WrEx - Wrist Exercise Trainer a System for Monitoring Physical Therapy Exercises

INTERACTIVE MOBILE APPLICATION FOR MONITORING WRIST MEASUREMENTS

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Daniel Pereira e Silva

Software Engineer with a solid background in software design, development, and testing. I graduated with a master's degree in Computer Science and Engineering from the Nova School of Science & Technology and, throughout my academic and professional experience, I have acquired fundamental knowledge of fullstack development technologies and experience in a variety of programming languages, platforms and embedded systems, with a greater interest in artificial intelligence and machine learning fields. Also, during my academic journey, I worked on a European project within a scientific initiation scholarship which, besides giving me web and mobile app development skills, it inspired me to explore advancements in programming technologies to improve the systems I work with.

CONTENTS

01 INTRODUCTION

- MOTIVATION
- OBJECTIVES

A **sedentary lifestyle**, **excessive use of the cell phone**, and even **daily accidents**, can cause **inflammatory problems in the joints** and wear on the cushioning between the bones, causing **pain** and in some cases, **disability**

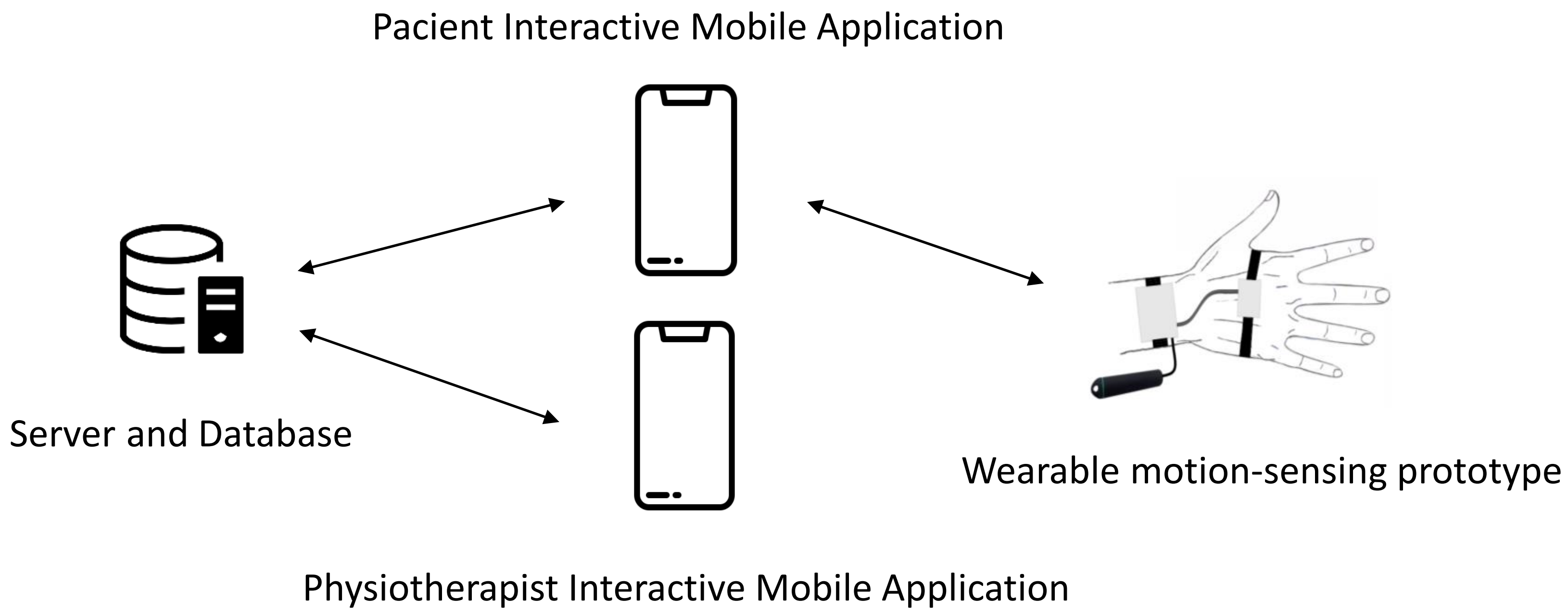
- Poor quality of life
- It is important to motivate the practice of rehabilitation exercises
- Practice of physiotherapy exercises may be strongly recommended or even essential

Telemedicine, a **remote health service**, aims to prioritize health and improve quality of life

REMOTE HEALTH SERVICES

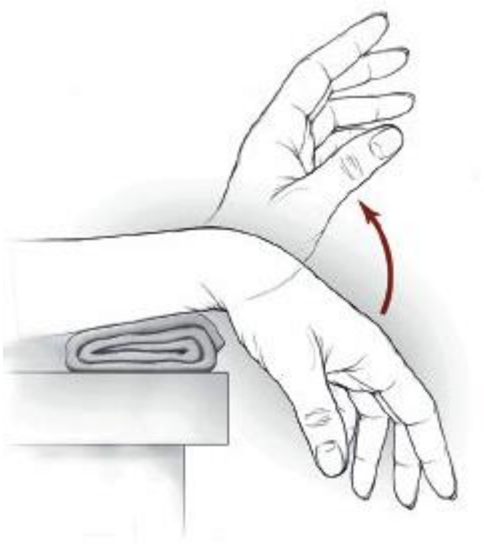
- **Cover a large geographical scope** and **share data** among several centers
- **Better distribution and management of medical services**
- **Reduce transportation costs** and **crowding of medical centers**
- Powerful tool capable of **breaking down barriers of time and space**
- Measurements can be **performed automatically** and **outside the clinical environment**
- **No need to have more than one professional** to perform manual measurements

- The system developed seeks to innovate or even optimize other solutions
- The focus of this work is the development of an **interactive mobile application** that is **connected with sensors** to **monitor physiotherapy exercises**, more specifically, the musculoskeletal rehabilitation of the wrist



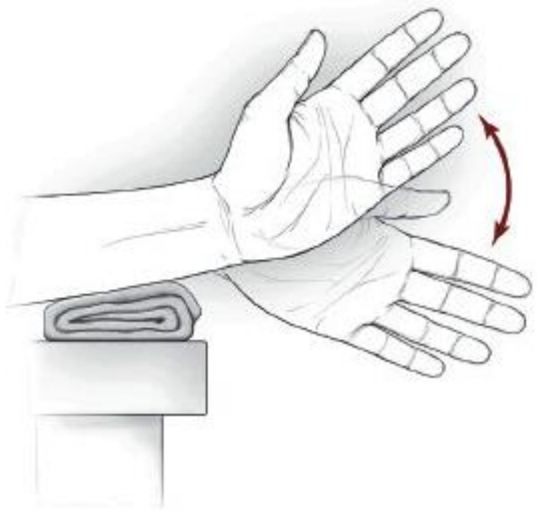
- The movements being evaluated will be four physiotherapy exercises for the wrist: flexion and extension, and also radial and ulnar deviation

- Can be performed with and without load, and with the left or right hand



Extension
0° to 70°

Flexion
0° to -90°



Radial Deviation
0° to 20°

Ulnar Deviation
0° to -45°

02 RELATED WORK

- APPLICATIONS

Study of best positioning of sensors

Hiung, F. Jin et al.,2020 [1]

Front

Middle

End

Measurement	Manual goniometer	Front spot	Middle spot	End spot
Extension	40º-50º	59.52º	51.83º	48.86º
Flexion	35º	48.51º	38.54º	50.58º
Pronation	45º-50º	51.45º	44.24º	41.05º
Supination	50º-55º	76.38º	68.44º	63.58º
Radial deviation	10º	18.63º	12.48º	11.00º
Ulnar deviation	15º-30º	40.43º	33.14º	29.35º

- **Best results** are obtained when the device is placed at the **middle and end spot of the hand**
- The **end spot is much more suitable** for radial and ulnar deviation movements

Comparison between IMU and Flex Sensor

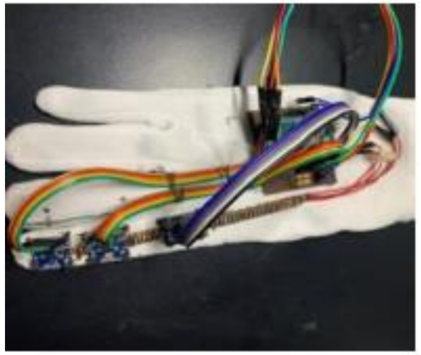
M. A. W. Hazman et al., 2020 [2]

Flex sensor

- Poor accuracy due to lack of flexibility of the plastic sensor component
- Higher error percentage (11.11% to 19.35%)

IMU

- Low error percentage (0.81% to 5.41%)
- Higher precision in the measurements

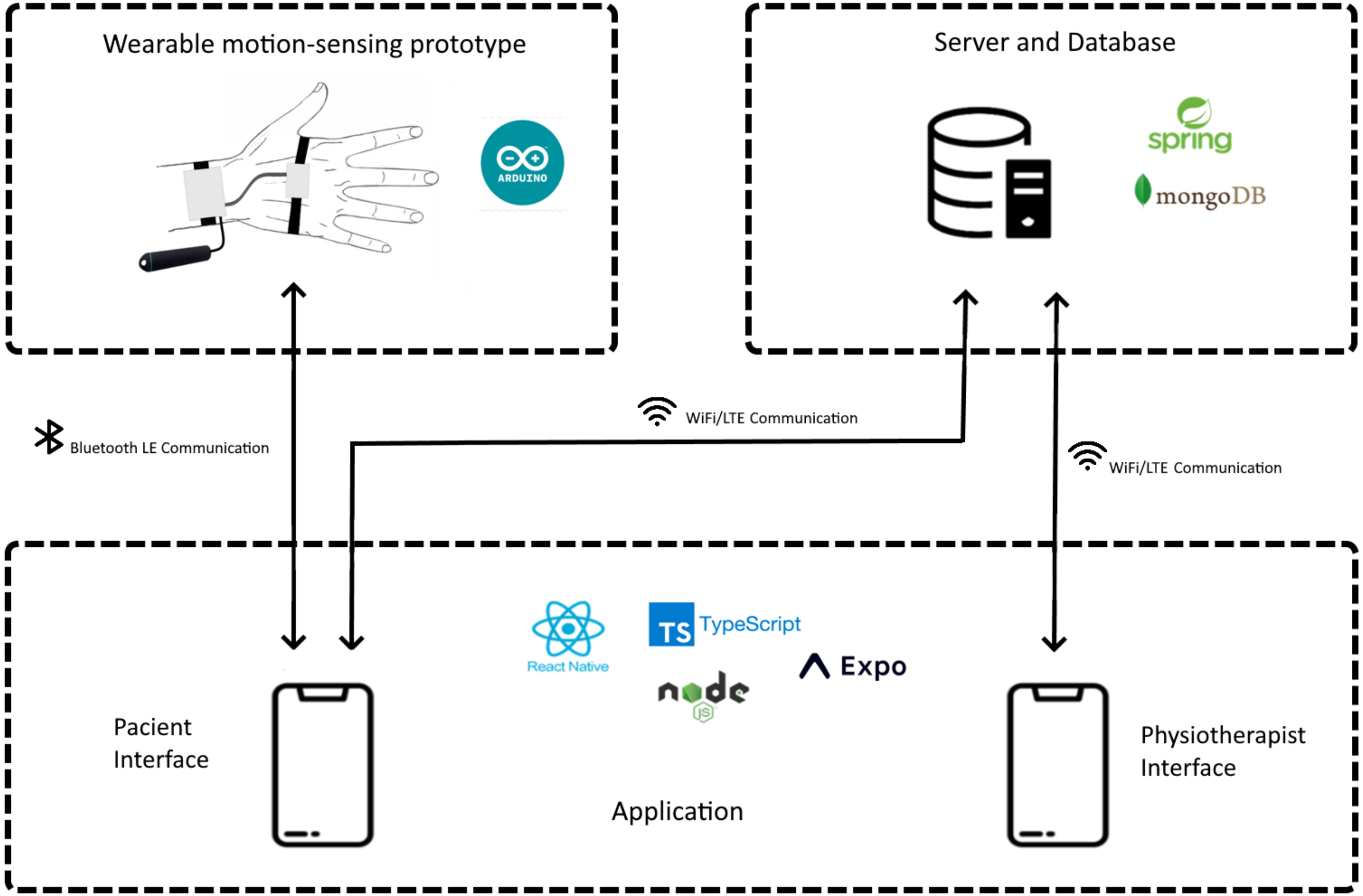


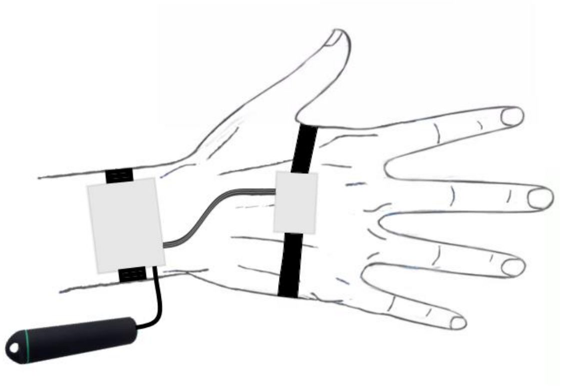
Inertial Unit Sensor (IMU) is the most suitable due to its greater accuracy and efficiency in the readings

03 DEVELOPED SYSTEM

- ARCHITECTURE
- WEARABLE MOTION-SENSING PROTOTYPE
- MOBILE APPLICATION
- SERVER AND DATABASE

03 – Architecture

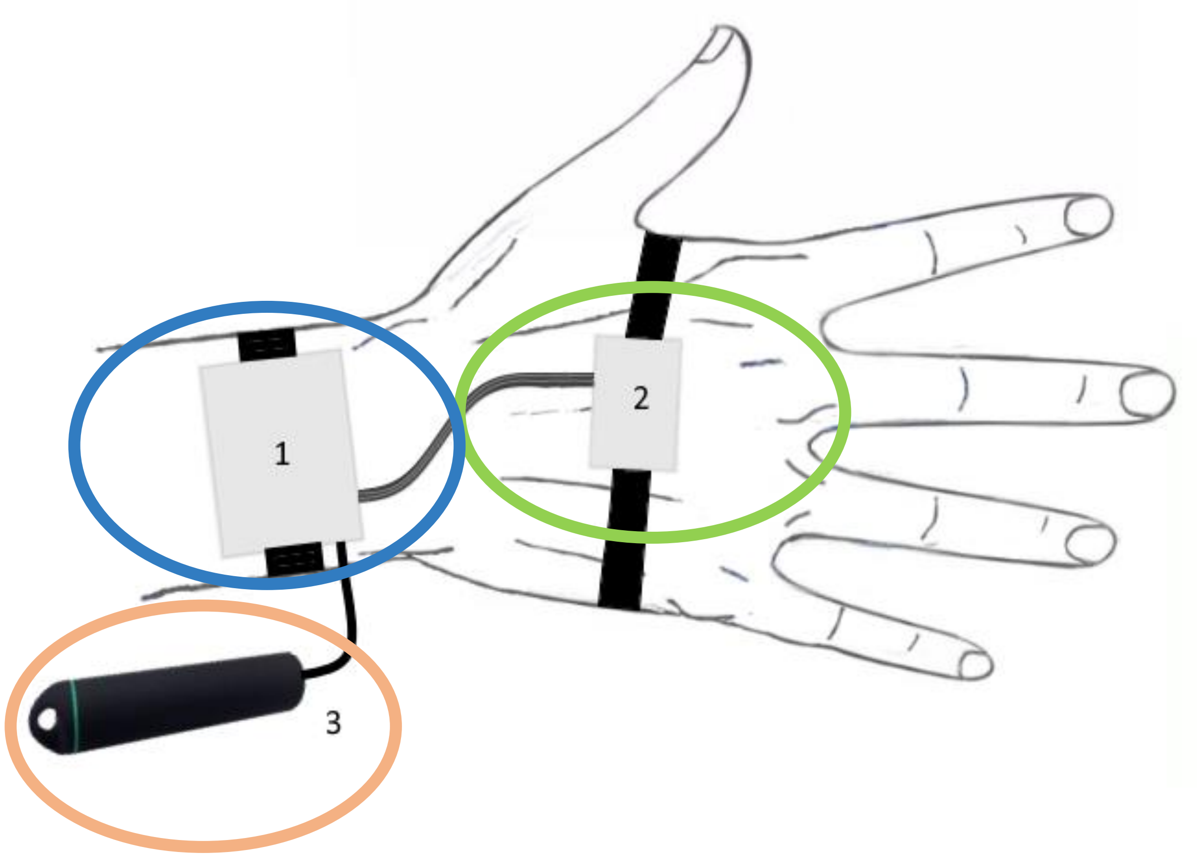




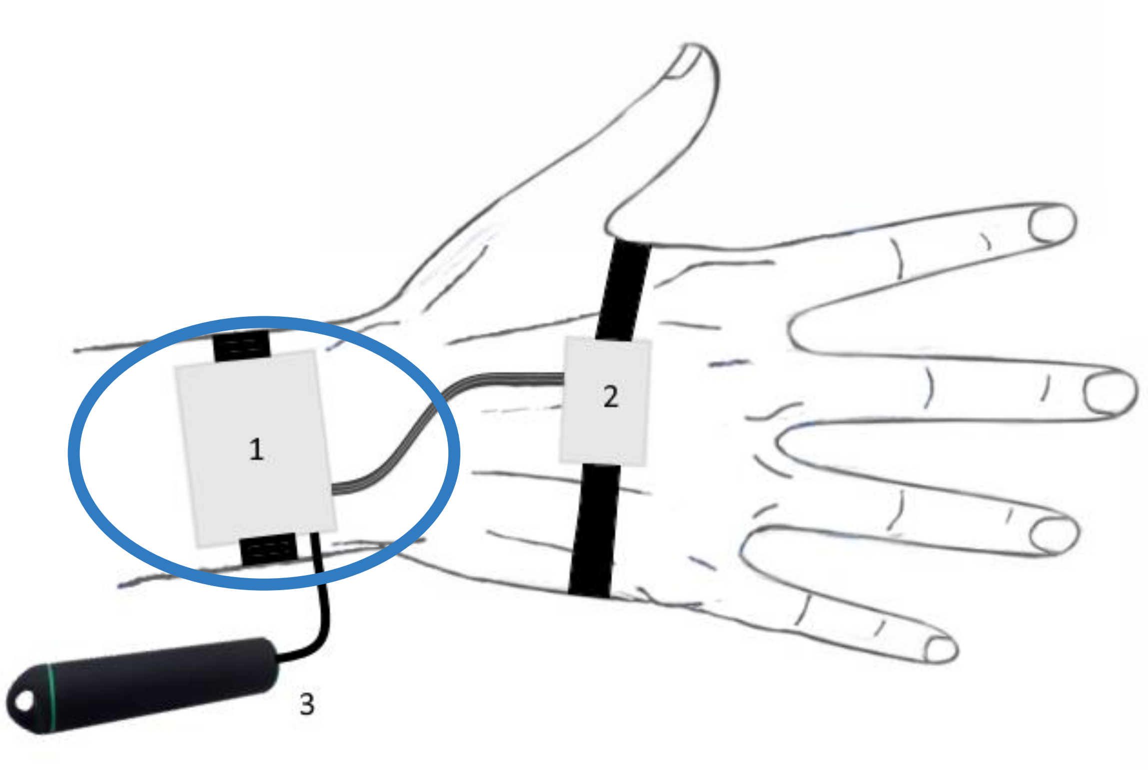
Wearable motion-sensing prototype component

- Low cost and affordable
- Easy to use and comfortable
- Collect, process and send data to the application

03 – Wearable Motion-Sensing Prototype

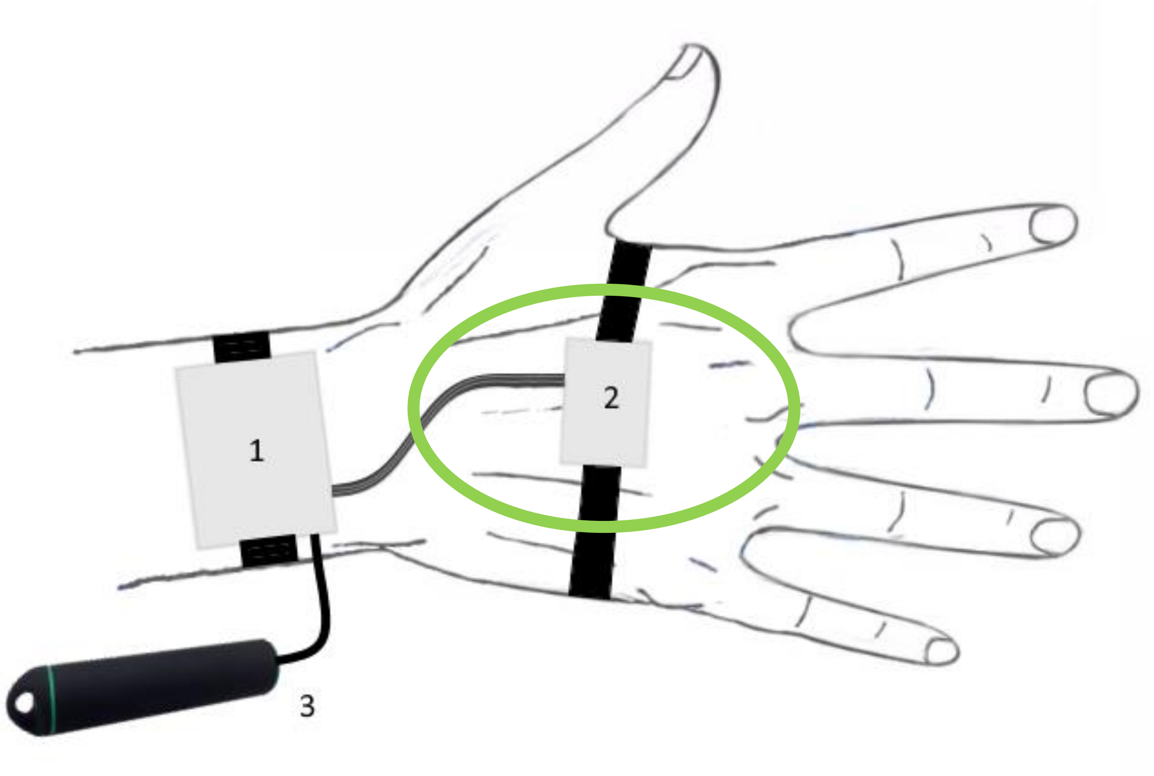


1	1x ESP32 TTGO T7 v1.3 1x IMU MPU-9250/6500
2	1x IMU MPU-9250/6500
3	1x Powerbank 2000mAh 5V



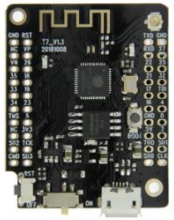
1	1x ESP32 TTGO T7 v1.3 1x IMU MPU-9250/6500

- The sensor placed in **box one** has the main function of **assessing whether there is movement of the forearm** during physiotherapy movements



2	1x IMU MPU-9250/6500

- The sensor in **box two** will **measure the orientation of the wrist angles** during all exercises and provide the data for most of the interactive interface displayed during the performance of the exercise

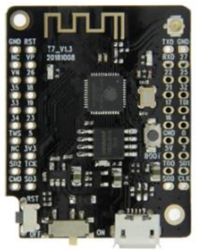


I2C Protocol

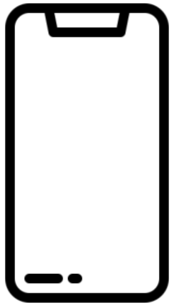
ESP32 Microcontroller

IMU MPU-9250

- **Protocol used:** Simple serial communication protocol called **I2C** [3]
- **Arduino library used**: MPU9250 Nine-Axis MEMS MotionTracking Device **by hideakitai** [4]
- **Madgwick filter** [5] used to estimate the orientation in quaternions based on the raw measurements



Bluetooth Low Energy (BLE)



ESP32 Microcontroller

Mobile Application

- **Communication protocol used:** Bluetooth Low Energy
  - Ideal to transmit and receive small amounts of data
  - Low power consumption
  - Works over short distances

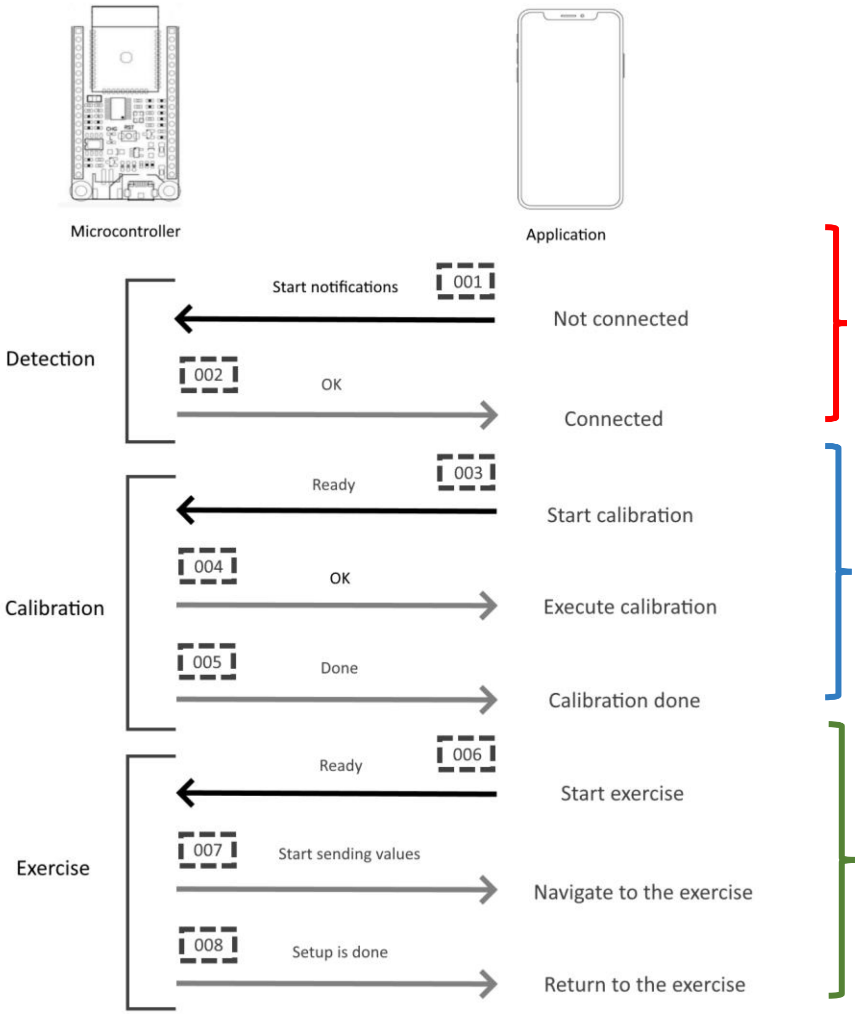
- Example of the data sent by the microcontroller (44 bytes)

$$\boxed{0.15;0.12;0.58;0.79}\ ;\ \boxed{-5.92;-21.10;-70.51}$$

Quaternion Euler angles

- The quaternion value is an average of about 63 sensor readings (~8ms each)
- The Euler angles were calculated by converting the quaternion value to the Euler system
- Data sent to the application at intervals of about 508 milliseconds
- The method used to increase the default MTU limit was through packet length extension (DLE), introduced in Bluetooth 4.2 [6]

03 – Wearable Motion-Sensing Prototype



The mobile device (CLIENT) scans for BLE devices and attempts to establish a connection if it finds the ESP32 microcontroller (SERVER)

Calibration of the accelerometer and gyroscope of both sensors.

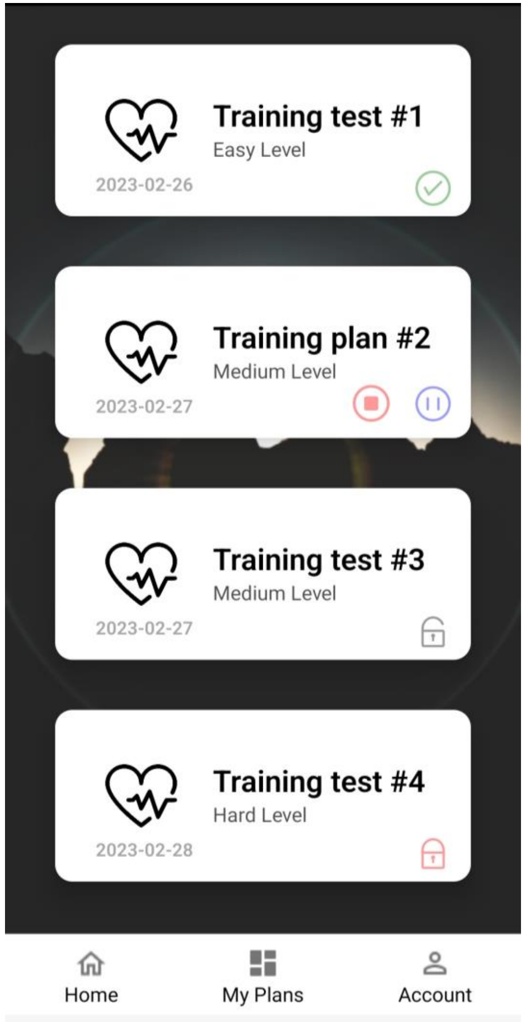
The sensors start collecting data and the microcontroller will send the processed data to the application

Patient Interface: features and requirements

What can a patient do?

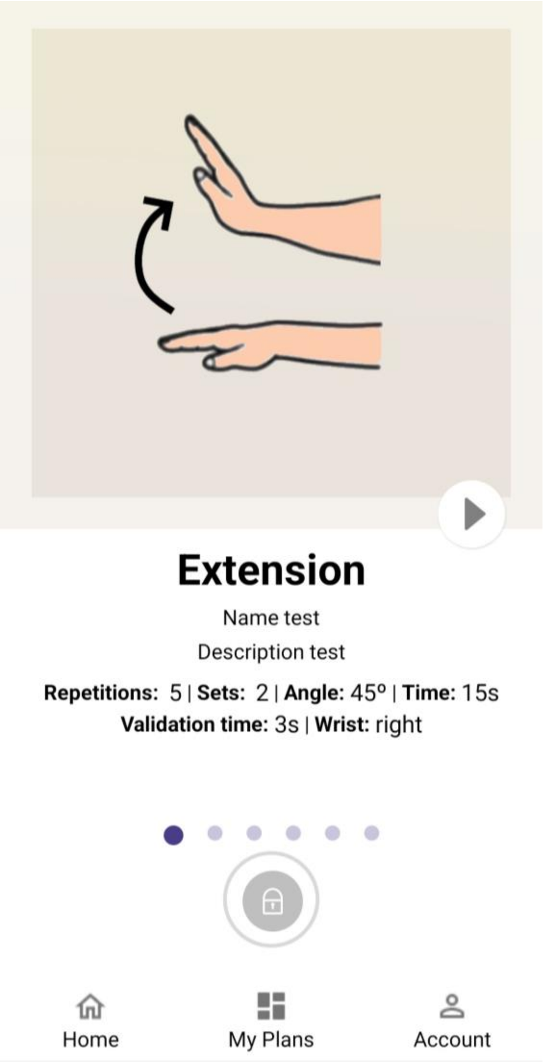
- **View and start a training plan**
- Connect with the wearable motion-sensing prototype component
- Perform a physiotherapy exercise

03 – Mobile Application



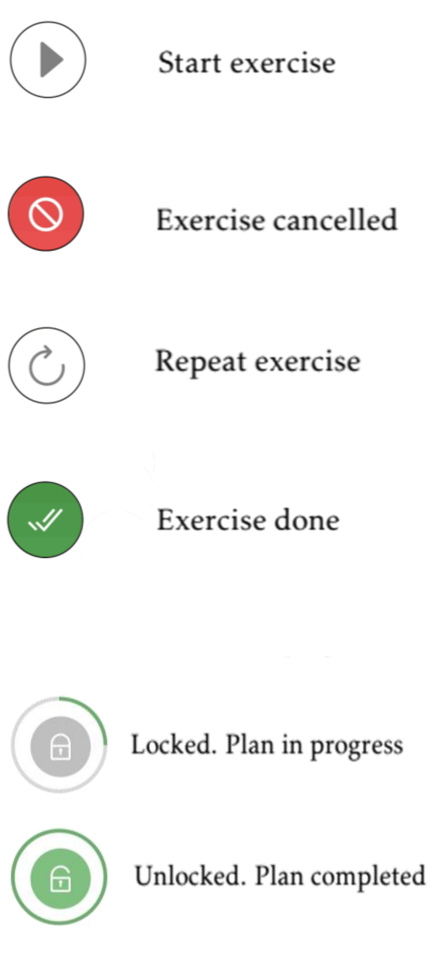
- Done
- In progress
  - Only one at a time
- Unlocked
- Locked

03 – Mobile Application



Exercise States

Plan States

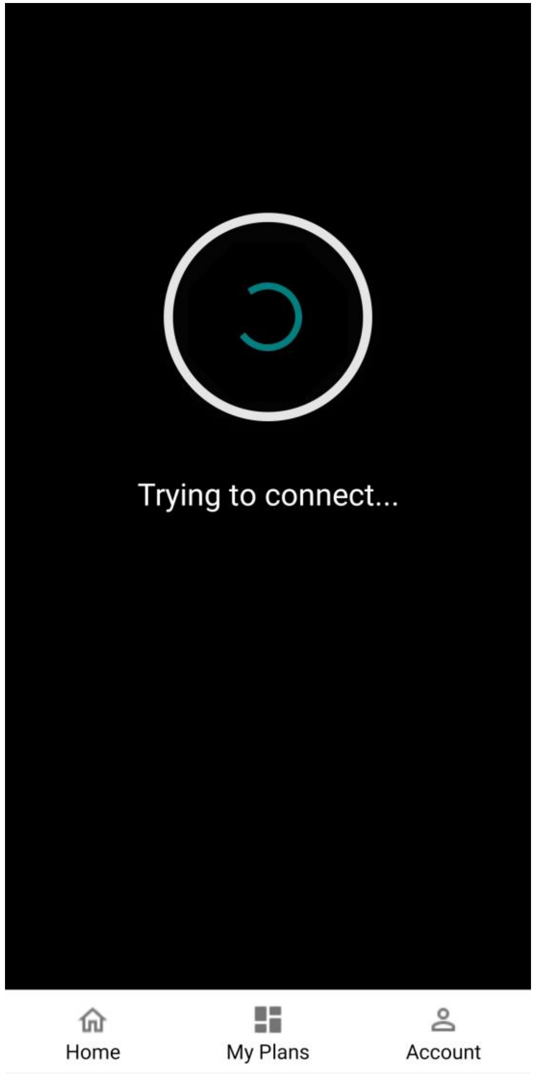


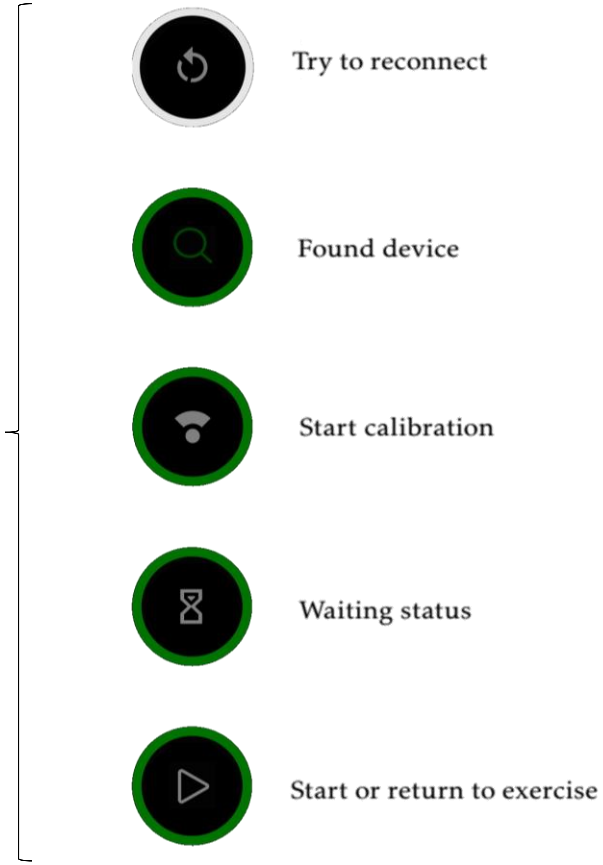
Patient Interface: features and requirements

What can a patient do?

- View and start a training plan
- **Connect with the wearable motion-sensing prototype component**
- Perform a physiotherapy exercise

03 – Mobile Application





- Library used: **React native BLE manager** [7] is a React Native library to support BLE communication

Patient Interface: features and requirements

What can a patient do?

- View and start a training plan
- Connect with the wearable motion-sensing prototype component
- **Perform a physiotherapy exercise**

03 – Mobile Application

Turn on/off sounds

Switch view

Interactive graph

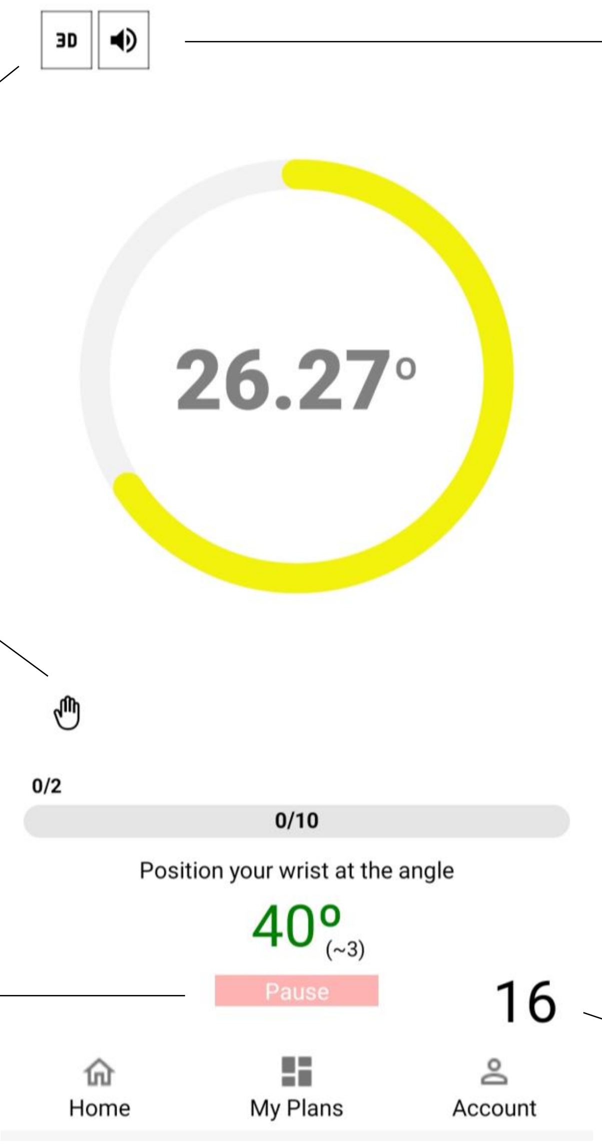
Hand indicator

Nr. Sets and Repetitions

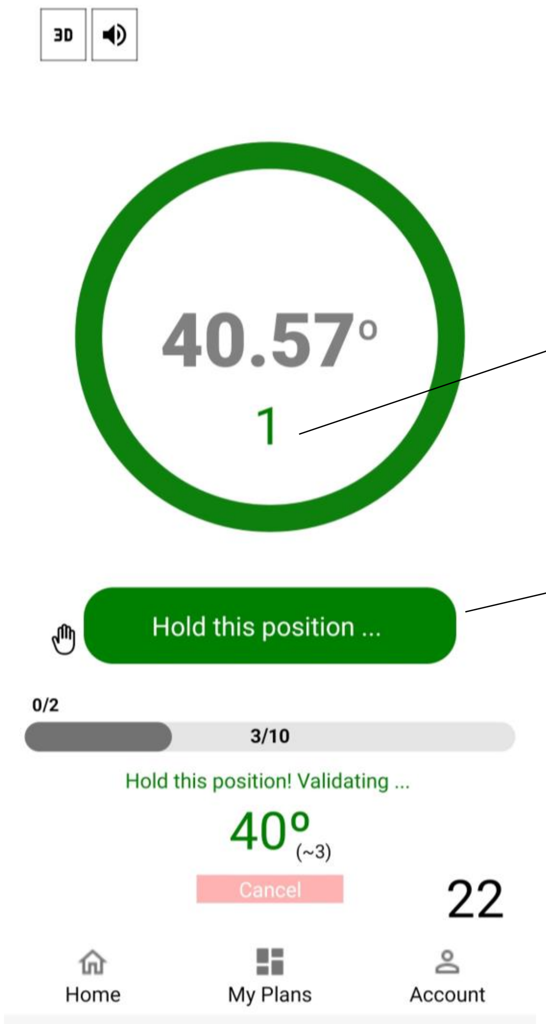
Objectives

Pause button

Repetition time



03 – Mobile Application

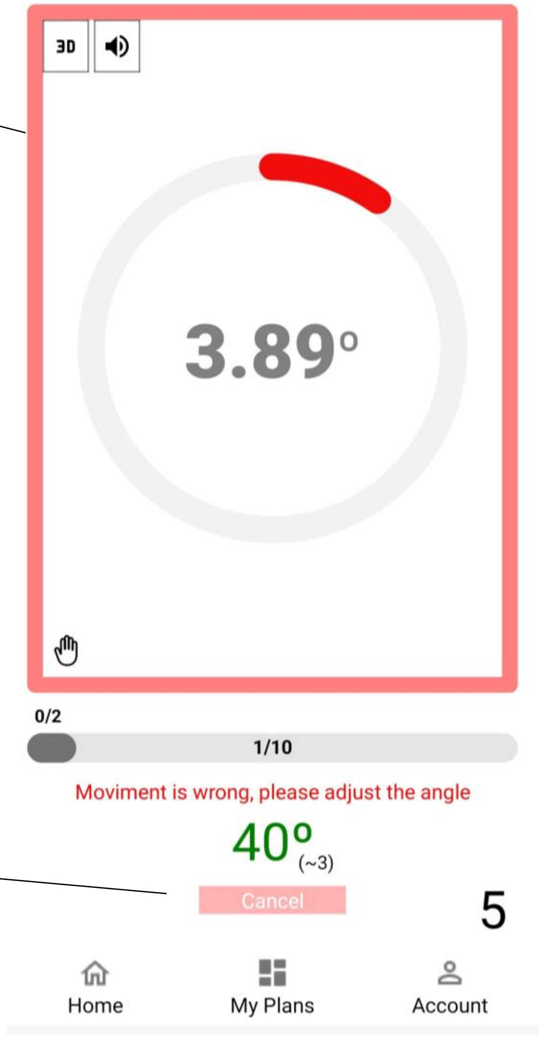


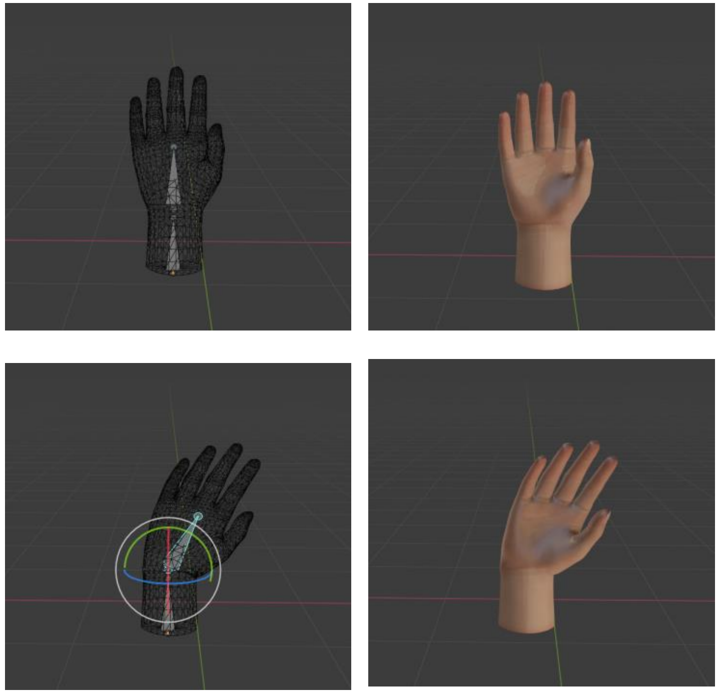
Colored borders

Validation Time

Temporary message

Cancel button





- **Blender** software was used to create the 3D model
- A skeleton was created consisting of two interconnected bones
- **React Three Fiber** library for React Native used to load the 3D model into the application

Physiotherapist Interface: features and requirements

What can a physiotherapist do?

- **Can search for a specific user**
- Can access any plan and exercise but can only manage the ones which they have created
- Can observe a patient's progress in any given exercise

Access a patient or physiotherapist profile

Patient Profile:

- Access all plans and exercises of a patient

Physiotherapist Profile:

- Access all the plans and exercises created by a physiotherapist

Physiotherapist Interface: features and requirements

What can a physiotherapist do?

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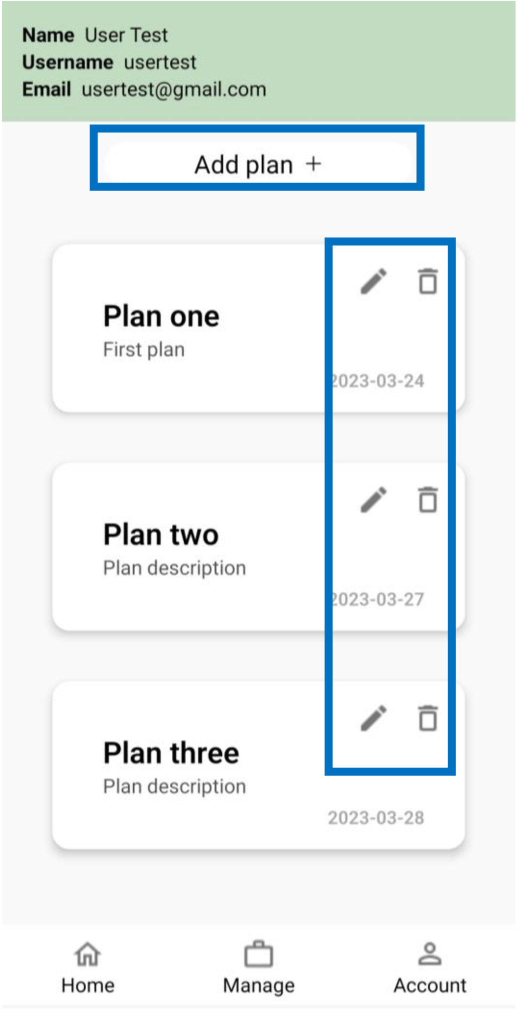
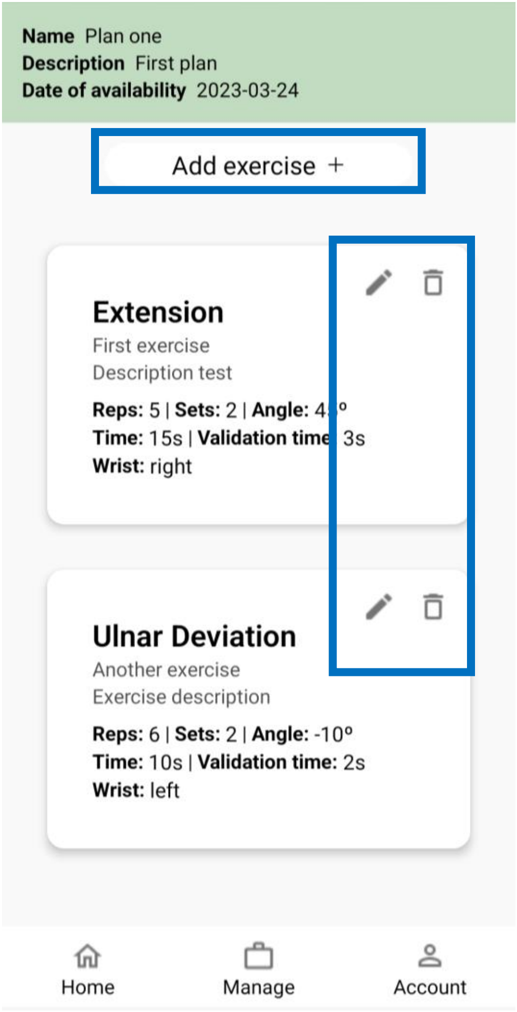


Name User Test
Username usertest
Email usertest@gmail.com
Add plan +
Plan one
First plan
2023-03-24
Plan two
Plan description
2023-03-27
Plan three
Plan description
2023-03-28
Home
Manage
Account

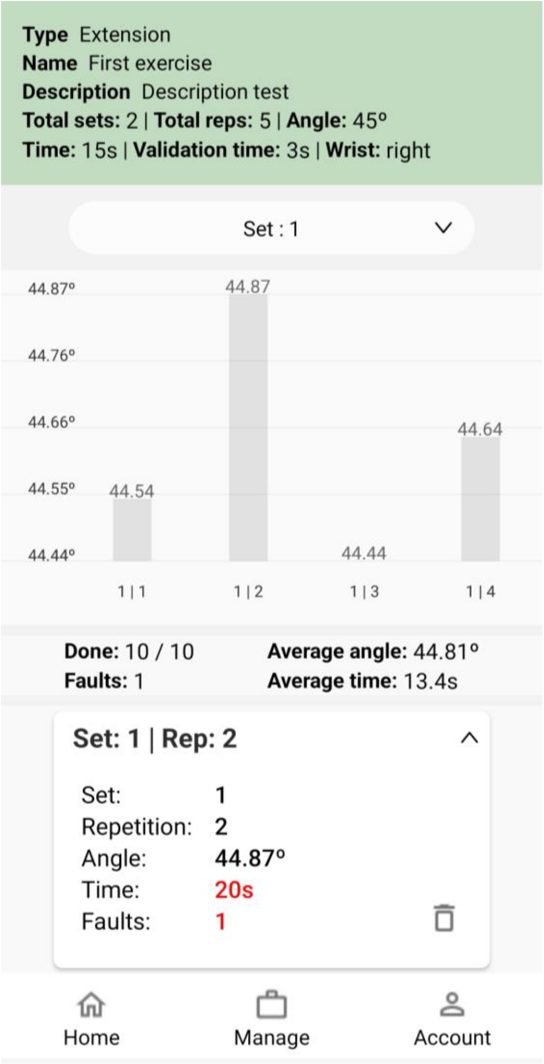


Name Plan one
Description First plan
Date of availability 2023-03-24
Add exercise +
Extension
First exercise
Description test
Time: 15s | Validation time
Wrist: right
Ulnar Deviation
Another exercise
Exercise description
Reps: 6 | Sets: 2 | Angle: -10º
Time: 10s | Validation time: 2s
Wrist: left
Home
Manage
Account

Physiotherapist Interface: features and requirements

What can a physiotherapist do?

- Can search for a specific user
- Can access any plan and exercise but can only manage the ones which they have created
- **Can observe a patient's progress in any given exercise**



Select the exercise set to filter the graph

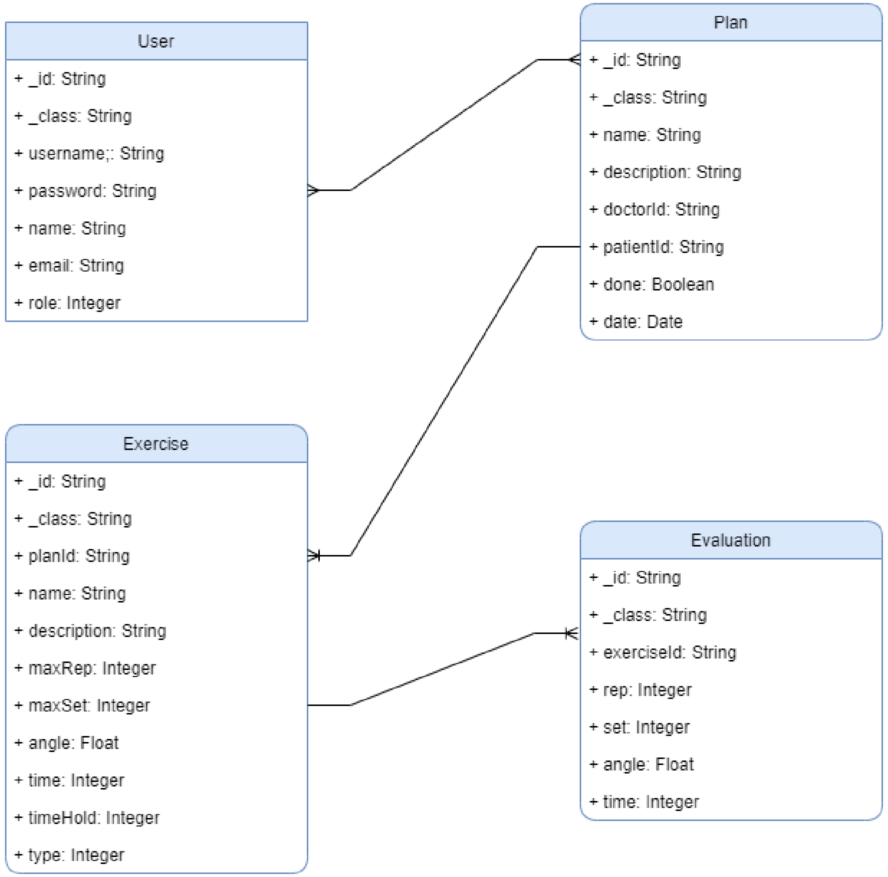
Bar graph with the different angles achieved during the various repetitions

General statistics

List with detailed information about each repetition

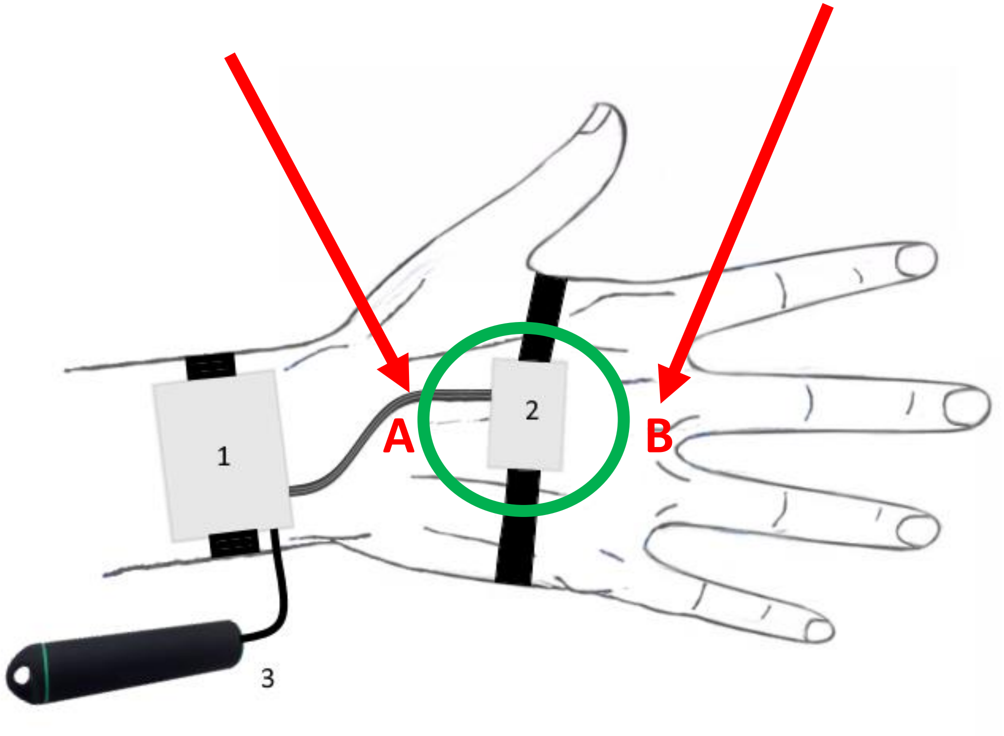
Definitions

- Local server
- **Spring Boot** server and **MongoDB** database
- **Spring Security** was configured and used
- Four collections:
  - Users
  - Plans
  - Exercises
  - Evaluations



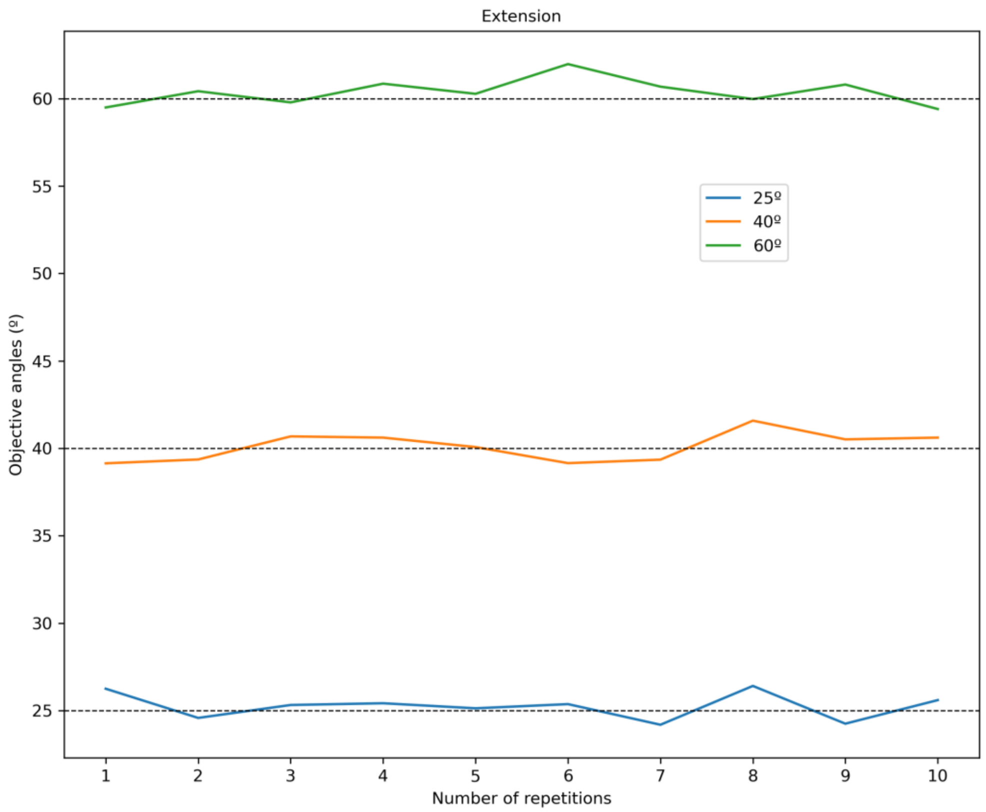
04 EVALUATION

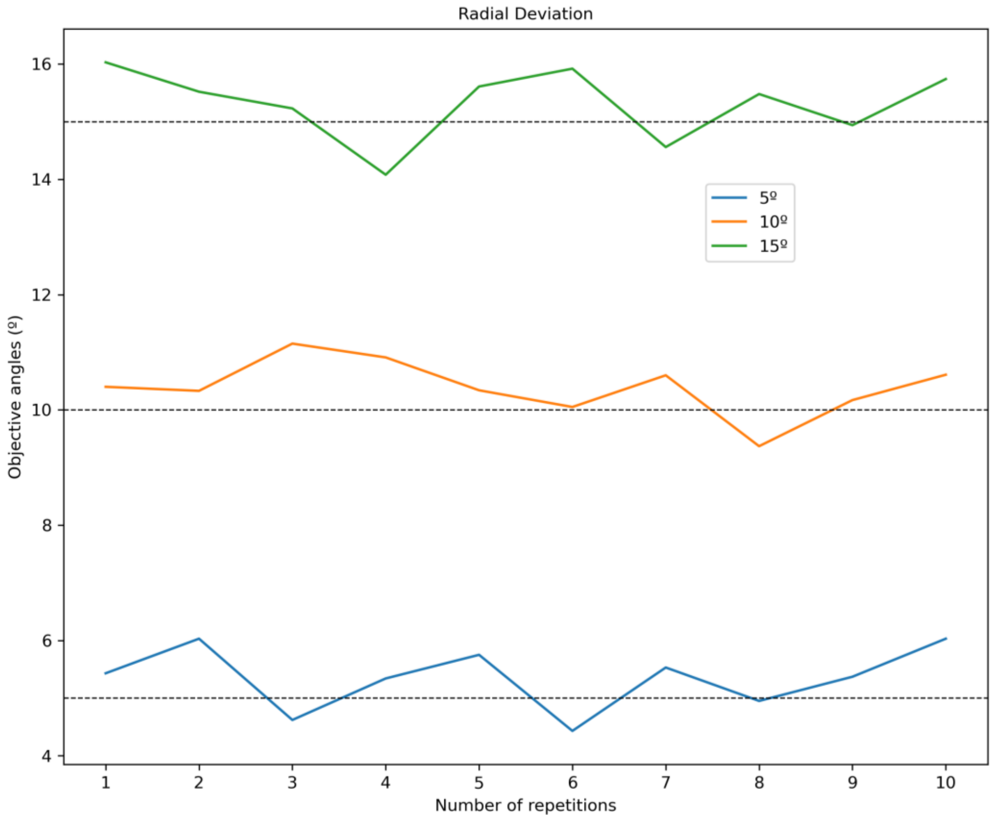
- SENSOR PLACEMENT
- FUNCTIONALITY TESTS
- USABILITY TEST
- COST OF THE SYSTEM



- When placed in **A** it was hard to read values below -30º (>-45º) in **ulnar deviation**
- When placed in **B** it was hard to read values below -70º (>-90º) in **flexion**

- **Ten** measurements at **three** different angles for **each physiotherapy exercise**



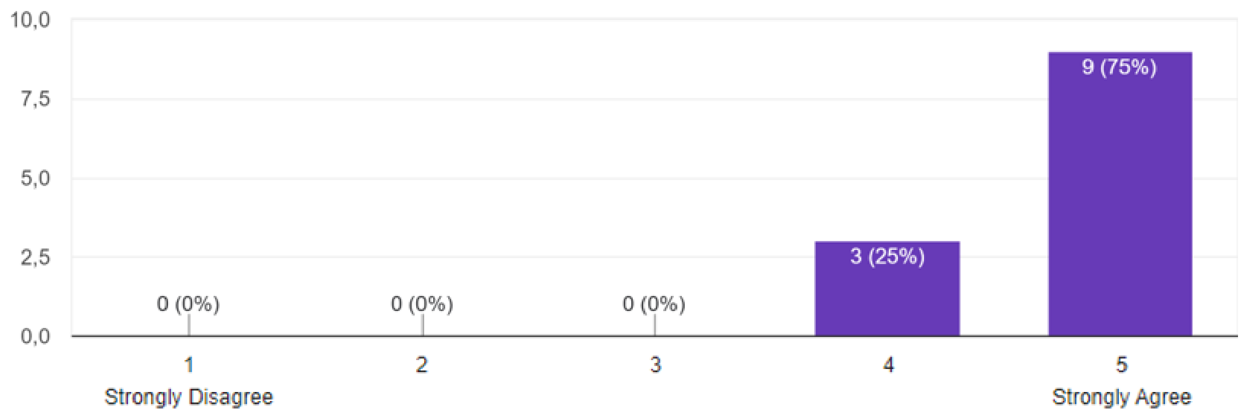


- A set of user stories was created
- Both patients and physiotherapist were asked about their experience
- The System Usability Scale (SUS) [8] was used
- Tests were performed with **twelve patients** aged between 21 and 60 years old and **one physiotherapist**
- Some changes were made to the system regarding the feedback in order to improve the application

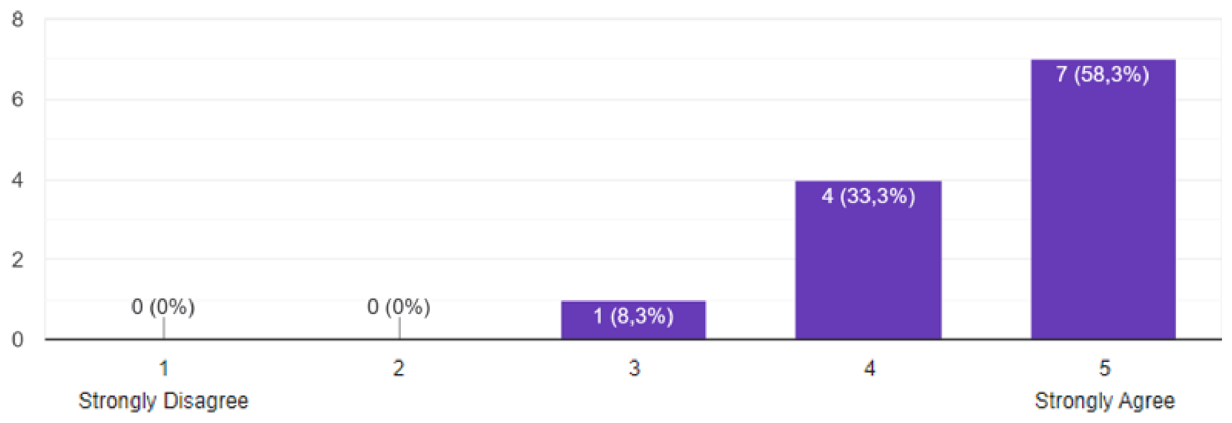
PATIENTS

- Overall the results were **positive**
- All patients were able to **easily access their plans and exercises**, as well as start a physiotherapy plan and exercise without any difficulty
- All patients were able to **successfully perform the phase of placing and connecting** the wearable prototype to the mobile device
- The wearable motion-sensing prototype was found to be **comfortable and easy to use**
- Most of the **feedback** regarding the exercise interface was related to the **design and how the information was presented in the interface** and not about the performance of the system's functionalities
- SUS Result: **83.3%** which on the scale is equivalent to **GOOD**

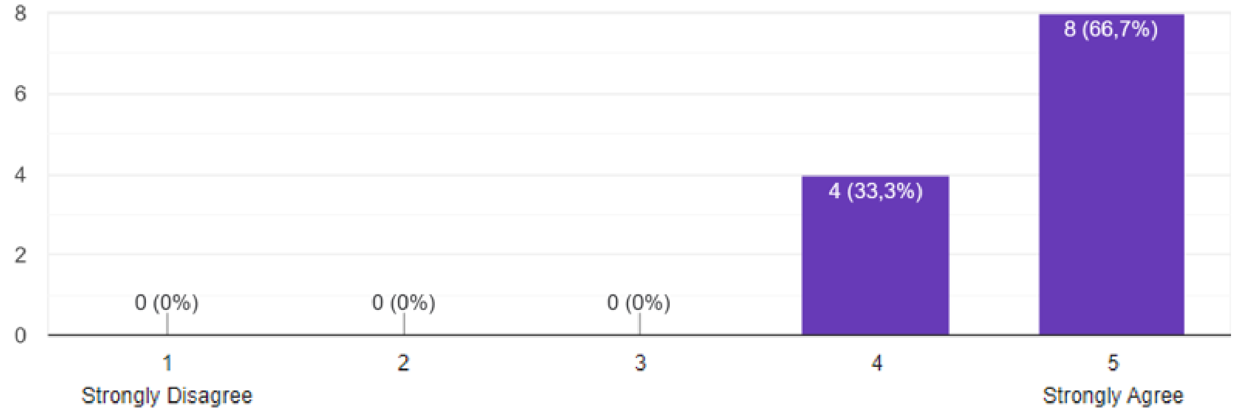
Was it intuitive and easy to access your plan page and start a physiotherapy exercise?



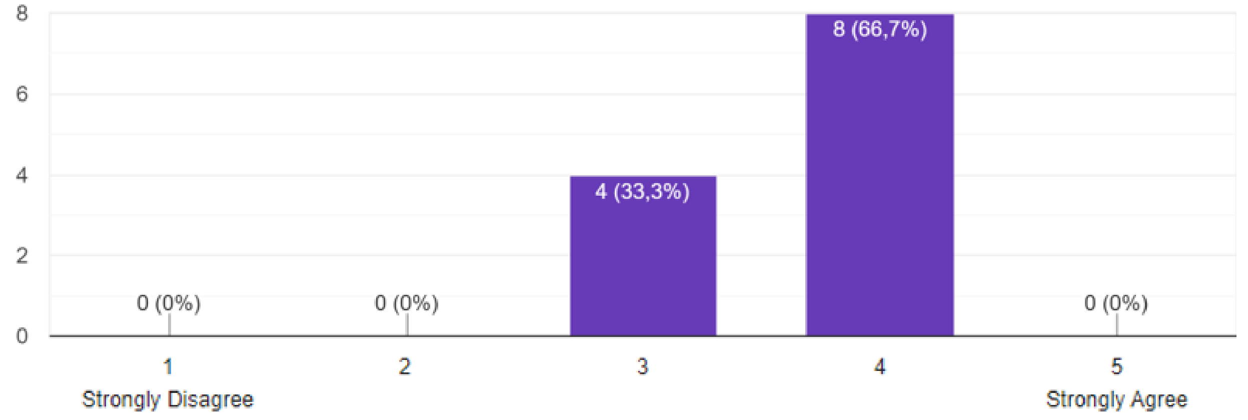
Was the wearable motion-sensing prototype comfortable and easy to use?



Was the process of connecting the wearable motion-sensing prototype to the mobile device and sensors calibration easy to accomplish?



Regarding the interface presented while performing the physiotherapy exercise, did you find the interface helpful and intuitive to finish the exercise successfully?



PHYSIOTHERAPIST

- Overall the results were **positive**
- The **tests were performed with a specialist at a clinic** that provides specialized, individual and personalized physical therapy treatments
- The physiotherapist was able **to easily access and manage the physiotherapy plans and exercises** for a given patient
- The physiotherapist **easily identified and accessed the page showing the patient's progress** throughout a given exercise
- SUS Result**: 75%** which on the scale is equivalent to **GOOD**

04 – Usability Tests

Without load

With load

- **Wearable Motion-Sensing Prototype**

  Price of the material used <40€

- **Mobile Application**

  Cost related to software distribution

- **Server and Database**

  Cost of hardware and software to run the server and database

05 CONCLUSION

- CONCLUSIONS
- FUTURE WORK

- Prototype of a system designed to **improve the rehabilitation process of a problem associated with the wrist joint**, as well as to help the evaluation and **monitoring** of the process

- The system presents some problems when the wearable motion-sensing prototype component is not properly used and positioned, or because the velcro straps used in this prototype loosen slightly, causing minor setbacks during the execution of the movements

- The **main goal** of this work was **accomplished**

- Include **new physiotherapy exercises** for the wrist, and also **integrate new sensors** in order to correct bad postures while performing movements
- The wearable motion-sensing prototype component could be improved in terms of using **better material**
- Some types of **actuators could be included** to allow a more interactive feedback during the exercises
- Migrate the system to a server available on the Internet, with its own domain
- Make the application also **compatible for iOS**

References

[1] F.J. Hiung and I.M. Sahat, “Development of wrist monitoring device to measure wrist range of motion,” In: IOP Conference Series: Materials Science and Engineering 788.1 (Apr. 2020), p. 012033, doi: 10.1088/1757- 899X/788/1/012033 (cit. on pp. 3, 42).

[2] M. Hazman et al, “IMU sensor-based data glove for finger joint measurement,” In: Indonesian Journal of Electrical Engineering and Computer Science 20 (Oct. 2020), pp. 82–88, issn: 2502-4752, doi:10.11591/ijeecs.v20.i1.pp82-88 (cit. on p. 4).

[3] N. Semiconductors, “I2C-bus specification and user manual,” In: NXP Semiconductors 4 (2014) (cit. on p. 53).

[4] H. Tai, 2018, Arduino library for MPU9250 Nine-Axis (Gyro + Accelerometer + Compass) MEMS MotionTracking Device, retrieved August 30, 2023, from https://github.com/hideakitai/MPU9250.

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[6] K. T’Jonck, B. Pang, H. Hallez, and J. Boydens, “Optimizing the Bluetooth Low Energy Service Discovery Process,” In: Sensors 21.11 (2021), p. 3812. issn: 1424-8220, doi: 10.3390/s21113812.

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[8] J. Brooke, ”SUS: A quick and dirty usability scale,” 1995, Usability Eval. Ind, 189.

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THANK YOU

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