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TECHNOLOGY, COMMUNICATION AND TRANSPORT

SMART CONE PROJECT

Development of a Smart Navigation System for Athletes using Raspberry Pi and RTK GNSS Technology

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THESIS
Abstract

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Abstract

The Smart cone project involved the development and implementation of cutting-edge smart navigation system designed to enhance athlete training procedures through the integration of sensors and real time kinetics global navigation satellite system (RTK GNSS) technology. The project aimed to revolutionize traditional training methodologies by providing both athletes and coaches with an intelligent training tool that will enable precise location tracking & navigation capabilities, communication, and data exchange empowering athletes to engage in targeted and personalized training sessions.

The design of the system was divided into three working parts to include the communication part between cones and RTK GNSS technology, the identification of athletes and navigation system. The communication part uses Raspberry Pi 4B acting as hub and a bridge server to communicate between Pi Pico's which outputs data from attached sensors mounted inside a cone to serve as the identification part and the Rutronik System Solutions RDK3 + RAB4-RTK GNSS modules for centimetre-level precise positioning as the navigation part. The identification part comprises of the mounted Pico's in cones that connects a PIR sensor with a 2m range allowing person identification, a LED that blinks when the PIR sensor identifies person and a buzzer that alerts when the LED starts to blink.

The results showed seamless integration of the Pico with the PIR sensor and buzzer to identify person, with communication established between each cone on the raspberry pi 4B and the rover module broadcasts real time position data with less than 5cm accuracy.

Keywords

Smart cone, Smart navigation system, GNSS, RTK GNSS, RAB4-RTK, RDK3, LED, Raspberry Pi 4 b, Raspberry Pi Pico, PIR sensor, Buzzer

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1 INTRODUCTION

1.1 Background

Among the many definitions of Internet of things (IoT), a simple yet relatable definition coined from the Merriam-Webster dictionary (2024), describes IoT as the ability to network between objects and devices allowing information to be sent back and forth with the use of the internet; In another context, it is described as the ability to autonomously share information and respond to physical world events which are triggered by some processes regardless of the existence of human intervention or otherwise (Schoder 2018), yet another text portrays it as a concept of the interconnection of all things anywhere, anytime through intelligent controls, processing and transmission characterized by the integration of sensors and other supporting technologies (Chen & Jin 2012).

These definitions have some interesting phrases such as the 'ability to communicate', 'act autonomously' and 'Process information' while connected to a network, all of which are features used to create valuable solutions that makes daily livelihood better and as such having a great impact on athletics and sporting activities by creating an avenue to monitor events and make informed decisions based on results to enhance athletic capabilities.

With the focus on sporting activities, this project will analyze and develop a solution targeted at enhancing athletic performances and training habits through the creation of an intelligent navigation system that offers real-time tracking of athletic activities with precise navigation by integrating sensors with an advanced Global Navigation Satellite System (GNSS). (Hegarty & Chatre 2008.)

1.2 Aim of thesis

The sole aim of this thesis is to address the limitations of traditional navigation systems that fall short of meeting the specific needs of athletes such as accuracy in navigation, increased safety, and customizable features (determining speed for example) needed to maximize training sessions and enhance sports performance. A sophisticated navigation and positioning system that bridges the gap between these needs and limitations will thus be required to optimize training results.

1.3 Objective

The primary objective of this project is to design, develop and evaluate a smart navigation system that will utilize Global navigation satellite system (GNSS) and sensor technologies to provide accurate real-time tracking of athletes movements, dynamic navigation guidance based on athletes performance metrics such as speed, distance & route preferences also, a comprehensive performance analysis tool to track progress while identifying areas for improvement to optimize training strategies with a seamless integration of processing data for the ease of athletes and coaches.

1.4 Scope of project

This project delves into the design, development, and evaluation of a smart navigation system for athletes through the selection and integration of appropriate sensors and GNSS technology for tracking athletes’ movements and processing athletes’ performance data & metrics in real time.

2 THEORETICAL FRAMEWORK

2.1 Overview of Technology & Navigation Systems in Sports

2.1.1 Technology in Sports

Electronic advancements in sports transitioned from the introduction of electronic timing systems used to measure movement in competitive sports to computer digitization where digital video analysis emerged, offering valuable insights into athletes' techniques and biomechanics (Powell, Stuart, & Godfrey 2021). It has recently evolved to having chips and sensors installed on sports equipment and wears as seen in Figure 1.

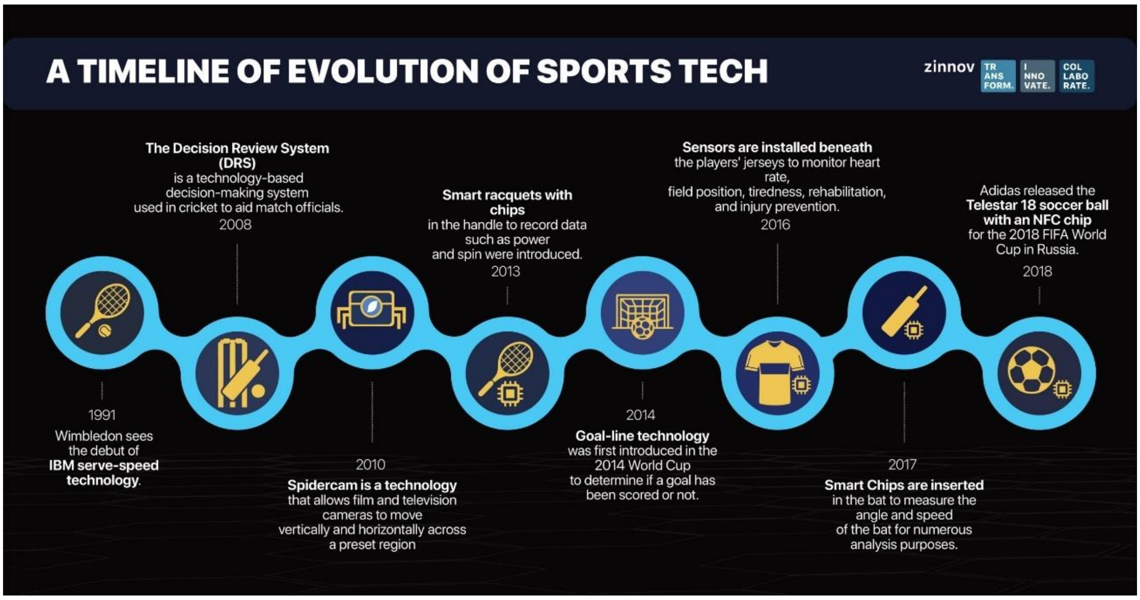

Figure 1. Sports Evolution (Zinnov 2023).

Global Navigation Satellite Systems (GNSS) such as the Global positioning System (GPS) which were primarily utilized for military purposes is now playing an important role in sports by improving the way athletes' positions, speeds, and distances covered during training and competitions are being tracked in real-time (Baker 2017). This technology offers significant data that could be utilized to enhance training programs and boost performance.

Real Time Kinetic (RTK) GNSS technology which is a technique used to enhance the precision of position data derived from satellite-based positioning systems on the other hand is a breakthrough in improving positioning accuracy. It provides centimetre-level precision by utilizing carrier phase measurements and correction data from a fixed base station, in contrast to standard GPS which only offers accuracy within a few meters. (Ferreira, Matias, Almeida, & Silva 2020.)

The Internet of Things (IoT) has revolutionized sports technology by facilitating seamless communication and real-time data sharing among interconnected devices with the use of advanced sensors, microcontrollers which once incorporated, results in the development of smart systems one which is the formation of advanced smart navigation systems offering real-time feedback, precise

tracking of movements, and data analytics of athletes to enhance their overall performances. (Borgia 2014.)

2.1.2 Analysis of Contemporary Patterns and Anticipated Trajectories

Currently, there is a growing trend towards the development and availability of highly sophisticated navigation systems tailored specifically for athletes utilizing cost-effective microcontrollers in conjunction with state-of-the-art sensors and RTK GNSS technology to enable the development of precise training systems which will provide a comprehensive range of data for performance analysis and improvement (Janos, Kuras & Ortyl 2022; Torres-Ronda et al. 2022).

In the coming years, it is expected that even greater integration of artificial intelligence and machine learning in the field of sports technology will pave the way for advanced predictive analytics and personalized training programs. In addition, the progress in wearable technology and wireless communication will further improve the capabilities and usability of smart navigation systems for athletes. (Cossich, Carlgren, Holash, & Katz 2023.)

2.1.3 Advantages of smart navigation systems in sports and athletics

The advantages of smart navigation systems in sports are primarily centered around their ability to greatly improve precision and accuracy which is a feature of the RTK GNSS technology compared to the standard GPS systems that provide accuracy within a few meters, which is inadequate for numerous sports applications (see Figure 2). (Liu, Huang, Hyyppä, Li, Gong, & Jiang 2023.)

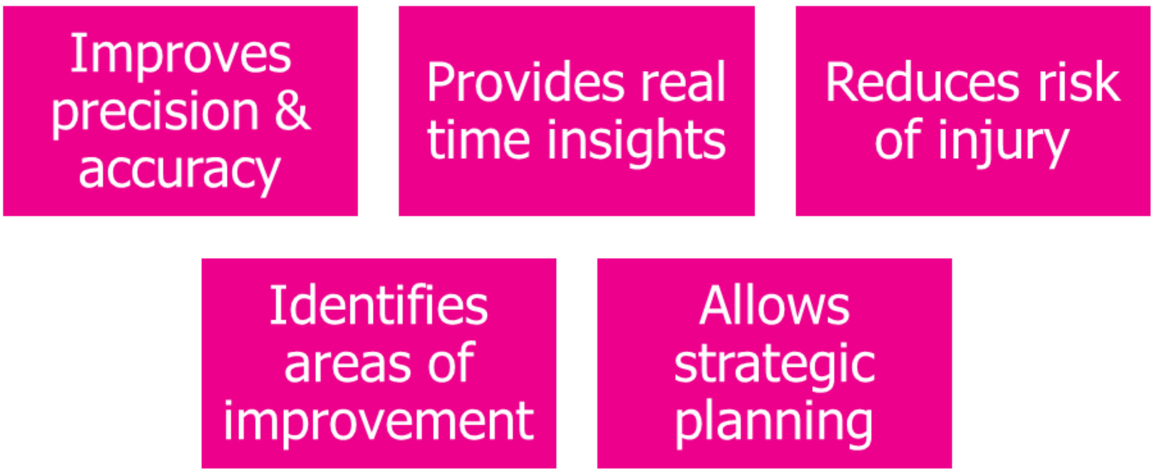

Figure 2. Some benefits of smart navigation systems (Ambler 2024).

RTK GNSS offers a high level of accuracy, allowing for precise monitoring of athletes' movements at the centimeter level to ensure accurate measurements are obtained for instance in essential in activities like sprinting, as even minor changes in trajectory can significantly affect performance outcomes. (Janos, Kuras & Ortyl 2022; Ambler 2024.)

Utilizing sensors, microcontrollers and RTK GNSS technology to develop advanced navigation systems that offer immediate feedback to athletes and coaches making available real-time data enables them to make instant adjustments to their techniques and strategies, thereby improving the overall effectiveness of training sessions. (Janos, Kuras & Ortyl 2022; Ambler 2024.)

These systems enable thorough data collection, capturing a range of metrics including speed, acceleration, distance covered, and heart rate. Integration of microcontrollers such as Raspberry Pi enables the processing and storage of large datasets, facilitating analysis to identify patterns, strengths, and areas for improvement. Utilizing advanced analytics enables the development of highly personalized training programs that are specifically designed to cater to the unique requirements and abilities of individual athletes. (Sheba, Mansour, & Abbasy. 2023.)

Precise tracking and monitoring of athletes' movements are essential for preventing injuries. Through the analysis of movement patterns and physical exertion data, coaches can detect indicators of fatigue or incorrect technique that could potentially result in injuries. Timely detection enables the implementation of interventions, such as modifying training intensity or prioritizing corrective exercises. In addition, after an injury, these systems can be utilized to track the progress of rehabilitation, guaranteeing that athletes can safely return to their optimal physical condition. (Seshadri et al. 2019.)

Effective strategic planning is crucial for achieving success in team sports. Advanced navigation systems offer in-depth analysis of player movements and positioning, enabling the development and enhancement of game strategies. Coaches can analyze data to gain insights into the impact of various formations and tactics on performance. This allows them to make informed decisions based on data, optimizing team dynamics and effectiveness during competitions. (Liu, Huang, Hyyppä, Li, Gong, & Jiang 2023; Ambler 2024.)

2.1.4 Applications in different sports

In Athletics, RTK GNSS technology enables precise analysis of sprinters' starts, turns, and finishes in track and field events. The data can be utilized by coaches to enhance athletes' techniques, thereby increasing their efficiency and speed. (Dellaserra, Gao & Ransdell 2014.)

In soccer, advanced navigation systems are employed to track players' movements, ensuring they maintain optimal positioning throughout the game. The provided data is valuable for strategic planning and evaluating the physical capabilities of players, including metrics like overall distance covered and number of sprints performed during a match. (Leser, Baca, & Ogris 2011.)

Rugby teams use these systems to monitor player positions and movements, aiding coaches in analyzing formations and strategies. The data collected helps in managing player workloads and

reducing the risk of overtraining and injuries (Torres-Ronda, Beanland, Whitehead, Sweeting & Clubb 2022).

Smart navigation systems offer real-time feedback on speed, distance, and route efficiency for cyclists. This data is crucial for optimizing training and planning race strategies and enables cyclists to make necessary adjustments to their efforts according to the terrain and conditions. (Oliveira, Nery, Costa, Silva & Lima 2021.)

Precise monitoring of skiers' trajectories and velocities can enhance both safety and performance in skiing. Coaches can utilize data analysis to improve techniques, minimize accident risks, and ensure skiers follow the most efficient routes down the slopes. (Supej & Holmberg 2021.)

The combination of Raspberry Pi and RTK GNSS technology for developing smart navigation systems provides significant advantages for sports training and performance.

2.2 Review of related technologies

2.2.1 Raspberry Pi Pico h

The Raspberry Pi Pico is a microcontroller board developed by the Raspberry Pi Foundation, it is a device constructed using the RP2040 microcontroller chip, which has been specifically engineered for use in embedded applications (see Figure 3). The Pico is a highly adaptable and robust platform that can be utilized for various projects, spanning from basic automation tasks to intricate IoT systems. The compact nature, affordable price, and versatile features of this device make it a highly suitable
option for creating advanced navigation systems tailored for athletes. Some of its features include a dual-core Arm cortex-M0+ processor, 2MB on board flash memory, 26 multifunction GPIO pins, 16 controllable Pulse width modulation (PWM) channels, drag and drop programming and interfaces such as I2C, SPI, UART, ADC. (Raspberry pi foundation 2020.)

The Pico can be programmed using Micro-python or C/C++, allowing developers to have flexibility in choosing their preferred programming language. The Raspberry Pi's GPIO capabilities make it highly compatible with a wide range of sensors and peripherals, making it a popular choice for embedded and IoT applications. (Raspberry pi foundation 2020.)

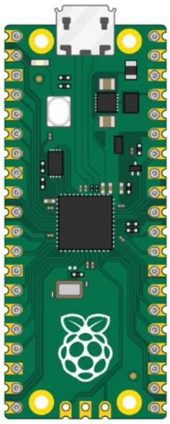

Figure 3. Pinout and design of Raspberry Pi Pico (Raspberry pi foundation 2020).

The Raspberry Pi Pico is a highly capable microcontroller that provides a range of advantages including real time data processing, low power operation and seamless integration with various thus it is a valuable component for creating intelligent systems and for this project it contributes greatly to building a smart navigation system for athletes. (Raspberry Pi Foundation. 2020.)

2.2.2 Infrared motion sensors in smart training systems

The advantages of smart navigation systems in sports are primarily centered around their ability to greatly improve precision and accuracy which is a feature of the RTK GNSS technology compared to the standard GPS systems that provide accuracy within a few meters, which is inadequate for numerous sports applications. (Liu, Huang, Hyyppä, Li, Gong, & Jiang 2023.)

Figure 4. Passive Infrared Sensor (Mouser 2024)

IR motion sensors have several advantages in athletic training, they provide accurate tracking, non-invasive monitoring, and real-time data collection, all of which improve the effectiveness of training programs. (Sun et al. 2022).

Infrared motion sensors work by detecting infrared radiation and are generally two types: active and passive. Active infrared sensors emit an infrared beam that is reflected by an object, enabling the sensor to detect movement when the beam is interrupted; Passive infrared (PIR) sensors detect infrared radiation emitted by warm objects, like the human body, without emitting any radiation themselves (see Figure 4). (Casaccia, Braccili, Scalise & Revel 2019.)

PIR sensors are frequently utilized in sports training systems because of their straightforward design, minimal energy usage, and ability to accurately detect human motion. The sensors are equipped with a pyroelectric material that produces a voltage in response to alterations in infrared radiation indicating the occurrence of movement. (Ismail et al. 2016.)

In training sessions, athletes' movements can be tracked and analysed using infrared motion sensors. Coaches can effectively monitor athletes' positions, speeds, and trajectories by strategically placing sensors on the training field or course, the provided data aids in comprehending movement patterns and pinpointing areas that require enhancement. (Sun et al. 2022.)

An important benefit of IR motion sensors is their capacity to monitor athletes without being intrusive, athletes can train without any discomfort or performance issues, as they operate from a distance and do not encounter the athletes. Its monitoring is especially advantageous in sports such as gymnastics or martial arts, where the ability to move freely is crucial. (Ismail et al. 2016.)

2.2.3 Buzzer Alerts in Sports Technology

Buzzer alerts play a vital role in contemporary sports technology by offering athletes and coaches instant auditory feedback. Alerts are commonly employed to indicate different events, including task completion, deviations from a predetermined path, or warnings about potential hazards. Integrating buzzers in intelligent navigation systems can enhance the training process by providing immediate notifications that can enhance performance and safety. (Powell, Stuart & Godfrey 2021.)

Figure 5. Buzzer (Mouser Electronics 2024).

Buzzers are electronic devices that transform electrical signals into audible sound, there are generally two types of buzzers being the active and passive. Active buzzers are equipped with an internal oscillator that easily produces sound when power is applied, resulting in a user-friendly. Passive buzzers, in contrast, rely on an external signal to generate sound, providing greater versatility in terms of tone and duration. (Jones & Smith 2020.)

In the field of sports technology, active buzzers are widely utilized for their seamless integration and dependable performance, its basic application is alerting by creating sounds to suit the purposes of the environment it is being used (see Figure 5). Microcontrollers like the Raspberry Pi Pico can control buzzers by receiving signals from sensors and monitoring devices. (Joseph, Kian & Begg 2023.)

2.2.4 RTK GNSS technology

RTK GNSS technology is a precise positioning system that improves the accuracy of GNSS data. It is extensively used in a range of disciplines, such as surveying, agriculture, and sports, where accurate location data is essential. (Dellaserra, Gao & Ransdell 2014.)

RTK GNSS enhances the precision of standard GNSS through the utilization of carrier-phase measurements of satellite signals. The system functions using a base station and one or more rover units. The base station, located at a known position, receives GNSS signals and calculates correction data. The correction information is transmitted to the rovers, which then apply these corrections to their own satellite signal measurements. The process described in the study by Leick et al. (2015) has been found to greatly minimize positional errors, resulting in a high level of accuracy at the centimetre scale.

Components of the RTK GNSS include a base station which can be a stationary receiver that is strategically positioned at a known location to gather information from the satellite and performs calculations to determine error corrections, a rover which is usually a mobile receiver that utilizes corrections from the base station to deliver accurate location data and a communication link used to establish connection usually through a radio or cellular network to transmit real-time correction data from the base station to the rover. (Su 2017.)

RTK GNSS technology is commonly employed in sports to track athletes' movements with utmost accuracy, enabling precise measurement of speed, distance, and trajectory. The precision provided by this technology is especially advantageous in sports such as running, cycling, and skiing. It allows for a more effective and safe training experience for athletes. (Real-time Kinematic Positioning 2024.)

Its advantages are to achieve centimetre-level accuracy, which is significantly higher than standard GNSS, provides real time data by making carrier phase measurements and calculations that pins positional information therefore it allows for performance optimization and ensures safety.

2.3 Existing smart training solutions

2.3.1 Review of Similar Projects and Products

Various projects and products have examined the integration of advanced technologies such as GNSS and microcontrollers to improve athletic training. Examining these projects offers valuable insights to the design and execution of intelligent navigation systems for athletes.

The Forerunner series by Garmin is well-known for its utilization of GPS and sophisticated sensors to offer athletes with comprehensive performance metrics, it is a wearable device with features such as real-time pace, distance tracking, and heart rate monitoring, utilizing GNSS technology for precise positioning. The Forerunner series showcases the effectiveness of combining GNSS with wearable technology to improve athletic training. (Garmin 2024.)

The STRYD Running Power Meter is a device that measures and analyses running power. It provides valuable insights into your running performance, helping you optimize your training and improve your overall efficiency. With its advanced technology and accurate measurements, the STRYD Running Power Meter is a valuable tool for athletes and runners looking to take their performance to the next level. The STRYD running power meter is a foot-pod that utilizes state-of-the-art sensors and algorithms to accurately measure a runner's power output. STRYD assists athletes in maximizing their performance by offering comprehensive data on running dynamics, encompassing form, efficiency, and pace. While not utilizing RTK GNSS, the study emphasizes the advantages of real-time feedback in enhancing training results. (Stryd 2024.)

The Nike+ Training System is a comprehensive fitness program designed to help individuals achieve their fitness goals, it offers a wide range of workouts and training plans that cater to different fitness levels and objectives, its user-friendly interface with intuitive features makes it a convenient and effective way to track progress and stay motivated. The Nike+ system utilizes shoe-embedded sensors and mobile applications to meticulously monitor and evaluate running performance. It gives immediate feedback on metrics like distance, speed, and calories burned. The way Nike+ seamlessly incorporates sensor data into user-friendly interfaces is a prime example of how technology can elevate the training experience. (Nike Run Club App 2024.)

The Polar Vantage V2 is a versatile sports watch that provides a range of advanced training features. These include GNSS-based tracking, running power measurement, and recovery analysis. The inclusion of GNSS technology for accurate tracking positions it as a pertinent illustration for the advancement of intelligent navigation systems designed for athletes. (Polar Global 2024.)

Suunto 9 Baro is a multisport GPS watch specifically designed to cater to the needs of endurance athletes. The device includes advanced GNSS tracking, precise barometric altitude measurement, and efficient battery modes. The Suunto 9 Baro exemplifies the effective utilization of GNSS technology to ensure precise performance monitoring. This serves as a valuable example for incorporating similar features into personalized navigation systems. (Suunto 2024.)

Zwift is an online platform that offers a virtual training environment for cycling and running. It utilizes sensors and GNSS data to provide a realistic experience. This device seamlessly integrates with various exercise equipment, allowing for instant feedback and the opportunity to engage in virtual competitions. Zwift demonstrates the potential of integrating GNSS and sensor data to improve training by creating interactive and effective training experiences. (Zwift 2024.)

These projects and products demonstrate a wide range of applications for GNSS and sensor technologies in sports training that greatly improves the accuracy and functionality of athletic training systems providing real-time, high-precision feedback to optimize performances and ensure safety.

2.3.2 Evaluating strengths and weaknesses of similar projects

An evaluation of strengths and weaknesses of previous projects is important in determining the suitable components to suit specific purposes and give the desired results in the developing of a smart navigation system.

Table 1. Strengths and weaknesses of previous products (Garmin 2024; Nike 2024; Polar 2024; Suunto 2024).

Products	Strengths	Weaknesses
Garmin series smartwatches	High precision, data tracking abilities, user friendly	High price & power consumption.
Polar smartwatch	Accurate route tracking, measures performance metrics	Complex features
Suunto 9 Baro watch	Good battery management, designed for harsh conditions, GPS tracking	Heavy device
Nike run club	User friendly	Limited advanced metrics

Smart navigation systems and fitness trackers currently available provide a range of benefits, including precise tracking, thorough data analysis, and engaging user experiences. Nevertheless, there are certain drawbacks associated with them, such as their expensive price, short battery lifespan, and potential compatibility problems (see Table 1). These are factors considered for the development of a smarter and more accessible navigation system for athletes.

2.3.3 Raspberry pi 4b analysis

Raspberry Pi 4B, is a highly adaptable single-board computer that finds extensive use in a range of applications, spanning from educational to industrial projects (see Figure 6). The device's powerful processing

capabilities and wide range of communication features make it a perfect option for developing intelligent navigation systems.

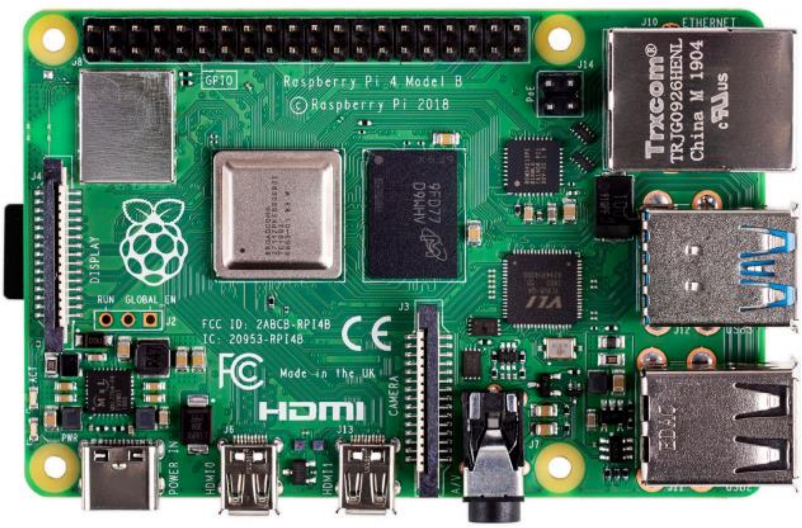

Figure 6. Raspberry Pi 4 B (Raspberry Pi Foundation 2024).

The Raspberry Pi 4B comes with a 1.5GHz quad-core ARM Cortex-A72 CPU, offering significant computational power. The device is available in various RAM configurations (2GB, 4GB, 8GB), which improve its performance and multitasking capabilities. In addition, the device features dual-band wireless networking, Bluetooth 5.0, and Gigabit Ethernet, which are essential for smooth real-time communication. (Raspberry Pi Foundation 2024.)

Raspberry Pi 4B's communication capabilities make it well-suited as a hub for a smart navigation system. The wireless and Bluetooth connectivity allows for immediate data exchange between the Raspberry Pi, RTK GNSS modules, and other peripheral sensors. Stable data transmission is guaranteed by the Gigabit Ethernet, facilitating system updates and large data transfers. In addition, the inclusion of USB 3.0 ports and GPIO pins allows for the seamless integration of extra sensors and modules, which are crucial for athlete monitoring and navigation assistance. (Raspberry Pi Foundation 2024.)

2.4 Communication Protocols in IoT Systems

Wireless communication protocols play a crucial role in ensuring the smooth operation and optimal performance of Internet of Things (IoT) systems. The protocols enable efficient data exchange among devices, promoting smooth connectivity and interaction within the IoT ecosystem. For the successful implementation of a smart navigation system for athletes using Raspberry Pi and RTK

GNSS technology, a thorough grasp of these protocols is essential to ensure dependable and streamlined data communication.

Wi-Fi is a popular wireless communication protocol in IoT systems because of its fast data transfer rates and wide coverage. This device operates on the IEEE 802.11 standards and is well-suited for applications that demand high data throughput and dependable connectivity in a local area. As an example, the Raspberry Pi 4B in a smart navigation system can be connected to a local network using Wi-Fi. This connection allows for the easy transmission of data and enables remote monitoring. (Madakam, Ramaswamy & Tripathi 2015.)

Bluetooth Low Energy (BLE) is widely used for short-range communication among IoT devices. It is specifically designed to minimize power consumption, making it an ideal choice for wearable devices and sensors that require intermittent communication while preserving battery life. Efficient and low-power communication can be achieved in a smart navigation system by using BLE to transmit data from sensors to the Raspberry Pi Pico. (Madakam, Ramaswamy & Tripathi 2015; Latré et al. 2016.)

Zigbee is a wireless communication protocol that operates on low power and low data rates. It is based on the IEE E 802.15.4 standard. This solution is specifically tailored for IoT applications that necessitate secure, dependable, and energy-efficient communication within a limited to moderate distance. Zigbee is highly valuable in mesh networking, as it enables devices to establish communication with one another through intermediate nodes. This effectively extends the range and enhances the reliability of the network. This can be advantageous in a smart navigation system for establishing a strong communication network among multiple devices. (Madakam, Ramaswamy & Tripathi 2015.)

LoRaWAN is a protocol specifically developed to facilitate long-range, low-power communication. It operates in spectrum bands that do not require a license and is well-suited for applications that need extensive coverage and low power usage, such as environmental monitoring and remote sensing. LoRaWAN enables efficient communication between devices across a wide area, ensuring reliable data transmission without the need for frequent battery replacements. (Madakam, Ramaswamy & Tripathi 2015.)

Cellular technology has evolved significantly with the introduction of 4G and 5G networks. These advancements have revolutionized the way we communicate and access information on our mobile devices. With faster speeds and improved connectivity, 4G and 5G have opened new possibilities for mobile applications and services. Cellular networks, such as 4G and the upcoming 5G, offer extensive coverage and fast data transfer rates. These networks are well-suited for IoT applications that necessitate mobility and wide coverage, such as vehicle tracking and remote health monitoring. In the field of smart navigation systems, the utilization of cellular connectivity allows for the seamless transmission of real-time data and the convenient access to performance data from any location. (Madakam, Ramaswamy & Tripathi 2015.)

The choice of wireless communication protocol is influenced by various factors including range, power consumption, data rate, and network topology. For example, Wi-Fi and cellular networks offer

strong data transmission capabilities for remote monitoring and data analysis. BLE is commonly employed for establishing low-power communication between sensors and the main processing unit, like the Raspberry Pi. Zigbee and LoRaWAN enable dependable communication in a mesh network or across extended distances while minimizing power consumption. (Madakam, Ramaswamy & Tripathi 2015; Pahlavan & Krishnamurthy 2020.)

Having a solid grasp of wireless communication protocols is crucial when it comes to creating effective and dependable IoT systems. In the development of a smart navigation system for athletes, it is important to consider utilizing the most suitable protocols to significantly improve the system's performance for efficient results.

2.5 System architecture & conceptual design

2.5.1 System components

The Raspberry Pi 4B functions as the system's central processing unit (CPU). The system manages various tasks including data processing, communication, and user interface. The device offers a range of features, including GPIO pins for sensor integration, ample processing power for real-time data processing, and multiple connectivity options like Wi-Fi, Bluetooth, and USB. (Upton & Halfacree 2019.)

The Raspberry Pi Pico is a microcontroller that enables seamless integration with a wide range of sensors and peripherals, including infrared motion sensors and buzzers (see Figure 7). It functions as a secondary processing unit, overseeing the collection and initial processing of data before transmitting it to the Raspberry Pi 4B for further analysis. (Upton & Halfacree 2021.)

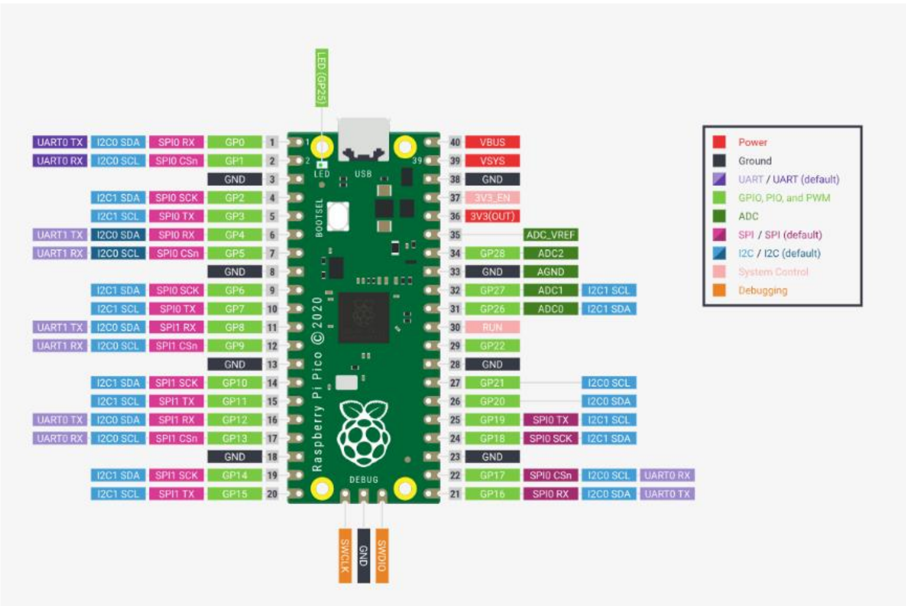

Figure 7. Details of Raspberry Pi Pico pinout (Raspberry Pi Foundation 2020).

The RTK GNSS module offers highly precise positioning data with centimetre-level accuracy, its system comprises of a base station and a rover. The base station remains fixed in place and transmits correction data to the rover within 20km (Leick et al. 2015). Rutronik solutions RAB4-RDK delivery set includes the RAB4-RTK board, three antennas, USB 2.0 to USB-C cable and a nano sim card (see Figure 8).

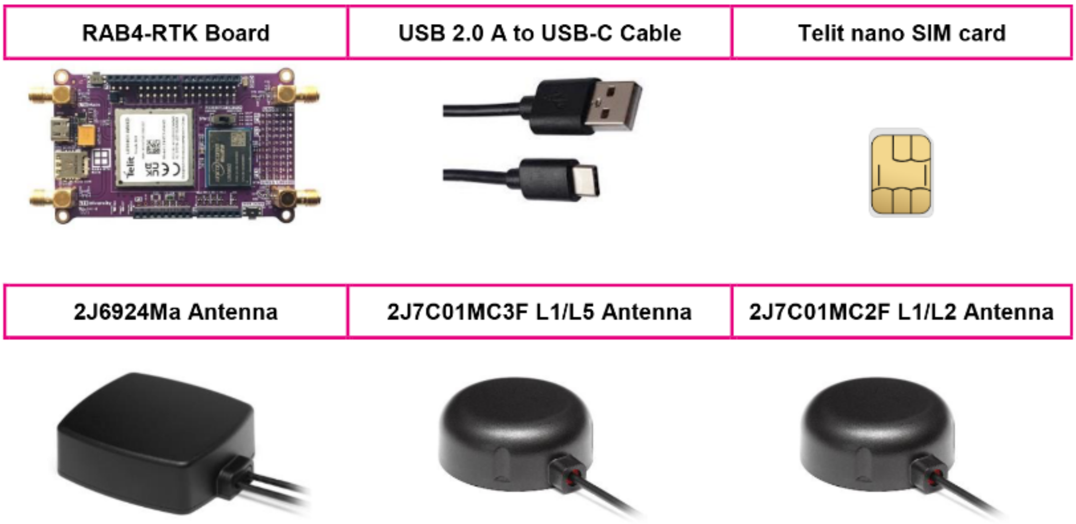

Figure 8. RAB4-RTK Set (RAB4-RTK User Manual s.a.)

This board stacked with RDK3 board together to form the rover (see Figure 9). Then it uses the credentials from the National Land Survey of Finland to connect to a nearby base station and receives correction data over an internet protocol called the NTRIP (Networked Transport of RTCM via Internet Protocol 2023; RTK service s.a.).

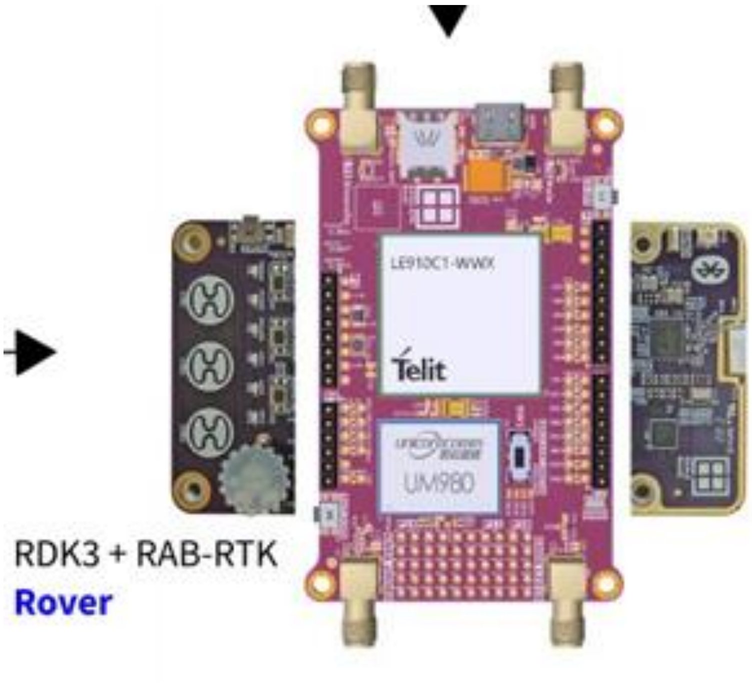

Figure 9. Rutronik System Solutions RDK3 + RAB-RTK components (RAB4-RTK documents s.a.).

Passive infrared motion sensor (EKMB1293111) can detect the presence and movement of athletes within 2.2m range. The sensor is strategically positioned in a cone within the designated training zones to initiate data logging and alerts from the buzzer and blink a LED when an athlete passes by (Latré et al. 2016).

Buzzers are used to give athletes auditory feedback, indicating different events like course deviations, interval completions, or approaching hazards. The buzzer (CMI-1295IC-0585T) is synchronized with the motion sensor to create sound alerts indicating person identification and to provide athletes with prompt and unobtrusive notifications during their training sessions (Anderson & Walker 2019; Jones & Smith 2020).

Wireless communication modules, like Wi-Fi and Bluetooth, facilitate data transmission between Raspberry Pi units and external devices. Real-time data monitoring, remote control, and data logging is enabled for metrics analysis (Madakam, Ramaswamy & Tripathi 2015.)

The overall structure of the system is divided into an identification part, communication and the navigation parts all integrated to form a working smart navigation prototype. The identification part consists of the Raspberry Pi Pico, the PIR sensor and buzzer for easy identification of person, it also includes an LED whose function is to serve as a visual alert and a way of communicating between cones. The communication part consists of the raspberry pi 4B which acts as a hub and allows for data transfer and processing between the navigation and the identification parts however the navigation parts comprise of the RDK3+RAB4-RTK components.

2.5.2 Integration of Hardware and Software Components

Raspberry Pi Pico h serves as a microcontroller to interface with the PIR sensor, buzzer, and LED (see Figure 10). The specification of the individual components such as power inputs & output including correct positioning of the sensors pinout is taken into consideration for efficient results.

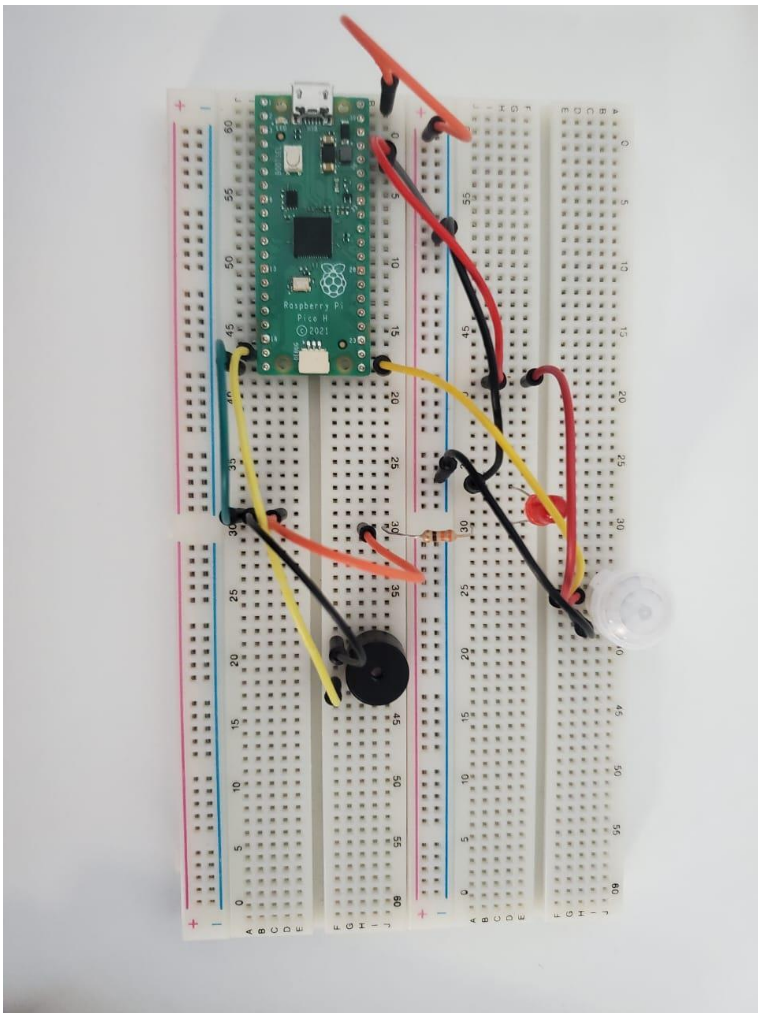

Figure 10. Raspberry Pi Pico, buzzer, and PIR sensor setup

The setup of the smart navigation cone also includes orange cones (see Figure 11). It houses the identification part of the design which are placed in designated parts on training grounds to keep the sensors working without interfering with athletes training routines.

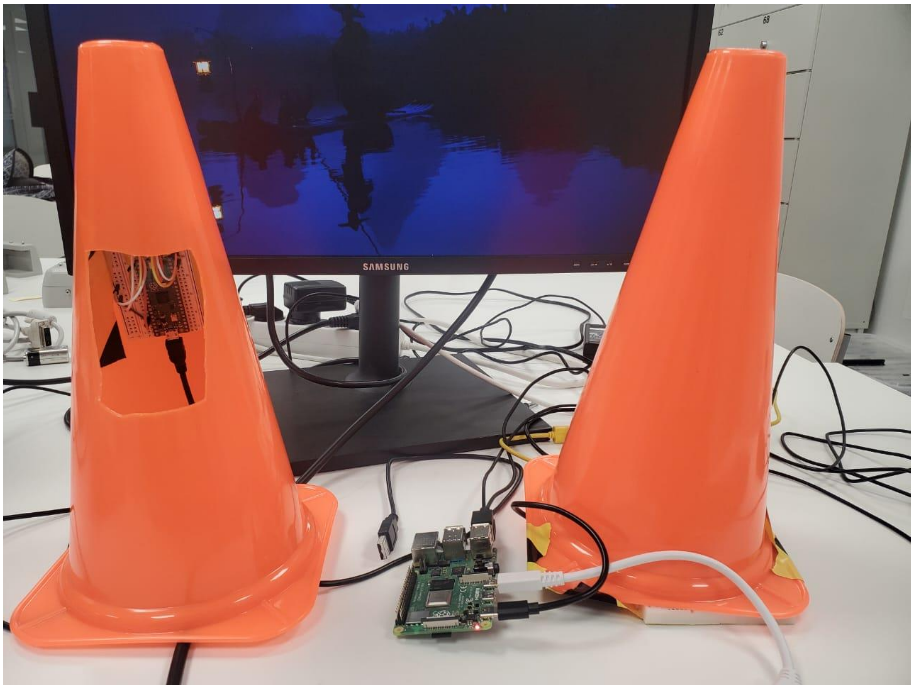

Figure 11. Cone prototype with the raspberry pi 4B

The Raspberry Pi 4B acts as a hub for communicating between the two cones each having the Raspberry Pi Pico and sensors mounted. The Picos are connected to the USB ports of the Raspberry Pi 4B.

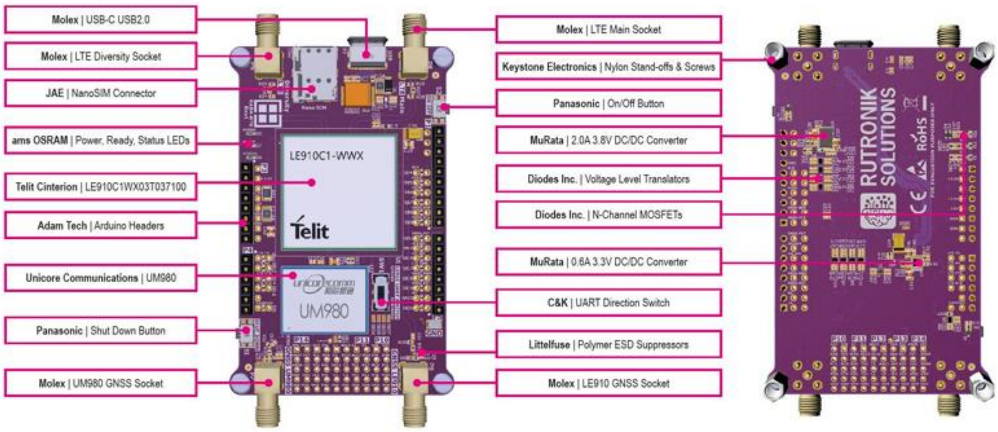

Figure 12. Rutronik System Solutions RAB4-RTK (RAB4-RTK User manual s.a.).

RAB4-RTK has two major components, the Telit LE910C1-WWXD for LTE connectivity and Unicore Communication UM980 module which can calculate RTK corrections for precise positioning (see Figure 12). (Rutronik System Solutions RAB4-RTK User manual s.a.).

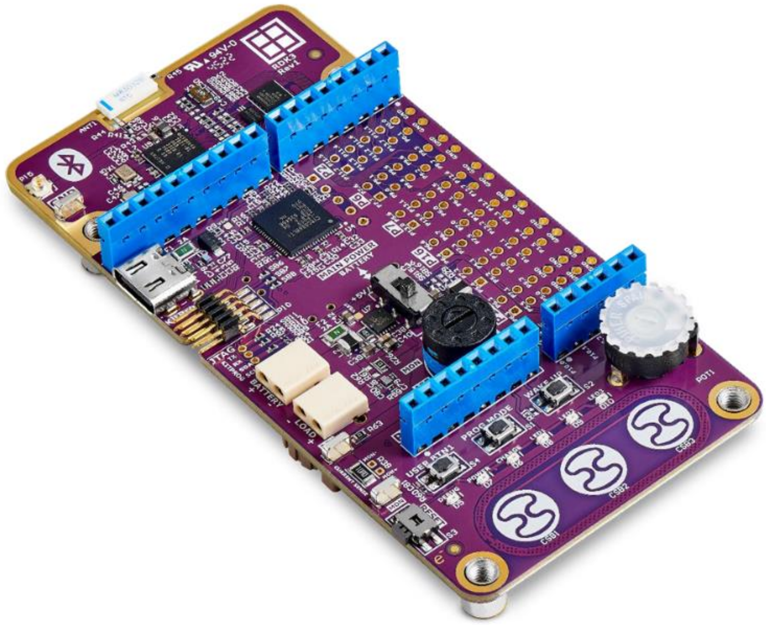

Figure 13. RDK3 module (RDK3 User Manual s.a.).

Raspberry Pi Operating System (OS) is a Debian-based OS designed specifically for Raspberry Pi hardware. It offers a stable environment for development and deployment (Raspberry Pi Foundation 2020). Python programming language is utilized for scripting sensor interactions, data processing, and system control due to its simplicity and wide range of libraries (Lutz 2013).

The software development involves the setup and installation of required libraries and files on the Raspberry Pi 4B and Pico, and configuration of the RTK GNSS module using the Rutronik System Solutions installation and setup guide for provisioning of RDK3 keys before mounting it on the RAB4-RTK for a seamless integration process in outputting precise location data on Rutronik mobile application (see Figures 9, 12 & 13). (Raspberry Pi 2024; Rutronik System Solutions s.a.).

Micropython script is utilized to read data from infrared motion sensors and control the buzzer (see Figure 14). The script has two imports for hardware and time functions, it then initializes variables for the PIR sensor as an input from Pico’s GPIO 16 set, the LED on GPIO 15 as output and the buzzer on Pico’s GPIO 14 as output. A function is now created to for what happens when the PIR sensor is triggered which is to toggle the LED and the buzzer with a for loop while including a delay function and printing a message to the console. An interrupt function is set to trigger the motion sensor when motion is detected and consequently triggers the LED to blink and the buzzer to alarm then a while loop which keeps running when motion is not detected is set to toggle LED and turn off the buzzer. (Instructables 2023.)

```
<untitled>  [ main.py ]
import machine #import machine module for accessing hardware functions
import utime #impport utime module for time related functions

sensor_pir = machine.Pin(16, machine.Pin.IN) #initialize PIR sensor on Pico GPIO 16 as input
led = machine.Pin(15, machine.Pin.OUT) #initialize LED on Pico GPIO 15 as output
buzzer = machine.Pin(14, machine.Pin.OUT) #initialize Buzzer on Pico GPIO 15 as output

def pir_handler(pin):
  print("CONE A! PERSON DETECTED!")   #print the message to shell console.
  for i in range(10): #repeat 10 times
    led.toggle() #toggle the LED state
    for j in range(5): #repeat 5 times
      buzzer.toggle() #toggle the buzzer state
      utime.sleep_ms(3) #Delay for 3 milliseconds

#set an interupt to call pir_handler when motion is detected
sensor_pir.irq(trigger = machine.Pin.IRQ_RISING, handler = pir_handler)

while True:
  led.toggle()   #toggle the led state
  buzzer.off()   #turns off buzzer
  utime.sleep(5) #delay for 5 seconds
```

Figure 14. Micropython script (Instructables 2023).

Output of script shows in the shell console of the Thonny IDE, allowing some text to be shown when sensors are triggered (see Figure 15).

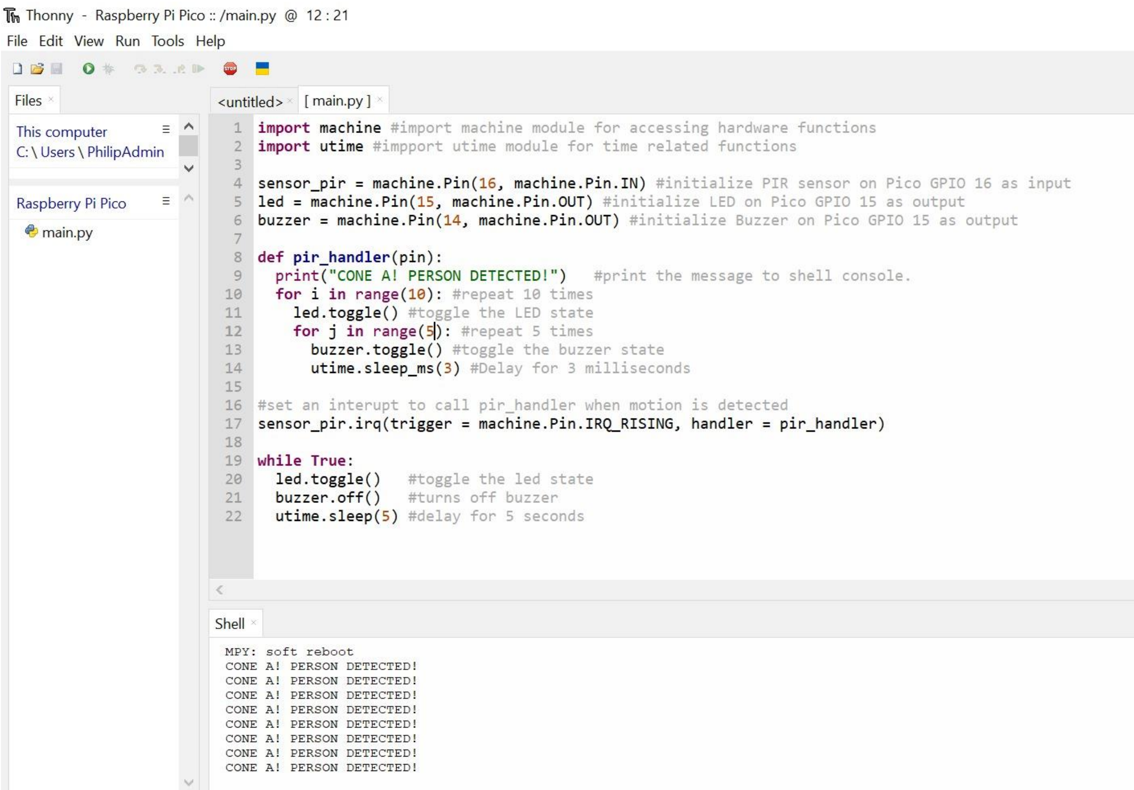

Figure 15. Thonny IDE, script & output shell

Meanwhile, credentials from the National Land Survey Finland are utilized to process raw GNSS data from a nearby base station to the RDK3+RAB4-RTK rover and calculate precise positions for GNSS

data processing and then, performing tests to validate the precision of GNSS data. Tests were carried out using the mobile GPS, credentials provided by National Land Survey of Finland that includes a caster address or IP, caster port with the username and password created form the website as well as the selection of a suitable mountpoint (data stream). Download a NTRIP client mobile application and set the credentials for tests to validate GNSS accuracy as shown in Figure 16.

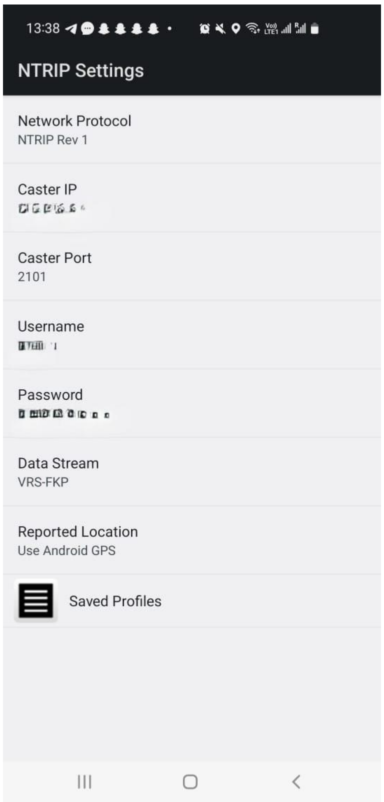

Figure 16. NTRIP credentials settings snapshot as set on Lefebure design mobile application.

3 IMPLEMENTATION AND TESTING

3.1 Hardware setup

3.1.1 Assembly of the hardware components

The assembly process starts by collecting all the necessary components, including the Raspberry Pi 4B, Raspberry Pi Pico, RTK GNSS modules, infrared motion sensors, and buzzers. The Raspberry Pi 4B functions as the primary processor, with the Raspberry Pi Pico serving as the interface for the sensors and buzzers. The RTK GNSS setup consists of a base station credentials and rover module of the mounted and already provisioned RDK3+RAB4 module.

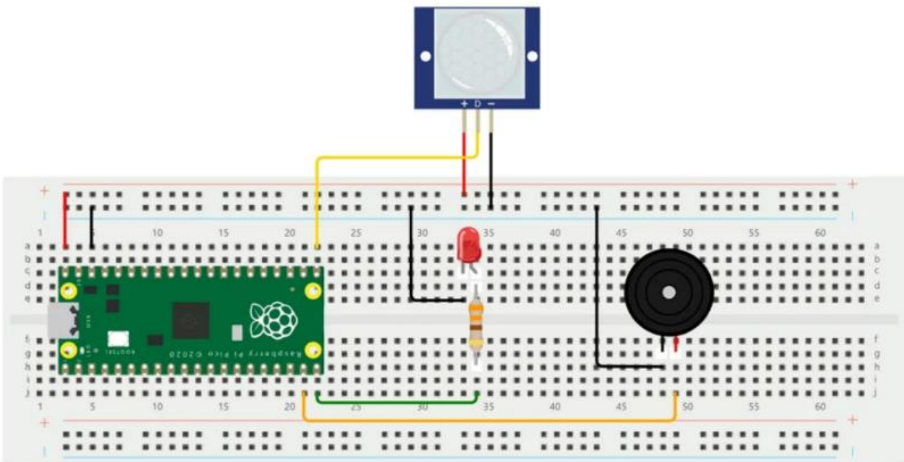

Figure 17. A sample breadboard connection (Instructables 2023).

Jumper cables are used to connect the EKMB1293111 PIR sensor and the piezo buzzer components on a breadboard taking into consideration the power recommendations and pinout (see Figure 17). The positive rail takes power from the Pico's VBUS pin 40, the negative rail is connected to the ground pin 38, the power pin of the PIR sensor is connected to the 3.3 volts pin 37 as recommended by product manufacturer, its ground pin connects to the negative rail while the output pin is connected to Pico's GPIO pin 16. The positive pin of the buzzer is connected to the GPIO pin 14 on the Pico and the negative pin goes to the ground rail while the LED has a 330-ohm resistor attached to its positive leg and then takes output from the GPIO pin 16 on the picot, its negative leg is attached to the negative rail. All connections are made before powering the Pico from the bootsel button.

3.1.2 Configuring the Raspberry Pi Pico

Raspberry Pi Pico requires uploading the U2 file which contains the OS of Pi Pico. This process is achieved by pressing the bootsel button for a few seconds and attaching its USB cable to a computer to power it on while pressing the button (see Figure 18).

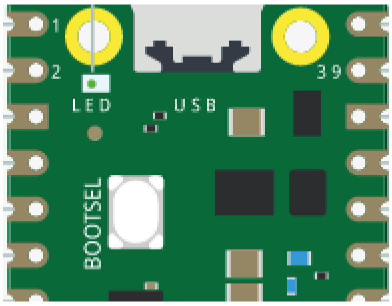

Figure 18. Bootsel button on Pico (Raspberry Pi Foundation 2020).

Pico mounts on the computer as a storage device, the next step is to drag and drop the downloaded U2 file to upload the OS after which it automatically unmounts and is ready for programming afterwards (see Figure 19).

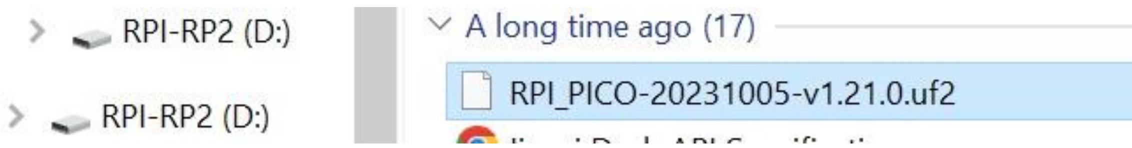

Figure 19. A snapshot showing how to mount Operating System file on Pico.

Thonny is a free and open-source integrated development environment for python coding available on Windows, macOS and Linux operating systems, it supports CPython and Micropython scripting and has various features some of which includes separate windows for function calls, file management and remote machine via SSH (Thonny 2024). The identification part of this project is created on the Thonny IDE to write, run, and save scripts on the Raspberry Pi Pico (see Figure 20).

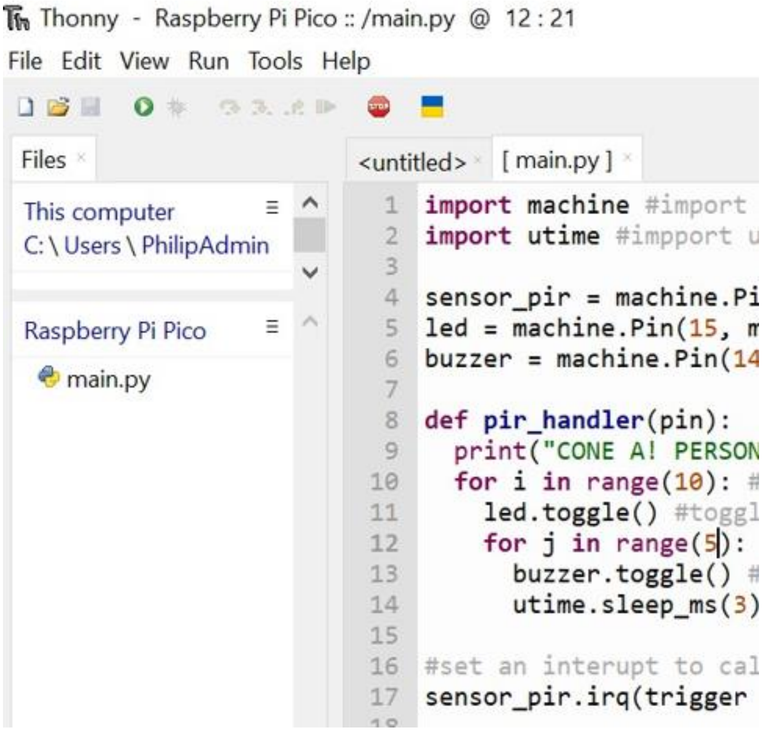

Figure 20. Thonny IDE computer workspace.

3.1.3 Setting up the rover

To set up the rover, the Rutronik Development Kit (RDK3) should be configured with keys and policies before mounted on the Rutronik Adapter Board (RAB4).

The RDK3 is a Bluetooth technology-based development board with several features that includes an On-board debugger KitProg3 with I2C and UART USB bridge, a M830320 On-board 2.45GHz Bluetooth antenna and an U. FL connector for external Bluetooth antenna with enhanced security features from the PSoC64 family of microcontrollers (RDK3 user manual s.a.).

Figure 21. MoodusToolbox 3.1 (Infineon Developer Center Launcher 2024).

The first step is to register on Infineon website for access to download the Modus Toolbox application software 3.1 which is a compatible version and installing it on the computer (see Figure 21). Then, power the board by connecting it to the USB socket marked KitProg3 on the RDK board to the computer (see Figure 22). It is important to note that these configuration settings were done a windows operating system.

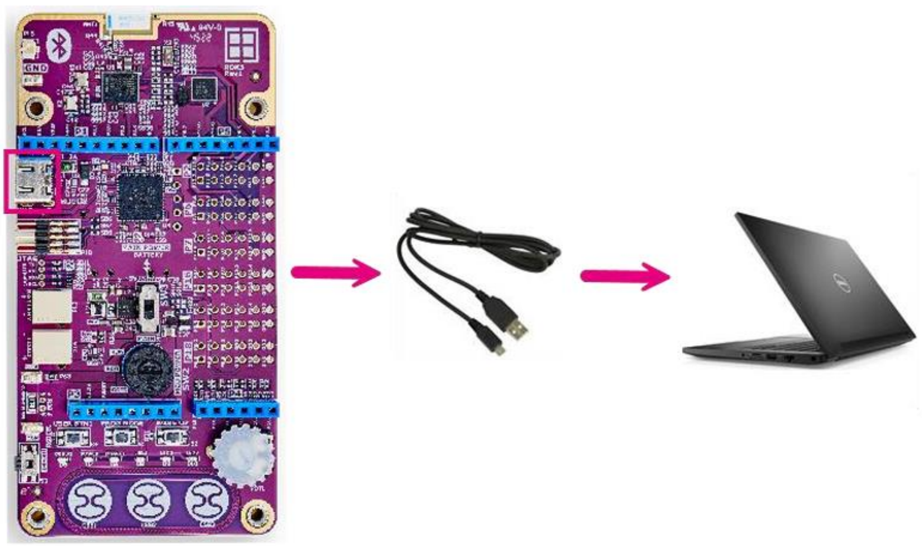

Figure 22. KitProg3 USB socket, USB cable and Computer (RDK3 User Manual s.a.).

To provision the device, open the Eclipse IDE for Modus Toolbox 3.1 by tying this name directly on the search pane of the computer. The IDE is included in the installation of the Modus Toolbox 3.1 application. Create a new application by navigating to a new Modus Toolbox application (see Figure 23).

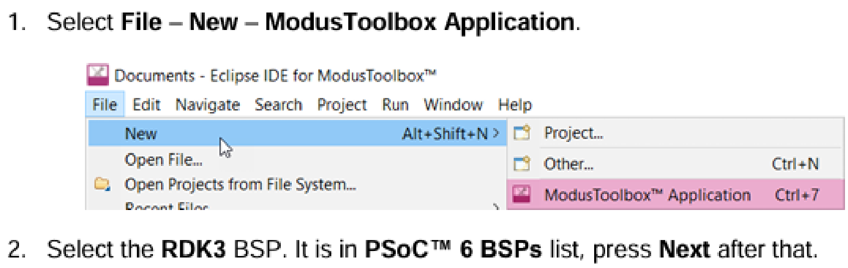

Figure 23. Creating a new Modus Toolbox application (RDK3 User Manual s.a.).

Next, select RDK3 Board Support Program (BSP) found in the PSoC6 BSP lists and then select the RDK3 Bluetooth application (see Figure 24).

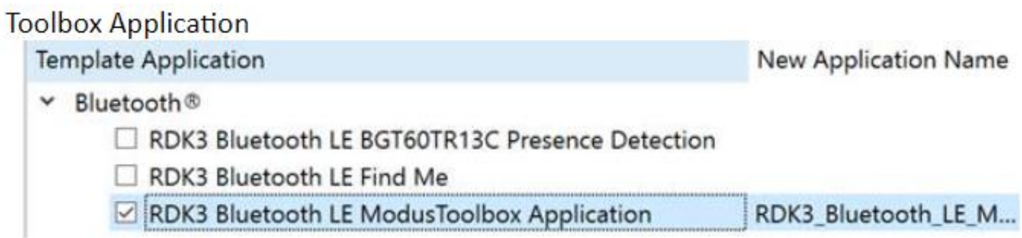

Figure 24. Navigating to the Bluetooth application for provisioning (RDK3 User Manual s.a.).

Once selected, the project opens inside the workspace, click on it to have access to view folders (see Figure 25).

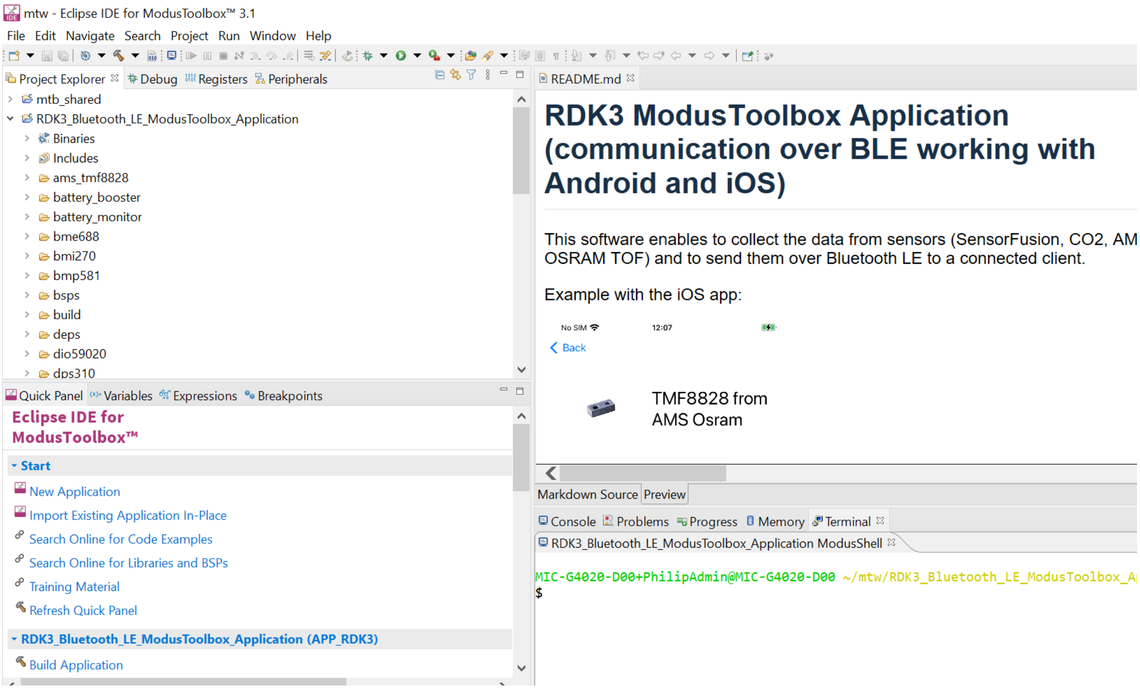

Figure 25. A snapshot of the Modus Toolbox workspace.

Download keys, packets, and policy folders from the RDK3 documents on GitHub directories into the workspace. These folders are needed for provisioning of the device (see Figure 26).

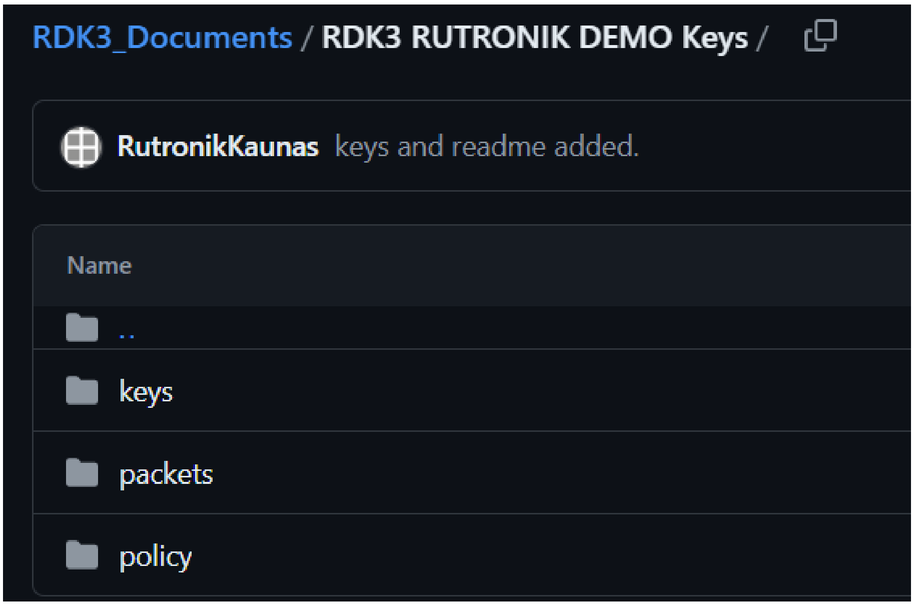

Figure 26. Download Keys, Packets and Policy (Rutronik System Solutions s.a.).

Once these are in place, remove the USB cable of the RDK3 to power off the board before switching the "SMPS OUTPUT" on the RDK3 to 2.5V then, plug the RDK3 back on the computer over USB (see Figure 27).

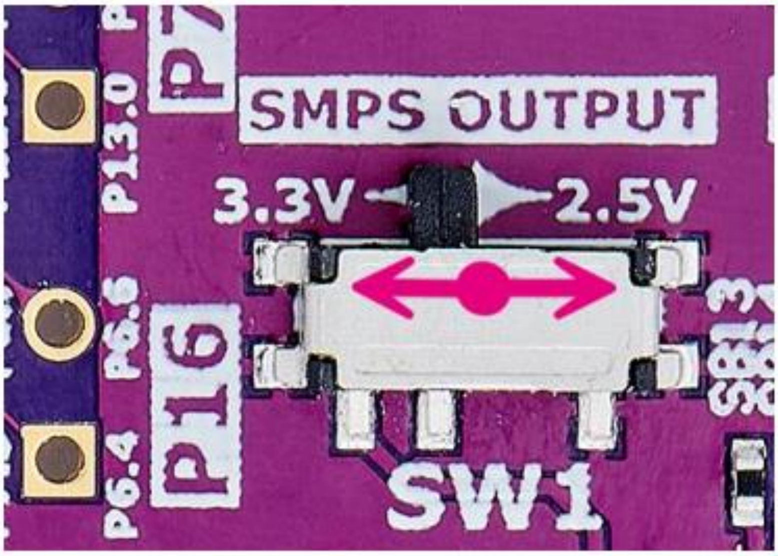

Figure 27. Identify and Switch the SMPS OUTPUT to 2.5V for provisioning (RDK3 User Manual s.a.).

Open the secure-policy-configurator application installed with the toolbox application by typing its name on the computers search pane to find and open the application to continue provisioning.

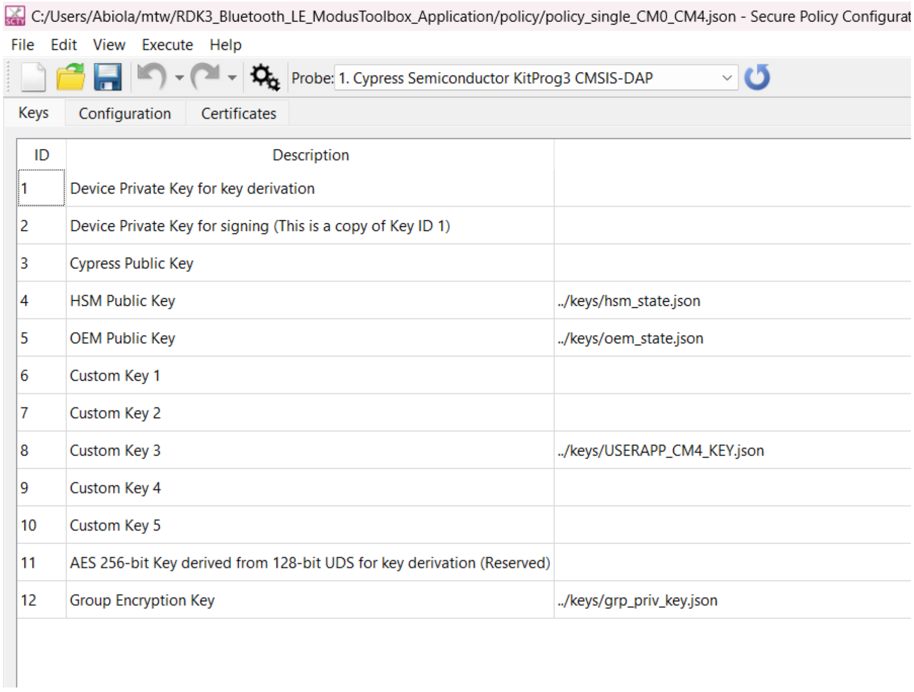

Figure 28. A snapshot of the Secure Policy Configurator application when provisioning RDK3.

Select probe from the drop-down list by clicking on the refresh button if nothing pops-up, click on open and navigate to the workspace application opened on the eclipse IDE to the policy folder and pick the file “policy\policy_single_CM0_CM4.json” (see Figure 28).

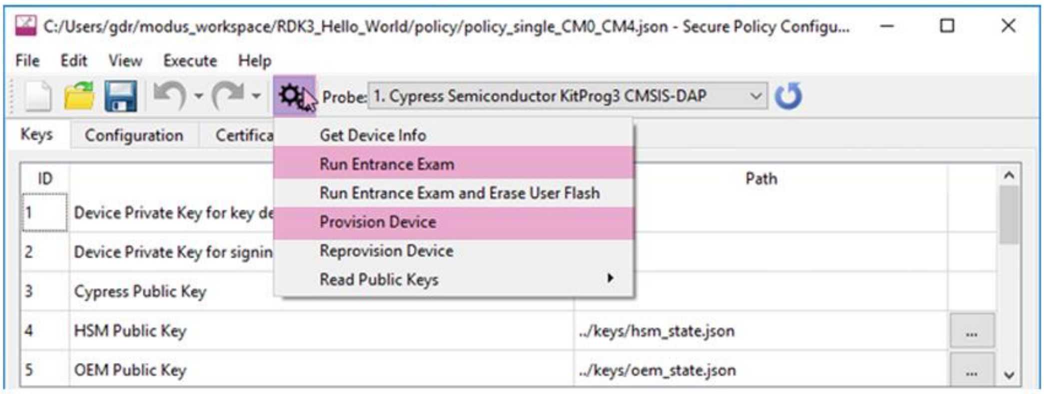

Figure 29. Run entrance exam to provision device (provisioning (RDK3 User Manual s.a.).

Click on Run entrance exam if this fails, click on "reprovision device" (see Figure 29). Once the provision succeeds, close the secure policy configurator application (see in Figure 30).

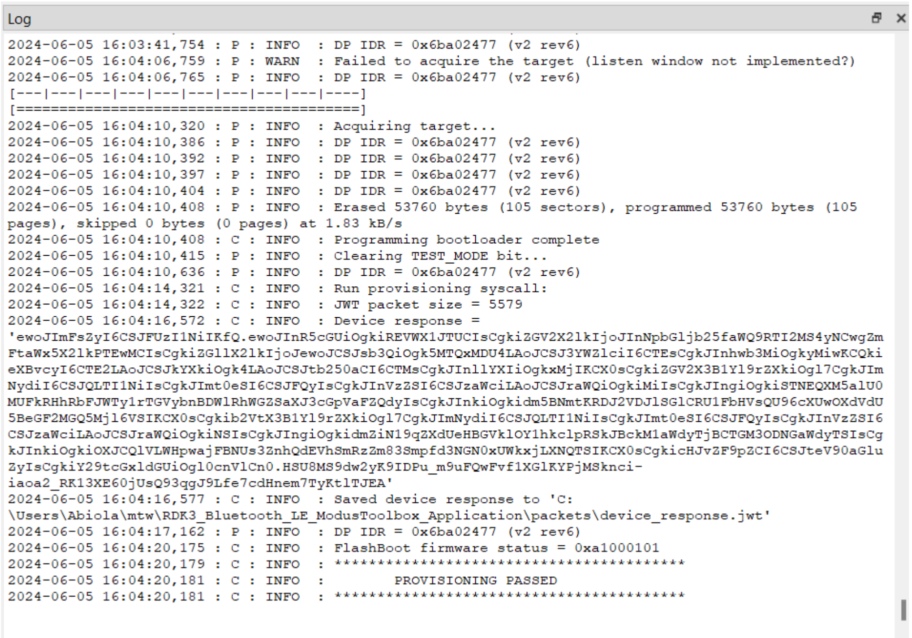

Figure 30. Snapshot of configurator log showing Provisioning passed.

Power off the board by disconnecting the USB from the computer and set the SMPS OUTPUT switch back to 3.3V, then power the board on to continue with the configuration process (see Figure 31).

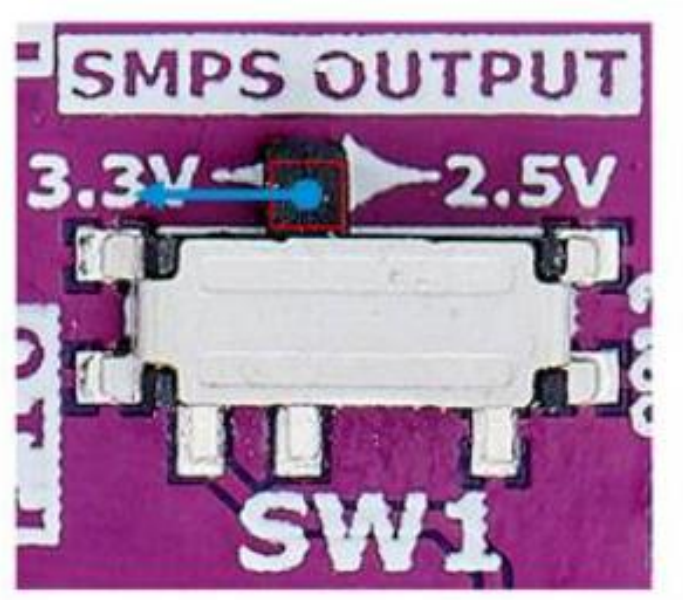

Figure 31. Switch back to 3.3V (RDK3 User Manual s.a.).

On the Modus Toolbox application click on "Build application" from the quick panel (see Figure 32).

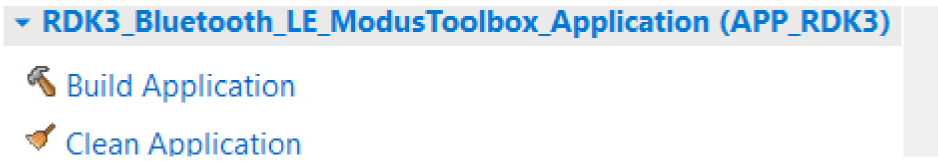

Figure 32. Build application snapshot.

Next, click on RDK3 program KitProg3 to load the application on the board and complete the configuration process of the RDK3 board (see Figure 33). The process makes the LED 1 blink rapidly to show the program is now running on the board.

Figure 33. Program application to the RDK3 board

The device is now ready to be mounted on the RAB4-RTK. Remove the USB cable to power off the RDK 3 board before mounting, on the RAB4-RTK ensure that the LE910 UART SWITCH is set to "Arduino", mount the boards and power the RDK3. This makes the device discoverable on the Rutronik System Solutions mobile application.

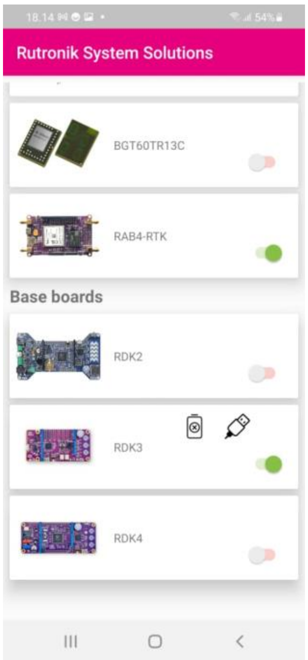

Figure 34. Select RAB4-RTK

Click to open the device discovered and select RAB4-RTK (see Figure 34). Available options and settings are seen on this page, click on RTK CONFIG to input credentials (see Figure 35).

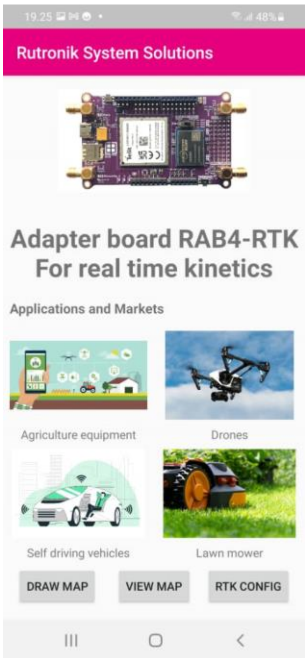

Figure 35. RAB4-RTK opened on the mobile application to show setting options.

Credentials initially created on the National Land Survey of Finland website is set here (see Figure 36).

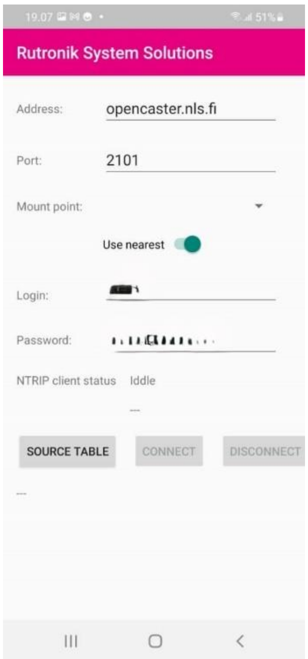

Figure 36. Set credentials.

Click on source table to search and load mountpoint (see Figure 37). Select VRS-FKP as recommended by National Land Survey of Finland and click connect (RTK Service s.a.).

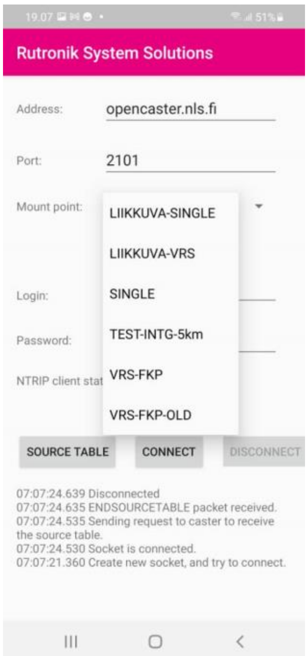

Figure 37. Click Source table to search for mount point.

Once connection is established the position coordinates can be seen broadcasted with the time stamp.

3.2 Software Development

3.2.1 Writing code for the Raspberry Pi Pico.

The software development for the Raspberry Pi Pico primarily revolves around scripting for sensor inputs and buzzer control with a simple micro-python code that initiates the GPIO pins which the PIR sensor and buzzers are connected to on the Pico to effectively activate the buzzers sound and LED to blink when the PIR sensor picks a movement (see Figure 38).

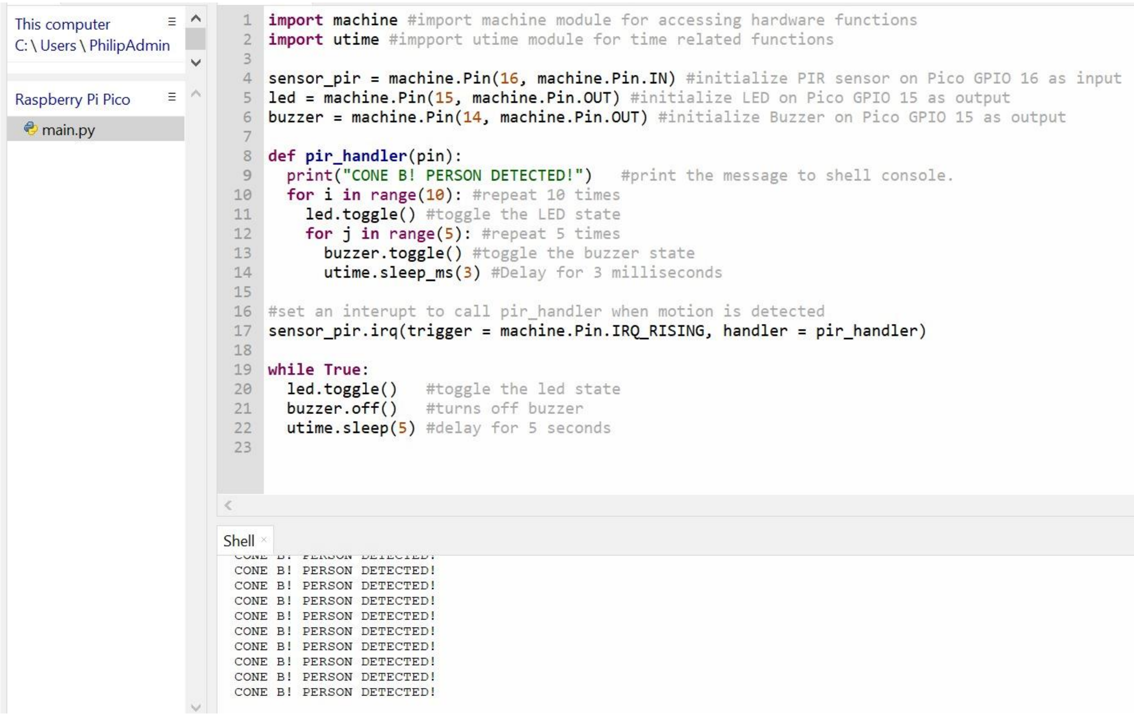

Figure 38. Script & output from Cone B.

The script is saved on the raspberry pi Pico as main.py this gives the Pico options for external power which for this project is connected to the USB port of the raspberry pi 4B to be deployed immediately the Pi 4B is running and cones are connected (see Figure 39).

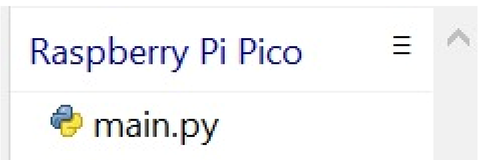

Figure 39. Script is saved as main.py.

3.2.2 Developing the Communication Interface on Raspberry Pi 4B

The Raspberry Pi 4B necessitates a strong communication interface to manage data from Raspberry Pi Picos cones and the RTK GNSS modules. Pi Pico also mounts on the storage device of Pi 4B if

powered by press holding the bootsel for the U2F binary file to be dragged and dropped but since the Pico's have the micropython script saved as main.py for ease of use especially in outdoor scenarios, the Pico and sensors starts to trigger once the raspberry pi 4B is powered on (see Figure 40).

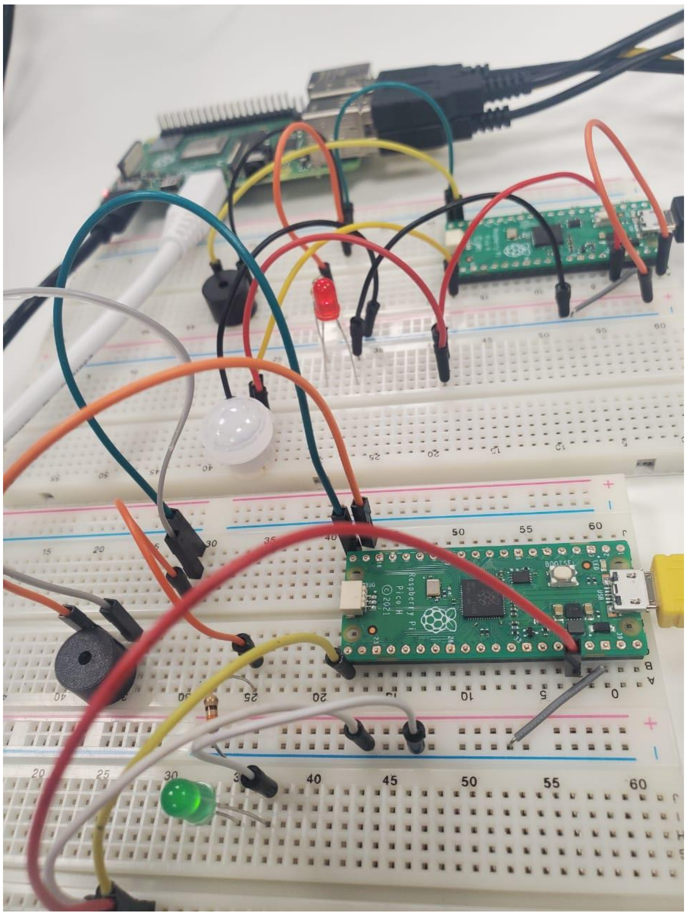

Figure 40. Sensors are triggered and LEDs are blinking.

To further ensure connectivity and communication, set the raspberry pi with the following commands in the Pi 4B terminal to create necessary folders and install firmware binaries (see Figure 41).

```
$ cd ~/ #to navigate to the home directory
$ mkdir pico #make a directory named pico
$ cd pico #navigate to the pico directory
$ git clone https://github.com/micropython/micropython.git --branch master #clone the micropython GIT repository
this creates a new directory named micropython
$ cd micropython #navigate into the micropython directory
$ make -C ports/rp2 submodules #this command fetches the submodules for the pico board
$ sudo apt update #for updates
$ sudo apt install cmake gcc-arm-none-eabi libnewlib-arm-none-eabi build-essential #additional tools
needed in micropython and the SDK
$ make -C mpy-cross
$ cd ports/rp2
$ make #this creates a directory called build-PICO containing the firmware binaries
```

Figure 41. A snapshot of compiled Pi 4B terminal commands.

To access the Pico through the USB ports of the Pi 4B run the commands as seen in Figure 42.

```
$ ls /dev/tty* #run this in command line to show the USB ports your Pico is connected to (/dev/ttyACM0)
$ sudo apt install minicom #to connect from a Raspberry Pi over USB
$ minicom -o -D /dev/ttyACM0 #press enter a few times to open the shell for scripting micropython and showing
what happens in the system.
```

Figure 42. To interface over USB.

Once all is correctly done, a soft reboot should show by pressing CTRL d which shows three arrows indicating it is now in the shell mode for micropython (see Figure 43).

```
MPY: soft reboot
MicroPython v1.13-422-g904433073 on 2021-01-19; Raspberry Pi Pico with RP2040
Type "help()" for more information.
>>>
```

Figure 43. Soft reboot (Raspberry Pi documentation s.a.)

Output of what is happening can be seen as shown in Figure 44.

```
raspberrypi@raspberrypi: ~
File  Edit  Tabs  Help
>>>
>>>
>>> minicom -o -D /dev/ttyACM0
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
NameError: name 'minicom' isn't defined
>>> CONE! Motion detected!
CONE! Motion detected!
CONE! Motion detected!
CONE! Motion detected!
CONE! Motion detected!
CONE! Motion detected!
CONE! Motion detected!
CONE! Motion detected!
```

Figure 44. Shell output

3.2.3 Data Collection and Processing

Rutronik System Solutions android application shows raw correction data after completing the configuration process of the base station. It displays details such as quality indicator of the positioning (Quality), the number of satellites (SAT) used to compute position, the Age which indicates in seconds the last received correction packet (RTCM), correction source which can either

be through an NTRIP caster broadcasting correction data over the internet or the “BASE” receiving correction data from a base station on the RDK3 over Bluetooth as seen in Figure 45. (RAB4-RTK Documents s.a.)

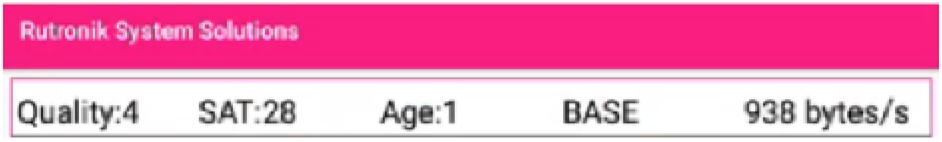

Figure 45. Signal Quality (RAB4-RTK Documents s.a.)

3.3 Integration and calibration

3.3.1 Testing the communication between Pico Boards and Raspberry Pi 4B.

Testing was done to ensure reliable communication between the Raspberry Pi Pico boards and the attached sensors while connected to the Pi 4B, the results indicated successful integration and cohesive functioning of sensors. PIR sensors once in detection mode will trigger the LEDs to blink ten times and the give sound five times according to the script uploaded, the system will keep running once it is still powered on.

3.3.2 Calibrating sensors and RTK GNSS is an essential step in the process.

Calibration is essential for ensuring the accuracy and reliability of all sensors and the RTK GNSS. The process requires installing several versions of the software application to test for the most compatible and suitable software to show correction data and optimizing the GNSS modules for accurate positioning (see Figure 46).

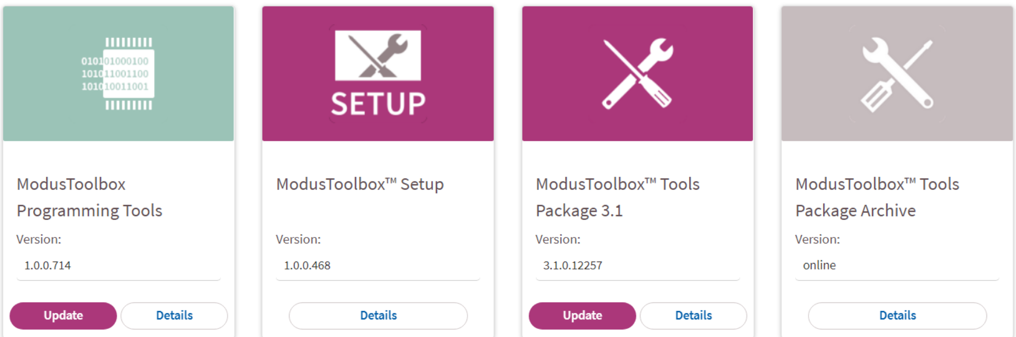

Figure 46. Installed tools on computer (Infineon Developer Center Launcher 2024)

3.4 Performance Evaluation

3.4.1 Metrics for Assessing System Performance

Important metrics for assessing system performance are accuracy, response time, data transmission reliability, and power consumption. Measuring these metrics aids in evaluating the system's effectiveness and pinpointing areas for enhancement. Validating the system's functionality relies heavily on accurate performance metrics (Williams 2019).

3.4.2 Result of initial tests

The preliminary tests and calibration results offer valuable insights into the operational efficiency of the system. The result promises a system accuracy in positioning to less than 5cm, while the responsiveness of sensor triggers in identifying person are functional and reliable.

4 RESULTS, DISCUSSION & CONCLUSSION

4.1 Analysis of the results

The Raspberry Pi Pico boards reliably enabled person identification through their distinct signals, consistently detected by using the Raspberry Pi 4B as a power and connection hub. While the RAB4-RTK and RDK3 had complex components with several complex configurations for each.

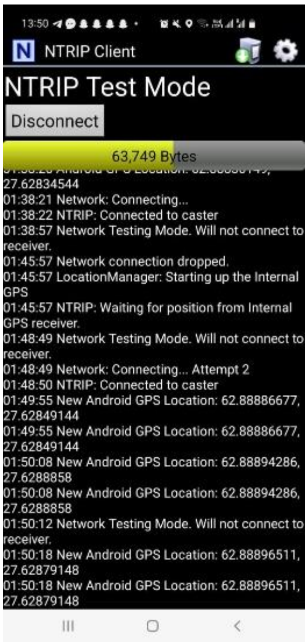

Figure 47. Preliminary test with RTK GNSS credentials.

Preliminary tests which were carried out showed that using the RTK credentials settings on the Rutronik mobile application was accurate in calculating position (see Figure 47). It is important to note that there were some limitations in carrying out real-life outdoor tests so only a similar representation of result is shown in the log of Figure 48.

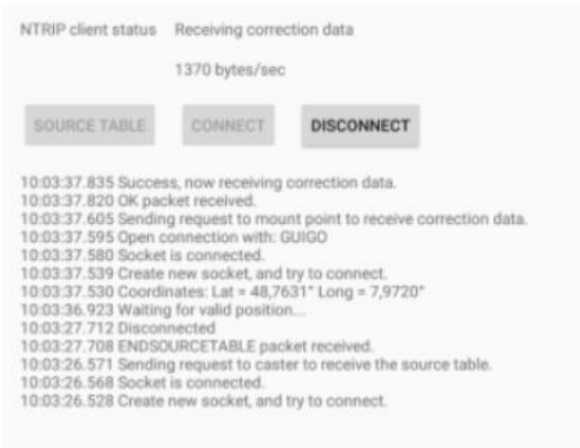

Figure 48. Sample result (RAB4-RTK Documents s.a.)

It allows accurate measurements of RTK GNSS correction data, allowing for accurate calculations of velocity. Route tracking can also be accomplished by setting a reference point and recording accurate GNSS coordinates at regular intervals, enabling a comprehensive mapping of the athletes' movements real-time (see Figure 49).

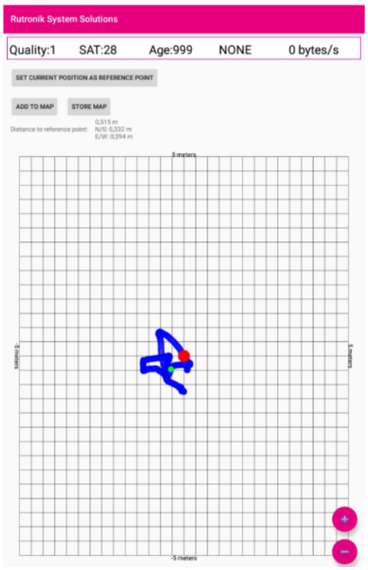

Figure 49. Route on map of mobile application (RAB4-RTK Documents s.a.).

The coordinates streamed in real time confirms the precision of the RTK GNSS technology. The route tracking was extremely precise, with deviations in position not exceeding 5 centimetres, which is consistent with the expected centimetre-level accuracy of the RTK-GNSS.

4.2 Discussion

4.2.1 Findings' Implications

The research suggests that the smart navigation system has the potential to greatly improve athletic training through the provision of accurate and immediate feedback on performance metrics. This feature enables athletes to quickly modify their technique and strategy, which can enhance training results and minimize the chances of injury by improving navigation and awareness (Williams 2019).

4.2.2 Comparison with Current Systems

The smart navigation system surpasses current systems in terms of accuracy and real-time data processing capabilities. Traditional training systems often depend on less accurate GPS technology, leading to notable discrepancies in position. This system stands out from conventional solutions due to its higher accuracy and reliability, thanks to the integration of RTK GNSS technology (Leick et al. 2015).

4.2.3 Limitations Discovered During Testing

Testing revealed several limitations, one significant drawback is the outdated documentation which did not allow for the complete configuration of the RAB4-RTK and the rover as whole which deterred real life testing that could give further validation in confirming the accuracy of the RTK-GNSS, other limitations include power and latency due to obstruction. In conclusion, the setup and calibration process were a time-consuming task that demanded meticulous adjustments to achieve the best possible performance.

4.2.4 The Effect of These Limitations on Overall Performance

The limitations had an impact on the completion of the project, the efficiency of the system and its overall performance which led to the inability to test several real-life scenarios and basing the results only on preliminary tests which is evidence of the importance of a compact and concise documentation.

4.3 Conclusion

4.3.1 Summary of Project Accomplishments

The project came close to the successful development of a smart navigation system that combines Raspberry Pi and RTK GNSS technology to offer accurate, real-time tracking and feedback for athletes. The systems identification part was successfully, the communication and navigation parts reached near completion leaving room for further works to achieve the desired design goals and demonstrate high accuracy in athlete identification, speed measurement, and route tracking.

4.3.2 Contribution to the Field of Sports Technology

This project makes a valuable contribution to the field of sports technology. It introduces a high-precision navigation system that has the potential to greatly enhance athletic training and performance monitoring by utilizing RTK GNSS technology that offers a substantial enhancement compared to conventional GPS-based systems, opening new avenues for real-time data analytics and performance optimization in sports.

4.4 Recommendations

4.4.1 Recommendations for Enhancing the System

Potential enhancements to the system could prioritize improving the wireless communication's resilience to minimize delays and enhance dependability in various setting, it would be beneficial to develop more advanced signal processing algorithms that can effectively mitigate the impact of environmental factors on GNSS signal quality thus enhancing system accuracy also streamlining the setup and calibration process into compact and concise process to enhance the system's user friendliness and expand its accessibility to a wider audience.

4.4.2 Potential Areas for Future Research

Further investigation may delve into making the system more compact and incorporating supplementary sensors, such as accelerometers, to yield a more comprehensive set of performance data. Exploring the application of machine learning algorithms for data analysis and generating predictive insights or personalized training recommendations is a promising area for future research (Del Giorgio Solfa & Simonato 2023).

4.5 Reflections on the Project's Impact and Future Potential

The navigation system developed in this project showcases the potential of advanced technology to greatly improve athletic training. It enables athletes to enhance their performance and coaches to make better decisions by offering accurate, immediate feedback. The implementation and testing of this system have paved the way for future innovations in sports technology, ensuring further advancements in the accuracy and effectiveness of athletic training tools.

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