powered by 3 AAA batteries connected in series. However, it could also be powered by two flat batteries connected in parallel. Holders are 3D printed, however, in the future different material is recommended.

Recommendation bolt-points

- The last iteration of the PCB Figure 16 was designed but was never implemented. Could be useful in imagining what the final product should look like.
- In the future, when the system can recognize the beginning and end of a trick, always use the raw data from the gyroscope when calculating rotations around an axis, since it's the most accurate data if the change of angle is the only part considered.
- Implementing sleep mode to the sensor while the master microcontroller is not communicating to the sensor was not researched enough. However, it should decrease the sensor's battery consumption, based on the data sheet .
- For the next phase of the project Skatrixx, it's recommended to be handled as a team project with an engineer's supervision. Since there are more tasks to do in parallel.
- When project Skatrixx is finalized and in the market, it could be considered to try to implement a second product, that if connected to Skatrixx, should result in increasing the targeted group of Skatrixx to include SenSkate's [1] target group.
- It's recommended that in the final product the sensor system should send raw data to the phone app with time stamps. The phone can certainly handle a couple of simple calculations. Which gives the system the time to do more iterations per second.

References

[1] "uspc.nl," Urban Sports Performance Center, [Online]. Available: https://uspc.nl/senskate/.

[2] Stichting InnoSportLab Sport & Beweeg, "SKATRIXX – EINDRAPPORTAGE," 2020.

[3] ostaquet, "GitHub," 24 Nov 2020. [Online]. Available: https://github.com/ostaquet/Arduino-Nano-33-IoT-Ultimate-Guide.

[4] USPC, "Speed test video," 2021. [Online]. Available: https://innosportslab-my.sharepoint.com/:v:/g/personal/info_innosportlabsportenbeweeg_nl/EWwoAbGxPxFFi9PHoUEz1BQBBXgezw2OWp8MxzmX9Pujew?e=h3c8Qx.

[5] USPC, "Kickflip video," USPC, 2020. [Online]. Available: https://innosportslab-my.sharepoint.com/:v:/g/personal/info_innosportlabsportenbeweeg_nl/EbOxBVVGR01JmZie0GAi6PsBt4Ds6zXXhpYybyljkruYNA?e=BWQ3e4.

Appendix 1

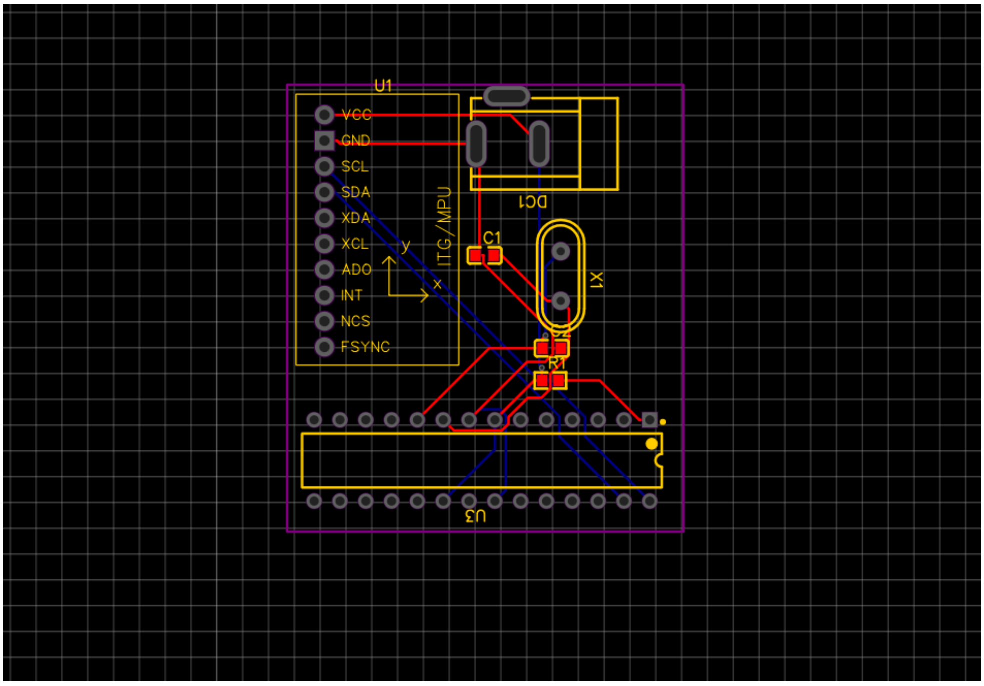


Figure 16

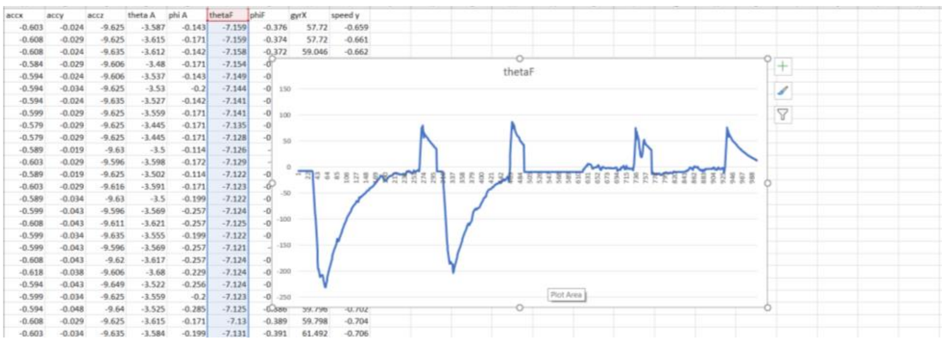


Figure 17

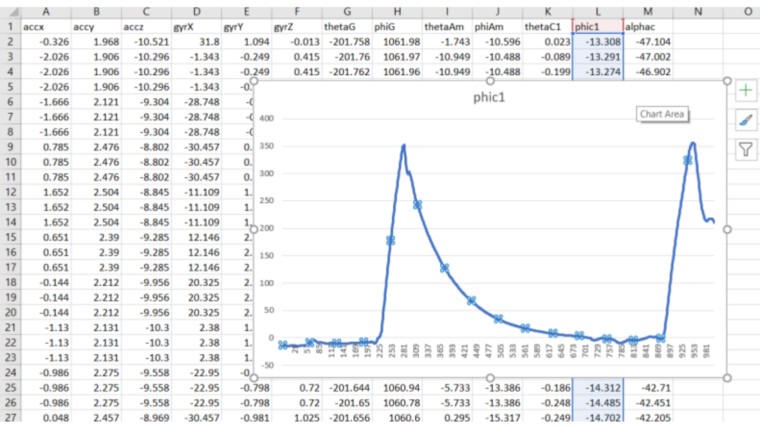
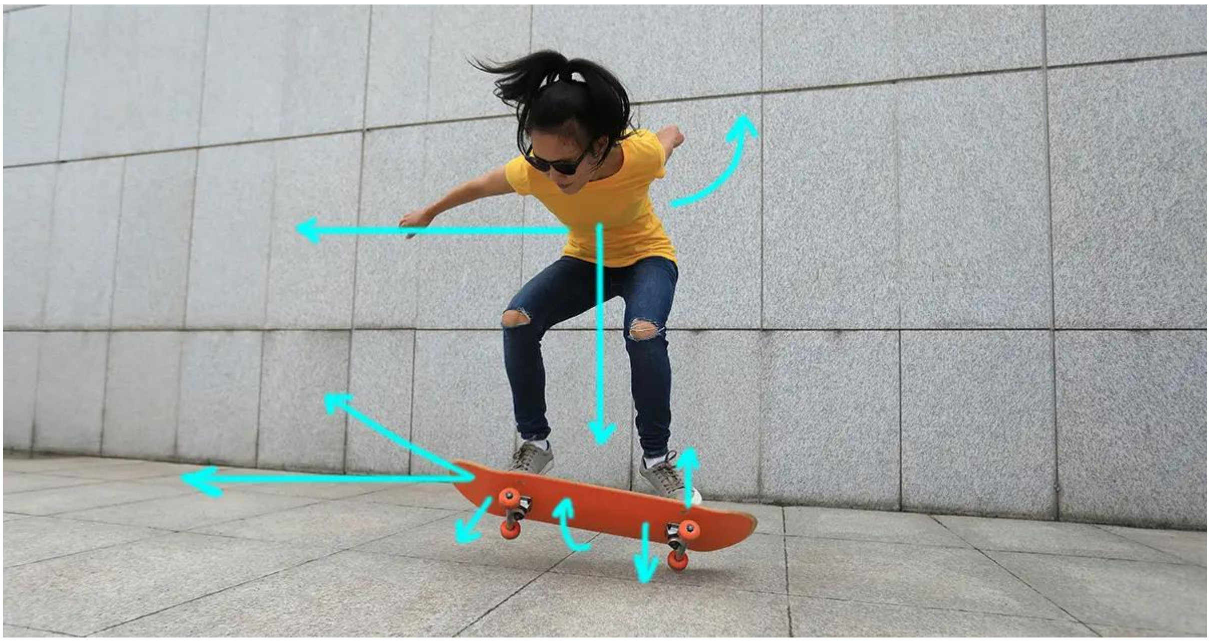


Figure 18

Appendix 2

SKATRIXX

Plan of approach



By: Mohannad Elattar Version
3.3
Student number: 3777243
client: USPC

Preface

In this plan of approach I will be describing the process and the planned steps for my internship contribution with USPC in developing the skatrix project. USPC is a non-profitable knowledge and innovation center, with the goal of improving the urban sport’s performance through the use of knowledge, innovation and technology. USPC is also trying to make Urban Sports more attractive for a broader target audience. since Urban Sports are becoming increasingly popular and more important because skateboarding and BMX freestyle in Tokyo are now on the Olympic program.

Student Information

Student name	Mohannad Elattar
Student number	3777243

Signature:

Business Mentor

Name	Harmen Bijsterbosch
Position	Manager USPC

Signature:

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Background

To understand my expected contribution in the Skatrix project, maybe I should start by explaining a more advanced version(SenSkate). SenSkate Is a skateboard that can accurately measure the rotation of the skateboard, acceleration, speed, foot placement and balance of the skater. Skatrix is a simplified, scalable version of SenSkate, with fewer sensors and an app for more consumer market reach. A mobile application has already been developed in an earlier project. In this project I will be creating the sensor system that will provide insight about speed and rotation. This information should help skateboarders improve their skills and performance.

Assignment description

Under the guidance of the project manager of the USPC, you will build a prototype for the Skatrixx sensor: a sensor under the skateboard that, among other things,
can measure rotation. The sensor connects via Bluetooth with a smartphone app for which the design and the wireframe has already been built (programming language: React Native). You add there the BT connection and the database functionalities (including login, profile).

Project's goal

My task is to design and implement a first prototype of a sensor system that calculates the acceleration and rotations of a skateboard. The system should be relatively easily attached, with Bluetooth connection and a power supply. The placement of the sensor should most probably be under the skateboard's wheels.

Research questions

To achieve these goals, I have to set a main question and some sub questions, dividing the main goal and questions into multiple tasks. Those questions require some research to be answered. However, by answering it, the full goal should be completed. In my opinion the main question of the skatrix project is "how to recreate the SenSkate smart skateboard in a simpler way and increase the reach/target group of the product"

Main question

The main research question of this project is "How to create a sensor system that obtains data on rotations, speed and has a way of communicating with a mobile application?"

Sub-questions

The sub-questions that clarifies the project's purpose are:
Should we use 1 or 2 sensors in the system ?
What type of sensors should be used ?
What is the best placement of the components ?
What is the best way to attach the components ?

What type of power supply should be used?
What microcontroller should be used?

User requirements:

User requirements	MoSCoW Status
A first prototype	Must
Sensor system	Must
Reading acceleration	Must
Reading rotation	Must
Calculates average speed	Must
Communication to a phone app	must
Communication via bluetooth	Should
User friendly placement	Must
Calculate airtime	Must
Calculate skating time	Could
height of jump	Should
Sysnor attached below the skateboard	Must

Project planning

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Introduction:

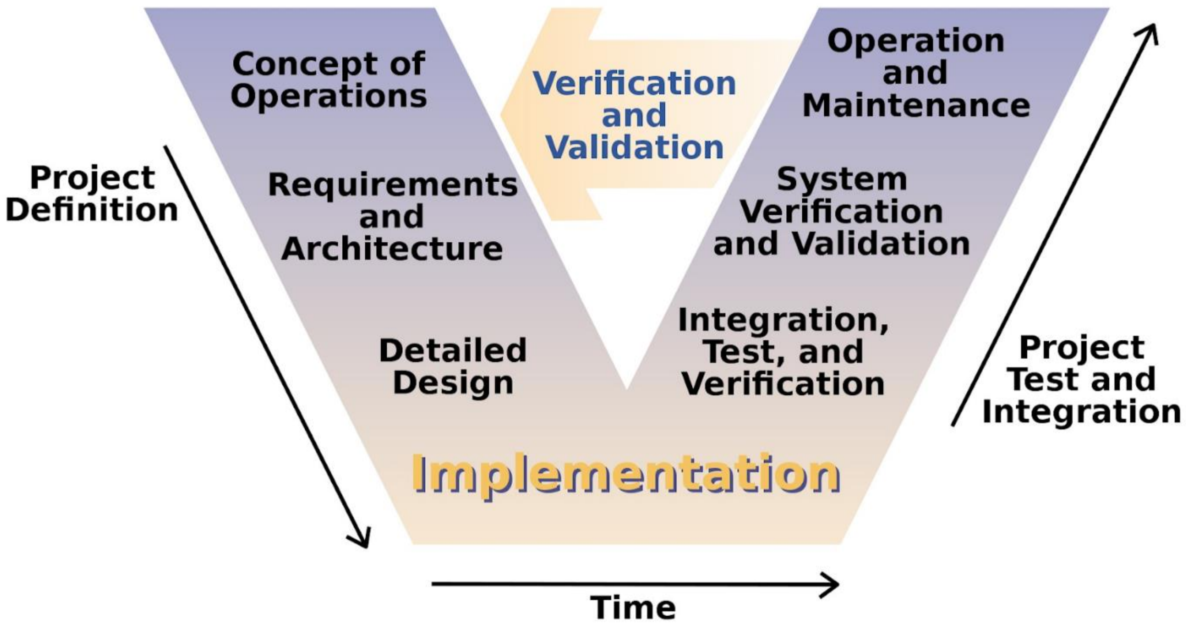
In this project there will be two main phases that will require two different methods. First will be the proof of concept which will require a V-model and some deliverables; and in the second phase we will be using Agile-SCRUM method to get forward step by step.

Iterative design methods:

Using iterative design and implementation methods helps in making sure that every new iteration is going to be an improved version of the last iteration. Which is an easy and efficient way to make sure you are always going forward with your project.

V-model:

The v-model is an iterative design method for software development (SDLC), that I will be used only for the proof of concept. See the model below.

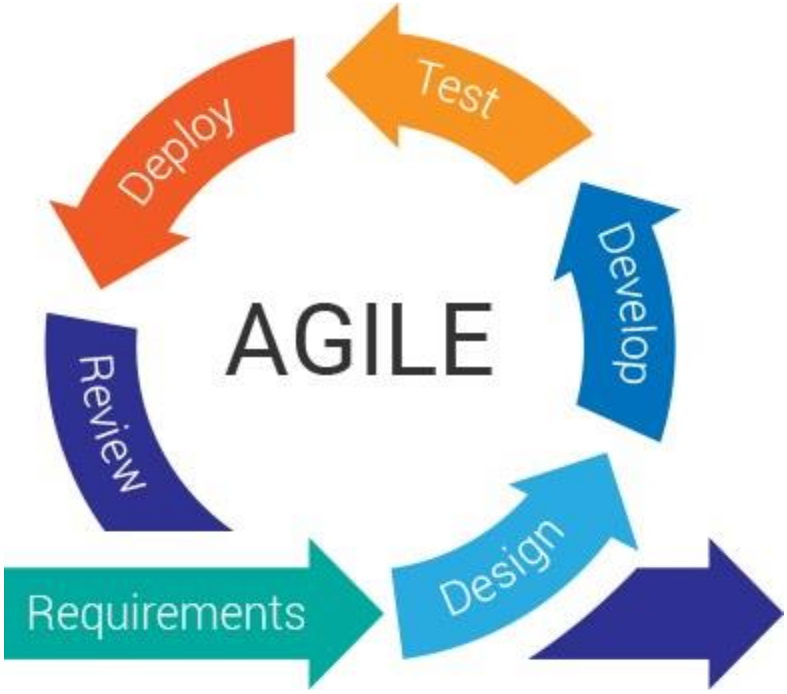


Each phase will have a required deliverable to initiate the start of the next phase and the deliverables will be available with their deadlines in the timeline plan. The phase's names are slightly changed to fit the project's requirements and deliverables required.

- **Initialization phase:** In this phase contracts, paperwork, and plans are made to help get a general idea, plus a plan for the internship period.
- **Research phase:** This phase will be about doing research on what components could be used and tried in the system, in addition to writing the user requirement and system requirements documents. In addition to answering the research questions.
- **Conception and prototyping:** In this phase prototyping starts,testing and getting reading to mark a starting point for the project and the system.
- **Detailed design phase:** In this phase I will be deciding on final hardware components and setting up software/code.
- **Implementation phase:** In this phase I will be putting everything together, and improving.
- **Integration test and verification :** In this phase all the testing happens, the system should be able to send the readings to a computer/laptop through bluetooth connection.
  (design => Implement => test=> Adjust) the most important part of the V-model
- **System verification :** checking that the proof of concept's prototype fulfills all the system requirements.

Agile Scrum:

Agile Scrum methodology is a project management system that relies on incremental development. Each iteration consists of two- to four-week sprints, where each sprint's goal is to build the most important features first and come out with a potentially deliverable product.



Our method:

During all the phases mentioned and in every step the following method will take place:

Plan => Implement => Check => Adjust

All the decisions taken will be followed by a plane. All planes will be checked after the implementation for applicable adjustments.

Deliverables:

Phases deliverables

- **Initialization phase:** Plan of approach - internship assignment - internship agreement

- **Research phase:** System requirement documents

- **Detailed design phase:** Final design concept with the client's approval

- **Implementation phase:** Complete code and proof of concept.

- **Project finalization:** Final report

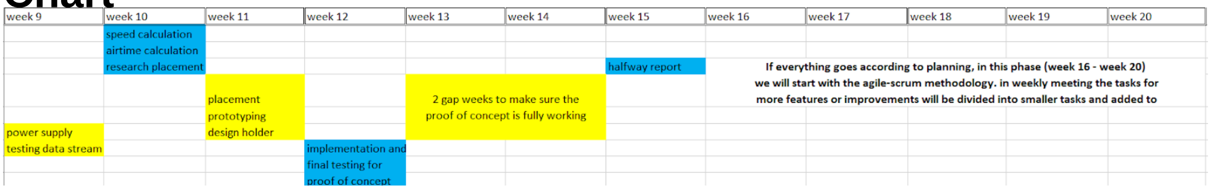
Agile scrum:

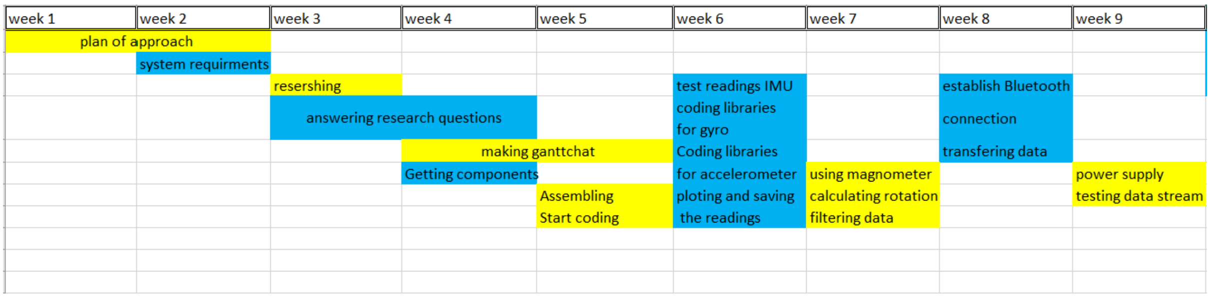
After the proof of concept the deliverables will be decided on weekly bases and added to the gantt chart[3]

Deadlines

Internship assignment	January 5th
Internship agreement	February 1st
Plan of approach	March 22th
First company visit	April 20th
Table of content final report	April 30th
Halfway report	May 17th
Second company visit	June 6th

Gantt Chart





Process Risk

Risks	Impact	Probability	Risk Rate	Vulnerability	Risk Priority
Bad communication	HIGH	MID	HIGH	HIGH	HIGH
No testing with my target group	LOW	HIGH	LOW	LOW	LOW
Absence of member	HIGH	LOW	LOW	HIGH	MID
Exam weeks	HIGH	LOW	MID	MID	MID

Loss or damage of components	HIGH	MID	MID	LOW	MID

Risk rate = impact x probability
Risk priority = impact x probability x vulnerability

Bad Communication

USPC

A weekly online meeting with USPC's mentor is required, in the case of missing or cancelation, the meeting should be replaced by at least email updating. If the communication is totally gone for a week, Raymond or Maxim can be contacted and the plan goes as is until next week's meeting.
If the miscommunication occurs 2 weeks in a row the school mentor will be informed of the situation for advice.

School tutor

An online meeting will take place every 2 weeks, meetings can be postponed and rescheduled if needed. However, if 3 weeks pass without some way of communication established (physical meeting, phone call, email, ect….). If not Cornielje,Jitske should be contacted.

Target group

For information: In case of any lack of communication between me and my target group I can always rely on the feasibility research, which includes a lot of information about our target group.

Testing

If testing wasn't applicable for any communication reason, or corona messrs, we can always rely on Raymond's 20 years of experience as a skateboarder.

Absence of member

Being the only member raises the vulnerability of any physical or mental problem that affects the progres, however the probability of this happening is too low.
In such case the project will be on hold until I am able to get back to working during the duration of my internship.

Loss or damage of components:

While testing on the skateboard the probability of damaging the components gets higher however, the components are reachable and feasible that's why the vulnerability of this risk isn't high. In this case ordering and getting a new/same exact component should be relatively easily done.

Exam weeks

In the timeline of the planning the exam weeks are taken into consideration.This way we can be more realistic and avoid losing progress, since in the exam weeks I'll be more focused on the exams.

Others

In the case of something going wrong in the project and a big change of plan has to be done, the school mentor and USPC's mentor will be informed ASAP to take a deicestion.

Budget

As per the feasibility research the budget for the skatrexx project is 20,000 euros [2], however for my prototype I am allowed to use 200 euros max on components. Although more can be offered if needed, depending on the situation.

4. Inzet van middelen

4.1 In hoeverre werden de middelen ingezet, zoals voorzien?

Kostenrubriek	Begroot	Realisatie	Deelnemer
Externe expertise en diensten	€ 20.000,-	€ 20.000,-	InnoSportLab Sport & Beweeg
Totale kosten excl. BTW	**€ 20.000,-**	**€ 20.000,-**	

4.2 Toelichting op de projectkosten

Er zijn geen afwijkingen t.o.v. de begroting.

4.3 Financiering

Financiering projectkosten	Bedrag	%
Eigen bijdrage InnoSportLab Sport&Beweeg	€ 10.000,-	50
Gevraagde subsidie (Crossroads2)	€ 10.000,-	50
Totaal financiering	**€ 20.000,-**	**100**

Resources

[1]: https://www.businessnewsdaily.com/4987-what-is-agile-scrum-methodology.html#:~:text=Agile%20scrum%20methodology%20is%20a,with%20a%20potentially%20deliverable%20product.
[2]:https://innosportslab-my.sharepoint.com/personal/info_innosportlabsportenbeweeg_nl/_layouts/15/onedrive.aspx?FolderCTID=0x012000C56A2200766C894487F61F66D261F8C0&id=%2Fpersonal%2Finfo%5Finnosportlabsportenbeweeg%5Fnl%2FDocuments%2FMedewerkers%20InnoSportLab%2FUSPC%20%2D%20general%2F2%2E%20Skateboarden%2FSkatrixx%20%28Crossroa

ds%29%2FRapportage%2FPROJ%2D02794%20Eindrapportage%20Skatrixx%2Epdf&parent=%2Fpersonal%2Finfo%5Finnosportlabsportenbeweeg%5Fnl%2FDocuments%2FMedewerkers%20InnoSportLab%2FUSPC%20%2D%20general%2F2%2E%20Skateboarden%2FSkatrixx%20%28Crossroads%29%2FRapportage