MotionMend

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***Abstract*—The rising demand for physical therapy puts additional strain on the Physical Medicine and Rehabilitation Doctors and the Physical Therapists. A need for an increase in access of remote physical therapy solutions are needed to help improve patient outcomes and accessibility. MotionMend allows patients to work independently and be in charge of their rehabilitation. By using two modules and a phone, patients can track their progress after total knee replacement surgery. MotionMend provides specific exercises for patients to do and receive instantaneous feedback as they exercise. Doctors and Physical Therapists are then able to provide feedback during in perssion sessions.**

***Index Terms*—MotionMend, physical therapy, remote patient access, bluetooth low energy, patient treatment, total knee replacement, recovery, improving patient outcomes, accessibility**

I. Introduction

THE physical therapy market is a large and growing market with space for technological improvement to improve patient outcomes. The continuous demand for physical therapy requires innovation to reduce the number of patient visits while maintaining the rigorous physical therapy routine. Remote physical therapy provides the opportunity for patients to oversee their recovery and continue to heal outside of the office. There is less than a 40% adherence to the physical therapy routine after 20 weeks and over 65% of patients did not do the number of target sets. There were over 3.6 million knee replacement surgeries in 2023 with over 40% of those occurring within the United States. MotionMend looks to provide a simple ecosystem to assist patients in their journey to recovery after total knee replacement surgery. This level of access to high-fidelity simulations and data may provide more effective care to patients.

MotionMend uses two modules to measure the knee joint angle for a patient and transmit this data to a phone app. On the phone app, the data is processed to determine the angle that the patient's knee is at. This enables us to record the data and provide feedback on the patient's current position and how much further they need to go to reach their goal. This data is then transmitted to the database after the exercise is completed. On the database, Doctors and Physical Therapists can review the data and modify exercises to keep the patient on track or understand why they are not reaching their goals.

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II. Design and Methodology

Our proposed solution is MotionMend, a complete hardware and software ecosystem that works seamlessly to provide a smooth patient experience. Our patient will wear two PCB modules that we have designed that incorporate inertial measurement units (IMUs) to calculate the angle around their knee joint. The data is then processed through a Kalman Filter which is communicated over Bluetooth Low Energy to the mobile app. The mobile app will do an angle calculation based on the IMU's data and display the angle to the patient. In addition, there is an angle visualization that is provided in the app. The app will tell the patient what their target angle is and visualize the difference. After the exercise is complete, the angle measurements and time of the exercise are transmitted to our cloud which is hosted on Amazon Web Services (AWS). The data is stored securely in AWS and is then hosted on a dashboard to provide an overview of patient data to the medical provider. A workflow diagram is shown in Figure 1.

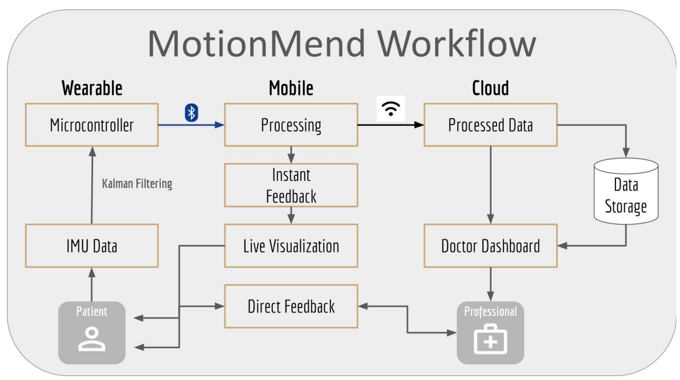

Fig. 1: Workflow Diagram of MotionMend

A. Hardware

1) Specifications and Requirements:

On the hardware side of MotionMend, we set out to design a product that could combine accurate angle measurements with effective and efficient packaging. For this, we must collect data about the relative position of the inertial measurement units (IMU) and transmit it to the phone app. To achieve this, we needed an IMU and microcontroller to work together to gather data and communicate it. The patient also must be free of wires to enable easy installation and wear. Which means that each module needs its own power source and additional peripherals to improve usability. Additionally, in the final design, they must fit into a small package so that it can easily be mounted and worn by the patient.

For the microcontroller, we considered different candidates for our device. Mainly, we compared using an STM32 vs. ESP32 variants. While STM32s provide efficient computing capabilities and more industrial applications; ultimately, we decided on an ESP32 variant due to its native wireless capabilities, high flexibility, small size, and decent power efficiency. We tested with various ESP32 modules including the ESP32-S3, ESP32-C6, and others; however, we settled on the ESP32-C3 for our final PCB Module for its higher power efficiency while still being more than capable of running our firmware. In addition to the ESP32 variant, we also considered whether to use the SoC or the integrated module on our PCB. Despite the smaller initial form factor of the SoC, we concluded that the additional decoupling capacitors in our footprint (0603) would end up using more space than the module itself. Thus, we arrived at our final choice of MCU, the ESP32-C3-MINI-1.

For our sensor selection, we tested many different IMU sensors to test their accuracy when measuring. We had an initial assortment of 6-DoF sensors (3 DoF gyroscope + 3 DoF accelerometer) and 9-DoF sensors (additional 3 DoF magnetometer). We compared their data rates, power consumption, ease of use, and form factor. We ended up deciding on the ICM-20948 IMU because of its accurate data readings, high output data rate (up to 9kHz), and small form factor (small QFN package - compact yet still possible to hand-solder).

The discrete ESP32 and IMU modules were relatively small, however, they required wires between them to communicate between them. To simplify the design and make a smaller design, we created a PCB module that had the ESP32 and IMU ICs on it. This allowed us to create an all in one package and to simplify the overall setup. Additionally, to make a more polished product, we implemented additional features on our board to complement the usability of the device. This includes an integrated charger via USB with configurable charge current, different indicator LEDs for user interface, and a power switch for easily turning the board on or off.

Another requirement is to be able to measure the range of motion within 5 degrees of accuracy. Based on our discussions of Dr. Wang, physical therapists are able to accurately measure within 5 degrees. Being able to replicate the same level of precision will be extremely important to the physical therapist to understand how the patient is exercising at home.

The following are the laid out requirements for the Microcontroller, IMU, battery, power management, and PCB / user interface.

- **Microcontroller:**
  - Low energy cost
  - The microcontroller must be powered by a battery
  - Bluetooth Low Energy capability
- **IMU:**
  - Low energy cost
  - Highly accurate and easy to extract data from
  - Able to provide data within 5 degrees of accuracy
  - Communication preferably via I2C
  - Logic level shifter between 3.3V and 1.8V
- **Battery:**
  - Lightweight and compact
  - Able to provide around 30 minutes of use
- **Power Management:**
  - Able to safely provide 3.3V to the MCU and 1.8V to the IMU
  - Safety features like overcurrent, undervoltage, and overtemperature protection
  - Fused power for added safety
  - Integrated Li-ion single cell charger via USB to be able to get fully charged in less than 1 hour.
  - Power MUX for power via USB or battery
- **PCB:**
  - Low energy cost
  - Small form factor to allow for easy mounting and use
  - Low cost to lower the financial burden of the final product
  - User LEDs to interface with the user

2) Original Design:

Our original design required three IMUs to gather data. We positioned an IMU in each of the following locations: upper femur, fibula, and sacrum. We used the upper femur and fibula to directly calculate the angle around the knee joint. The sacrum was used to help visualize the OpenSim simulation and provide a relative position for the other two IMUs. (5) These three IMUs are connected to an ESP32 Feather V2 through an I2C multiplexer (PCA9546) through STEMMA QT wiring. We used a 500mA 3.7V lithium-ion battery to power the ESP32. The embedded microcontroller, an ESP32 module, is responsible for collecting the raw data from the different IMUs using I2C, filtering, preprocessing, and sending it to the mobile application via Bluetooth Low Energy. The main preprocessing performed on the device is the sensor fusion of the raw gyroscope and accelerometer values into the relevant roll, pitch, and yaw values for each IMU. For the sensor fusion, we considered using different filters, including Complementary and Kalman filters. Based on their performance and output quality, we chose to use a Kalman filter for each IMU, allowing us to compute the principal axes in a stable manner with a higher degree of accuracy. This initial design allowed us to see that it was possible to measure the knee joint angle. However, there were many limitations in this design because of the many wires, clumsy setup, and unintuitive IMU placement. From this design we knew that we needed to improve the setup process by having each IMU have its own ESP32 so that there were no wires and also improve accuracy.

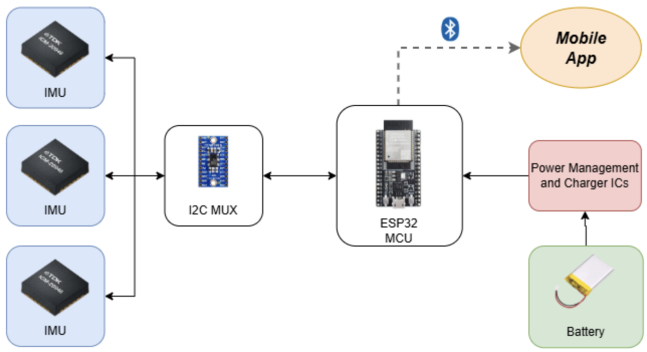

Fig. 2: Workflow Diagram of MotionMend

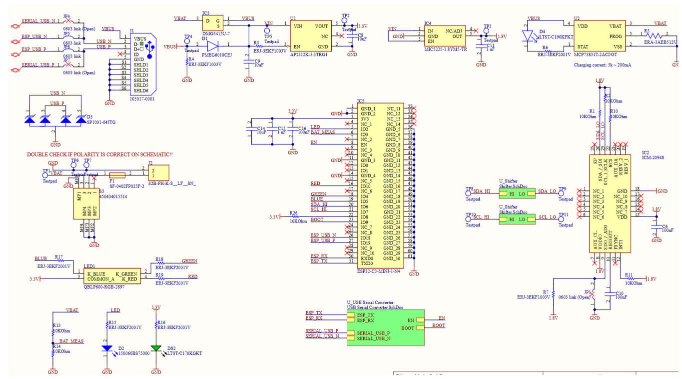

Fig. 4: Main page of the schematic

3) *Final Design:*

In our final design, we created our own PCB modules which contain the ESP-C3-MINI-1-N4 and ICM-20948 as the micro controller and IMU, respectively. The PCB we created can be seen in Figure 3. The PCB incorporated the ESP32-C3-MINI-1-N4 and ICM-20948 which we had identified as our necessary components before. The PCB also contains 3 LEDs to help provide patient orientation in the app. The overall PCB design fits into a 1.5 inch by 1.5 inch package which is extremely compact and allows the patient to be able to handle it with ease. We built an enclosure with holes for charging, LED lights, and the bluetooth antenna. The enclosure also contains the battery which is 150 mAh. We will work on quantifying the battery life of this final design.

We also decided to simplify our model and reduce to 2 modules. Based on feedback provided by Dr. Wang, visualization should not be a priority. However, providing an accurate maximum range of motion that was achieved, and the time of exercise was a greater priority. The overall design of this small module allows a patient to use any of the modules at either the femur or fibula location. Previously we were mounting the modules with velcro on a waist band, however, we are working on applying a gel patch around the module to allow for direct mounting on the skin. By mounting the module on the skin and not the clothing, we can improve the accuracy of the measurements. Additionally, we ensure that we are measuring the bone's position instead of the clothing's position.

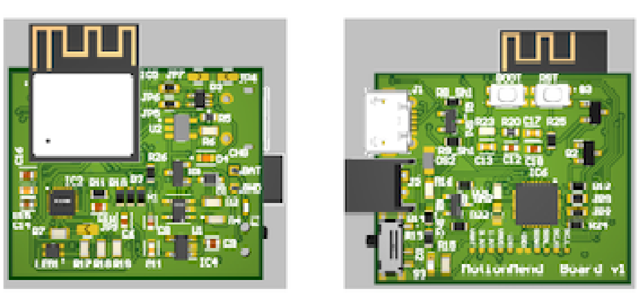

Fig. 3: Front and Back of the PCB

Our final hardware implementation must be able to measure within 5 degrees of accuracy, and we were able to visually verify this. We are confident that with proper setup and calibration, it is able to get within 5 degrees of accuracy.

B. *Software - App*

MotionMend's software suite enables the physical hardware to function as a complete exercise and rehabilitation system. This is accomplished through a multistage system. First the measured IMU data is sent from hardware modules to an iOS mobile app through a BLE connection. Second, the patient is able to interact with the app, where they can complete individual physical exercises. During the exercises, they receive real-time feedback on their performance. Upon completion of an exercise, the patient's performance is uploaded to MotionMend's cloud through an AWS instance. The data is then accessible to both the patient and the physician through a digital website. (see Figure 1).

1) *App Constraints:*

- **Platform:**
  - Application must be compatible with iPhone devices.
  - Application must be able to receive data from hardware modules over a BLE connection.
  - Data collected from exercises must be secured and sent immediately to cloud database.
  - Application must follow Apple App store guidelines.
- **Performance:**
  - The application must work consistently as expected, and not suffer from fatal bugs.
  - The application must be able to calculate angle data in real-time with a high degree of accuracy.
- **Ease of Access:**
  - Patients must be able to intuitively use all features of the app without prior instruction.
  - Application must be pleasant to use and not lead to unnecessary discomfort for patients.

2) *Design Development:* When developing the iOS app, the team's primary objective was to guarantee that the patient had a platform to complete exercises, while receiving useful feedback through an intuitive UI. To accomplish this, the first goal was to ensure that the basis of the ecosystem was viable, that is, that the hardware modules would be able to send

accurate angle data consistently and reliably over BLE to the iOS app.

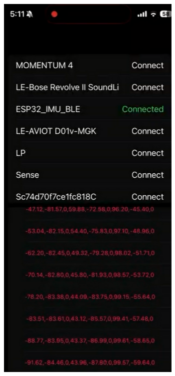

Fig. 5: Initial testing of BLE module to iOS connection

Following this, the team moved forward with creating a significantly more expanded upon app. This iteration consisted of a real-time angle visualization, exercise rep counting, and personalized feedback based on performance.

Fig. 6: 2nd App iteration with fully-implemented essential functionality

This iteration of the app was significantly more promising, and allowed team members to receive meaningful feedback on the look of UI aspects as well as some more essential features that needed to be implemented.

3) Final Version: The latest iteration of the iOS app features: a redesigned UI based on peer feedback, a 14-day exercise plan where patient progress is measured relative to previous exercises, and a system to upload data to the web dashboard. This enables exercises to then be accessed by patients and physicians.

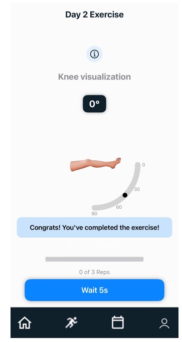

Fig. 7: Main UI of final app iteration

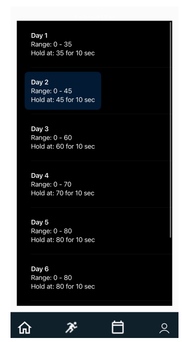

Fig. 8: Detailed app workout plan

4) Specifications: The MotionMend software system is designed to meet a series of functional and technical requirements which guarantee a positive patient experience and accurate hardware module integration,

- **Platform:**
  - The software is developed as a native iOS application using Swift, targeting devices running iOS 17.
- **Connectivity:**
  - MotionMend utilizes Bluetooth Low Energy (BLE) for real-time communication between the multiple hardware modules and the iOS app. BLE allows for limited latency while providing a seamless experience for patients - not requiring any physical connections.
- **Data Acquisition:**
  - Measured inertial measurement unit (IMU) data is processed on the iOS app in real-time. It is stored temporarily internally until completion of the exercise.
- **User Interface (UI):**
  - An intuitive, refined, and responsive UI design featuring real-time angle visualization, exercise rep counting, and dynamic feedback based on patient performance during a current exercise.
- **Cloud Integration:**
  - Patient performance data is uploaded to a secure AWS cloud instance upon completion of an exercise, allowing the exercise data to be accessed by physicians through a digital dashboard.

- **Exercise Management:**
  - MotionMend uses a 14-day customizable exercise plan to track progress and provide performance comparisons to previous daily sessions.

C. *Software - Doctor Dashboard*

The second component of the software suite is a dashboard for the physical therapist to view their patients' progress. After the app acquires data for a given exercise session, it is uploaded to an Amazon RDS database. The database consists of three tables: Doctors, Patients, Patient-Data. The Doctors and Patients tables contain identifying information regarding their respective entities (e.g. login credentials and name), while the Patient-Data contains summary statistics per session (e.g. maximum angle achieved, maximum range of motion).

1) Design Development: In developing the dashboard, the team sought to create an intuitive interface for physical therapists to add patients and track their progress. In earlier stages, all data gathered from the app was sent directly to the database – every record of the knee angle was uploaded and displayed on the dashboard (Fig. 9).

Fig. 9: Initial doctor dashboard

The team recognized that this approach resulted in reduced interpretability for patients (Fig. 8). To address this, summary statistics, such as the maximum range of motion per session, were instead uploaded and displayed onto the dashboard. The team also created a method to add patients and assign a 14-day exercise plan to their patients. The resulting workflow is illustrated below (Fig. 10, 11, 12, 13).

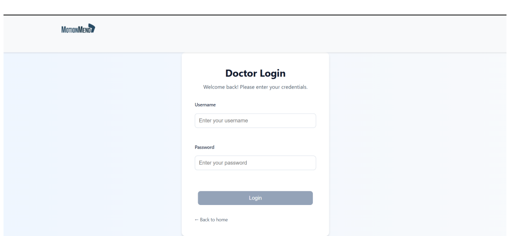

Fig. 10: Dashboard login page

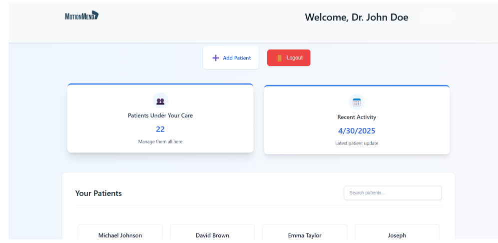

Fig. 11: Dashboard landing page

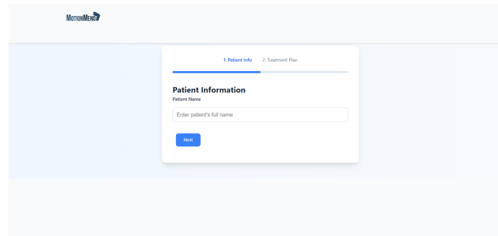

Fig. 12: Adding a patient (name)

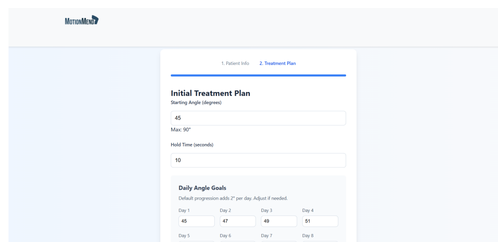

Fig. 13: Adding a patient (exercise plan)

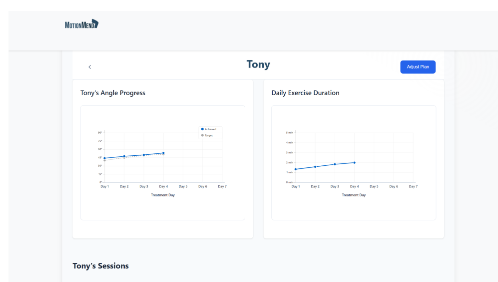

Fig. 14: Patient progress summary

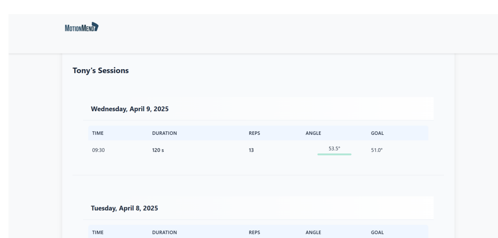

Fig. 15: Detailed breakdown per session

2) Specifications: The MotionMend dashboard seeks to provide physical therapists with an natural and secure platform to monitor patient progress. Below are the technical specifications to ensure the dashboard meets the needs of healthcare providers while remaining compliant with relevant standards.

- **Platform:**
  - The dashboard is a web-based application built using React.js for the frontend and Node.js for the backend.
- **Database:**
  - Patient and session data are stored in an Amazon RDS (Relational Database Service) MySQL instance of class db.t4g.micro, which costs $0.115 per GB per month along with an on-demand pricing of $0.017 per hour.
- **Data Security:**
  - All data transmissions are encrypted using HTTPS.
- **Patient Management:**
  - Doctors may add new patients to the system and assign them to their profile. Patient profiles include personal details and are linked to a table displaying a history of exercise sessions.
- **Data Visualization:**
  - Summary statistics, such as maximum range of motion are displayed using an easy-to-read format. Graphs and charts provide visual insights into patient progress over time.
- **User Interface:**
  - The dashboard features a clean, intuitive design optimized for ease of use. Key functionalities, such as adding patients and viewing session data, are accessible within a few clicks.

D. *Conclusion*

MotionMend's use of hardware and software provides a unique patient experience in physical therapy. A patient is able to get accurate data and feedback based on that data to improve their outcomes after surgery. Additionally, the Hardware and Software were designed so that they could be adapted to other parts of the body if necessary. This flexibility and design from the ground up allowed us to build a better system for the patient.

III. Implementation

The patient journey starts right after knee replacement surgery. The doctor adds a new patient to the system (Figure 12) and based on the person's history, the doctor can input a customized initial exercise plan for the patient (Figure 13). Then the patient receives login instructions to the mobile app, as well as two of our MotionMend modules. As seen below, the devices are compact and lightweight, measuring around 1.5 by 1.5 inches and can be easily brought home.

Fig. 16: 3D render of the module

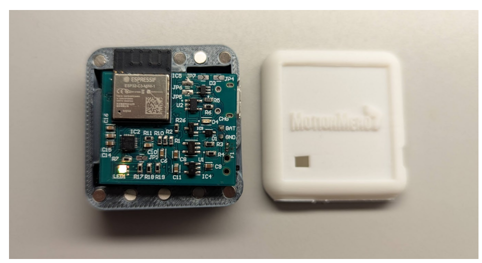

Fig. 17: Inside view of custom PCB

From the comfort of their home, when the patient is ready to exercise, they will log into the app and be greeted by easy to follow setup instructions (Figure 18). The modularity of our devices means that they are interchangeable, so the patient doesn't have to worry about which device to use. Moreover, the modules are easy to put on and don't have strict placement requirements, due to our calibration software.

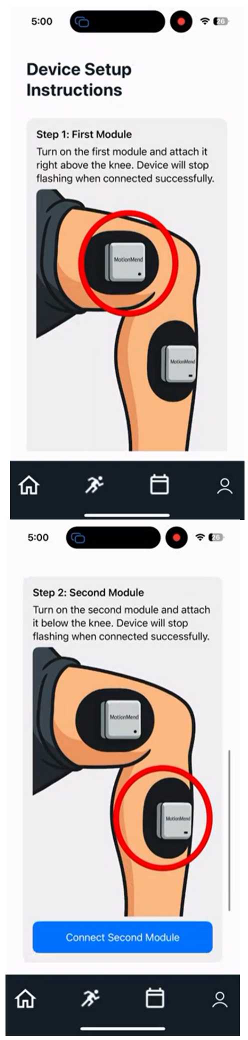

Fig. 18: User instructions on setting up the devices

After placing the modules, the patient is ready to start their exercises (Figure 19). They can see the current exercise set by the doctor directly on their app, allowing them to see their progress and clearly view what are the upcoming targets (Figure 8).

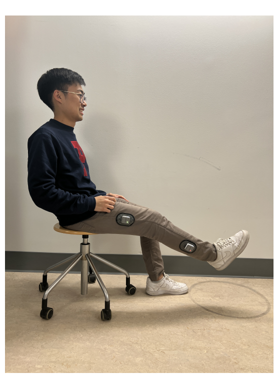

Fig. 19: User wearing two modules

When going into exercise mode, the app will fetch the next exercise from the schedule and display live feedback and instructions to the patient (Figure 7). The app will receive the data from the modules, show how well the patient is doing, count the current repetition, and provide encouragement to the patient.

Once the exercise is complete, the app will immediately send the data to the secure database. The physical therapy professional will then visualize this updated exercise on our dashboard (Figures 15 and 14), which displays all the relevant information, like current range of motion, target goals, and exercise duration. These automatic patient summaries allow the professional to check on patients faster, provide feedback, and update the target goals based on individual patient progress.

IV. Testing and Verifications

A. Hardware

On the hardware side, testing and verification was comprised of validating multiple aspects of the module, including IMU angle measurements, Bluetooth connectivity and integration, calibration of measurements with different people, PCB assembly validation, and battery life and charging capabilities.

1) Measurement Testing: From the beginning of our hardware evaluation, we compared multiple candidate IMU sensors to identify the model offering the most accurate orientation measurements and the fastest response time. To quantitatively validate sensor accuracy, we affixed two identical IMUs to rigid flat plates joined by a hinge. By varying the hinge angle across the full measurement range, we compared the physical angle betwen the plates against the output of our on-board Kalman filter. Across trials, we were able to achieve the 5° accuracy threshold established by professional physical therapists.

2) Calibration Validation Across Patients: To ensure that our module is inclusive and robust to different patients and sensor placements, we developed a dynamic calibration routine and tested it on all differnt team members. During calibration, the patient starts at a know position and th system records the baseline offsets for the current patient and position. From testing with different setups, patients, and positions, we validated that the calibration was able to account for these differences and ouptut accurate measurements.

3) PCB Assembly Testing and Verification: All custom PCBs were assembled in-house using a solder paste stencil and reflow oven for one side, followed by manual hand-soldering of the remaining components. After assembly, each board underwent different tests: we verified I^2C communication to each IMU, confirmed angle measurements, tested BLE pairing and data streaming, tested battery-charging circuitry to 4.2 V (measured with a bench voltmeter), validated LED status indicators, and performed a firmware flash cycle. Once a board passed this suite of checks, we ramped up to batch production by replicating the stencil/reflow process, drastically reducing the per-unit assembly time.

Fig. 20: 4 modules being assembled at the same time using the reflow oven.

4) Battery Life and Charging Validation: To evaluate energy endurance under worst-case operating conditions, we fully charged two modules to 4.2 V via the integrated charger (voltage verified with a digital voltmeter), then connected to them via Bluetooth to simulate the highest power consumption when the connection is active. Both units sustained operation for just over 1 hour, confirming that a single charge comfortably exceeds the duration of multiple therapy sessions. Similarly, for charging performance, we charged both modules from empty and recorded a time-to-full charge of approximately 20 minutes, thus also validating their full charge times.

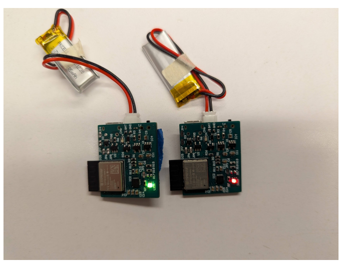

Fig. 21: Two charged modules being tested for battery life estimation.

5) BLE Throughput and Data Integrity Testing: We implemented a custom Python receiver script to log incoming BLE packets, verify packet integrity, and timestamp batches of preprocessed angle data. We measured 10 milliseconds between observations, thus resulting in preprocessed angle data at a frequency of 100 Hz with no instability or losses.

A major point of concern for the team was how long the battery would last for each hardware module. If the hardware modules did no last sufficiently long enough to complete several daily exercises, then it would potentially require a modified battery. To address these concerns, the team ran several tests using multiple completed PCB's. To do this, team members charged the modules completely, and then connected two modules at a time to the a phone using the iOS MotionMend app. Then, the team recorded the time until each module's battery ran out. By connecting the modules to the app, we were properly testing how long the modules would last considering their full use, that is, including having to broadcast and communicate over BLE. Following these tests, the team was satisfied to find that each battery lasted approximately an hour. Considering that each exercise/use session of MotionMend lasts around 10 minutes, the team was content with this performance.

B. *Software*

Software testing primarily involved testing BLE connections and general communication across the MotionMend system. To test the entire ecossystem, the team first started by confirming individual components worked completely, and then built up from there. First, team members would test each completed PCB module by connecting to the iOS app through BLE. Through the XCode debug system, uploaded IMU data could be accessed, and confirmed to follow correction orientation - data uploaded matched the current angle of the IMU. Then, randomized pairs of hardware modules were tested with the app, to ensure that angle calculation remained consistent across all PCB's, regardless of order or which were being used together. To verify angle accuracy, a protractor was used to confirm the relative angle between the two hardware modules, which confirmed what was being shown on the full app interface.

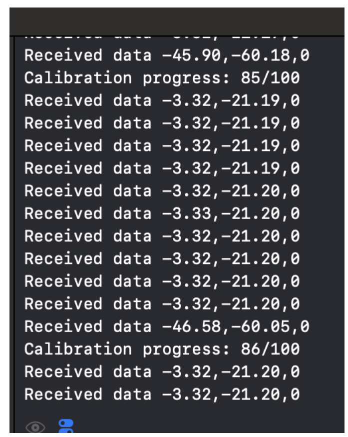

Fig. 22: Testing through XCode's debug console to confirm each PCB can communicate to an iOS device over BLE.

Following this, the team focused on ensuring that all features of the entire ecosystem worked. This involved a thorough walk-through of all uses of the app, hardware modules, and dashboard. With respect to the dashboard, end-to-end testing was done to ensure patient data was uploaded in a consistent and secure manner. Supplementary testing was done to confirm that patient names and passwords did not appear as plain-text within the database. Additionally, the team experimented and rigorously tested concurrent use of the MotionMend system, that is, experiments were run with two patients completing the pairing process, exercises, and dashboard uploading at the same time. This was done to guarantee that MotionMend could accommodate multiple patients at once. In terms of future goals, the team would be interested in testing higher scales of use (perhaps 100's of MotionMend patients at once) - however, this fell out of the scope of the senior design program.

V. Standards

There are many standards that this project needs to follow because of its application within the healthcare sector.

A.

HIPAA - Health Insurance Portability and Accountability Act. HIPAA is extremely important for patient privacy and safety. The collected patient data must be securely stored, encrypted and require strong authentication methods. This is to ensure that only the authorized medical personnel who need access to patient data, can access it. To be HIPAA compliant, the MotionMend team ensured that access controls were set appropriately and that passwords were stored using the bcrypt library with twn rounds of salting. An audit logs table was added to track all modifications and accesses to the database. Finally, the AES_ENCRYPT() function within MySQL was used to securely store patient data such as their names.

B.

IEEE 802.15.1 - WPAN / Bluetooth. Secure data communication is handled over bluetooth. The app communicates with the ESP32 over bluetooth low energy, and must follow the standards to ensure that the data is secure.

C.

UL 2054 - Certification of Lithium-ion Battery. The ESP32 is powered by a Lithium Ion battery, therefore, all guidelines on how to reduce the risk of any fire or injury to the patient must be followed.

D.

Apple App Review Guidelines. The Mobile Application is powered by iOS and is governed by Apple's Application Guidelines to be published to their App Store. Therefore, it needs to be compliant with any regulations set by Apple.

VI. Ethical and Social Considerations

The goal of MotionMend is to provide the resources for patients to be in charge of their recovery process. Patients are required to go to physical therapy often after total knee replacement surgery, and patients who are unable to do so consistently, are unable to go through surgery. Because of this, MotionMend's remote access will benefit these patients by reducing the number of required in person visits. Patients will work from home to improve their range of motion. MotionMend will allow people with limited mobility or inconsistent access to transportation, to exercise from home and not be required to go in person as frequently. This will ensure that they will be able to maintain their strict regimen from home. While MotionMend will not be able to replace in person therapy, its goal is to be a low-cost option to complement in person physical therapy.

Patients will be in severe pain immediately after surgery, however, overtime their pain will decrease. MotionMend is conscious and aware of the pain that patients are in and understands what type of devices and clothing that they can wear as a result. We hope to create an adaptor like object that can adhere to clothing so that the patient can wear it without wearing restrictive clothing.

Our hardware product does not store any patient data on it, so physical therapists can have several sets of IMU sensors and ESP32 devices to loan out to their patients for the weeks after their surgery. This is great for the environment as the device can be used by dozens of patients and is not disposable.

VII. Economic Considerations

From its core, MotionMend was developed with the goal of increasing accessibility to high-quality physical therapy. To achieve this, we prioritized affordability without compromising quality or performance. The final unit cost of our device is under $15, enabling adoption in underserved communities. Despite the low cost, our system maintains measurement accuracy and reliability. Furthermore, by employing a modular design, each device can be easily reused across different exercises and patients, eliminating the need for specialized hardware for specific cases. This reusability significantly reduces overall deployment costs and enhances scalability to reach an even broader audience.

VIII. Conclusion

MotionMend is an innovative medical device which will be able to help patients recover quicker and more independently while also receiving feedback from their physical therapist. Our flexible, modular design not only simplifies use for patients but also lays the foundation for future adaptations to measure additional joints. Beyond rehabilitation, precise knee-joint data can empower fitness professionals to optimize exercise form and performance at the gym. We have been able to show that a low cost but accurate device is possible and the results are powerful. By delivering a low-cost yet highly accurate solution, MotionMend has the potential to expand access to quality physical therapy, making essential rehabilitative care more affordable and widely available.

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IX. References Section

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