Physical Therapy Device for Shoulder Range of Motion Recovery

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Abstract

Extensive research has been conducted regarding surgical and otherwise invasive intervention for repairing or replacing the proximal humerus after fracture for older adults. However, in the less-researched young adult population, it is often recommended to opt out of surgery and instead recover through immobilization followed by physical therapy. In an interview with a patient recovering from proximal humerus fracture, we learn that one of the most important challenges in physical therapy is the ability to perform exercises in a convenient manner. As a result, in this study, we propose a device intended for young adult patients in the physical therapy stage of their recovery to help them regain range of motion in their shoulder. The device allows users to monitor their progress in shoulder abduction exercises through a system that displays inclination measured by an inertial measurement unit. In addition, the user can vary the resistance applied in the shoulder abduction to challenge themselves and further their recovery progress. Users will naturally integrate physical therapy into their routines by choosing to wear the device during activities of daily living.

I. Introduction

Proximal humerus fracture is common in older adults due to osteoporosis. The bone is typically treated surgically to increase the rate of recovery and quality of life in this age group [1]. However, for younger adults, immobilization through a sling followed by physical therapy is recommended to naturally regain strength and range of motion [2]. Physical therapy exercises are often assigned to these young adult patients to further progress, but such exercises can be painful as they push the limits of the injury, causing lack of motivation. As a result, we propose a device that allows patients to easily practice physical therapy exercises from home safely and effectively using exercises dictated by professional guidance. We address lack of motivation through a tracking system that allows the user to view their progress. Similarly, we allow users to challenge themselves with a modular resistance system to increase strength and range of motion. We hope that such features will provide more gradual and consistent improvement and increase accessibility to convenient physical therapy.

A. Background

Current recommended physical therapy exercises for proximal humerus fracture recovery utilize commonly found exercise equipment in the physical therapy office and little to no equipment at home [3]. Typically in the office with professionals present, patients will perform exercises such as scapular adduction on a foam roller and stretching with a medicine ball [4]. As these are more freeform exercises with greater risk, it is important that a professional is present to ensure proper form. At home, patients will perform assisted abduction with a stick held by the limb with normative function (see Figure 1) and eventually active abductions (see Figure 2) [4]. Overall, there is limited equipment readily available for at home use.

While the small amount of equipment used for at home exercises provides a simple and low cost solution, it can be discouraging for patients who wish to track their progress and further challenge themselves in their journey to recovery. Without a sensing system, they may only rely on their personal observations with little quantitative data to characterize their progress as measuring oneself's range of motion using external tools such as a goniometer or inclinometer poses a challenge [5]. Such stagnant periods in recovery discourage performing the exercises regularly and hinder recovery.

As a result, we hypothesize that including a tracking system for at home physical therapy and displaying this quantitative sensor data for the user will motivate users to more regularly perform their assigned exercises and improve their recovery experience. In addition, we hypothesize that making such a device wearable will increase convenience by allowing them to perform their exercises during daily living. Finally, we hypothesize that including variable resistance levels will offer more windows for the user to see improvement as they will be able to see both their strength and range of motion improve. Overall, we estimate that our device will motivate users to regularly practice their physical therapy exercises and consequently increase rate of recovery.

Fig. 1. Active-assisted abduction is typically performed with a stick for assistance. In our need-knower's case, the most convenient object is a broom, but this does not have even weight distribution. Figure from [4].

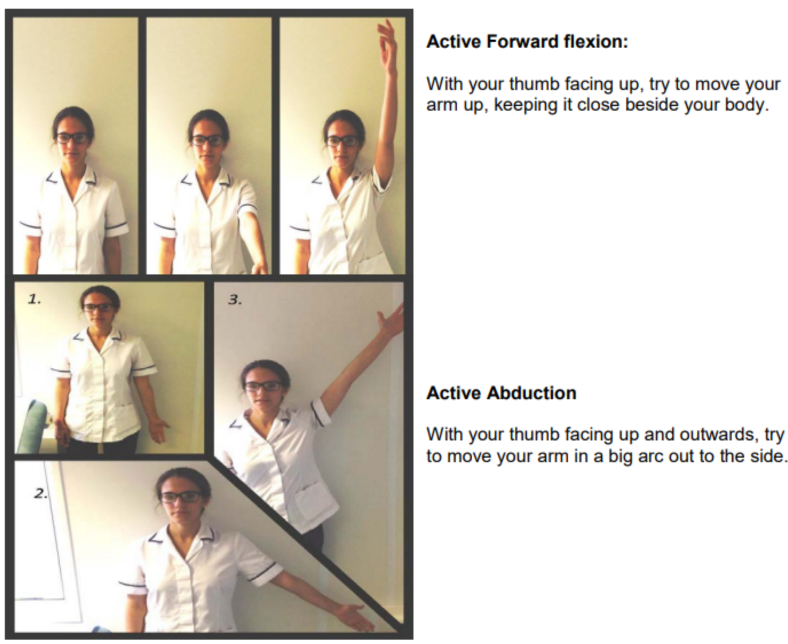

Fig. 2. Our device implements a tracking system for progress in active abduction. It also allows for increased resistance in the abduction motion. Figure from [4].

B. Overview

In Section II, we discuss early results from the interview with the need-knower, in which we learned about her experience after the proximal humerus fracture and her priorities in recovery. Section III includes our proposal for how we will quantify the motivation of patients using this device as well as how we will decide whether or not, and if so, to what extent, the product increases rate of recovery. In Sections IV and V, we discuss how our study contributes to current research in this field and how it may influence those recovering from proximal humerus fracture.

Question/Prompt	Need Knower Statement	Interpreted Need
Current Difficulties	I have trouble doing my hair and basic hygiene stuff like showering.	She needs a full range of motion in her arm.
Likes - Current Therapy	I saw a lot of progress in the first few weeks of PT but feel that my progress has plateaued.	She needs to see continuous progress in her physical therapy.
Dislikes - Current Therapy	I have a lot of pain during exercises, which can be unmotivating, causing me to skip physical therapy some days.	She needs either new strengthening or recovery exercises that are more comfortable during and post exercise that will motivate her to want to do them at home.
Likes - Current Devices/Tools	I don't have the right tools at home to perform the exact exercise I do in physical therapy. I only have a broom which is uneven in weight on both sides which is kind of uncomfortable.	She needs tools to properly perform her physical therapy exercises.
Dislikes - Current Devices/Tools	The broom is not ideal for the physical therapy exercise compared to what is available at the physical therapy center.	She needs a more effective tool that simulates what she does at the physical therapy center.

Fig. 3. Identified needs from the interview.

II. Preliminary results

In our interview with the need-knower, we sought to understand the background behind her condition and determine her priorities. Around December of last year, the need-knower suffered a proximal humerus fracture in her right shoulder. Although proximal humerus fractures often require invasive surgical procedures, due to her young age, she was able to choose a noninvasive recovery path. For the first six weeks of her recovery, she experienced extreme difficulty in daily tasks and required assistance from friends and family due to the intense pain from even slight movements of her right arm (dominant arm). Once she was able to move her shoulder with less pain, she began physical therapy. Currently, she has regained motion of her arm to 90 degrees from the side and the front of her body. She still struggles with carrying heavier loads with her right arm and applying downwards force. To compensate for this in her daily life, she has been switching more tasks to her left (less dominant) arm. Throughout the interview, one of our main takeaways was that she was more focused on recovery through physical therapy than pain management. The need-knower also stressed the importance of being able to regain her full range of motion. In physical therapy, she felt that she's stagnated at a range of motion of 90 degrees and expressed fear and anxiety about not being able to increase it. Although she is determined to regain her range of motion, she has found it difficult to balance the physical therapy she needs with her work schedule since it's often early in the morning and requires changing clothes. Physical therapy is also difficult due to the amount of pain it causes her, but she acknowledges the necessity of it. In her daily life, she saw an impact on her ability to reach and manipulate objects above her head, making tasks like doing her hair difficult. For more details regarding the needs identified from the interview, see Figure 3 and Appendix B.

III. Methods

We aim to address the concerns indicated in Section II by creating a compact device with an interactive progress tracking system. We designed our device to be compact and require three simple steps (strap on the waist unit, put on the wrist unit, and turn on the device) to set up for easy accessibility at any time. The device can be worn during daily living, adding resistance to the shoulder abduction movement used in everyday tasks. To carry out physical therapy exercises, the user will grasp the end of the resistance band and actively carry out an abduction motion in the frontal plane until they reach their set goal. The user can interact with the device to set a goal for their abduction angle, and the device responds with green and red light-emitting diodes to signify whether the user has reached the goal (see 4. In addition, the device automatically adjusts resistance based on progress to strengthen muscles and increase range of motion. For details on the design and function of the device, see Appendix B.

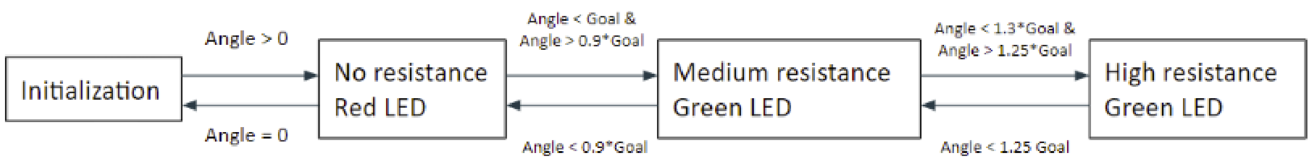

Fig. 4. Finite state machine diagram for the device. The motor, attached to the spool, actuates to adjust the length of the resistance band and therefore impacts the force required to perform the abduction. The LEDs turn on to indicate when the goal has been reached.

There are two main components in the device: the waist unit and the wrist unit (see 6). The waist belt holds the actuator of the system (the motor that varies the length of the resistance band). The band winds about a spool, eliminating the possibility of tangling around other actuator components. The AndyMark Neverest 60 gear motor outputted our desired torque and was a cheap and accessible option.

The wrist unit of the device houses the sensing and computing aspects of the system. We correlated our need-knower's progress in physical therapy with the increase in angular displacement of her arm relative to her body. The SparkFun 9DoF IMU (MPU 9250) sensor outputs the sensor's acceleration along different axes,which can be used to calculate the angular displacement of the user's arm. We measure the angle in the frontal plane relative to her body assuming the coordinate system illustrated in 5. Since the IMU has 9 degrees of freedom, her hand and wrist must be restricted so that there is no rotation about the x-axis (see 5) while she carries out the exercise because the trigonometric function for calculating the abduction angle is affected by rotation about the other axes. Therefore, the handle of the resistance band is designed so the user hand and wrist is guided in a linear motion with no rotation.

In the future, we'd like to study the impact of increasing resistance and the consistency of using the product on strengthening shoulder muscles and improving range of motion. Given that increasing resistance in the band achieves the goal of strengthening the shoulder muscles, studying how much force is exerted by the user in lifting their arm and comparing this to activities of daily living would be helpful in quantifying progress. For example, we can perform tests using a force gauge to determine the spring constant in the resistance band to quantify the amount of force exerted given the displacement of the band. We can combine this data with measurements with an electromyography (EMG) sensor to map the electrical signal from certain shoulder muscles to the force required to displace the band given a certain length.

To quantify the impact of the device on the user's motivation and consistency in performing physical therapy exercises, we will have two asymptomatic groups, one using our assistive device and the other using common physical therapy training tools like a weighted bar for abductions. We will then compare both the angular displacement progression over time and the consistency and frequency the products are used. In addition, we would include a limited number of symptomatic cases of patients recovering from proximal humerus fracture to gather evidence of how the device would be used in practice. Finally, we will perform interviews and distribute surveys to investigate subjects' satisfaction and experiences with

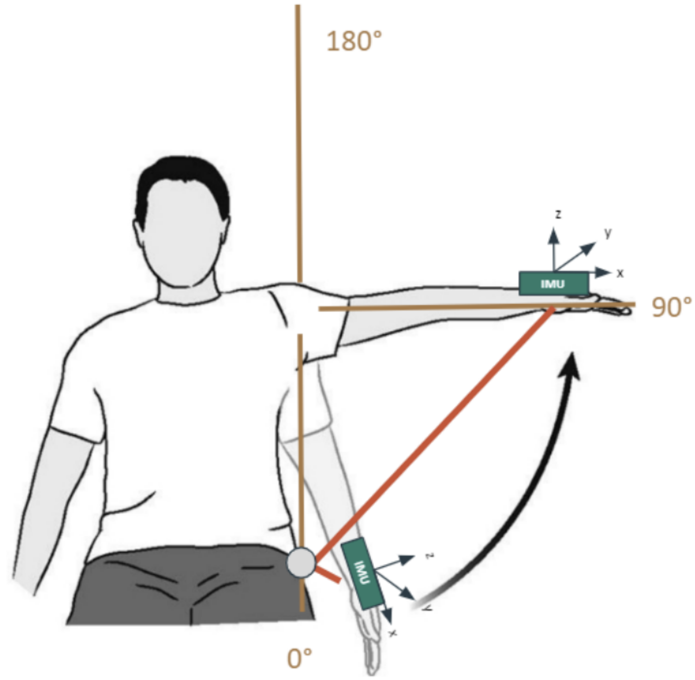

Fig. 5. We define zero degrees as the user's arm by their side and 180 degrees as their arm extended above their head.

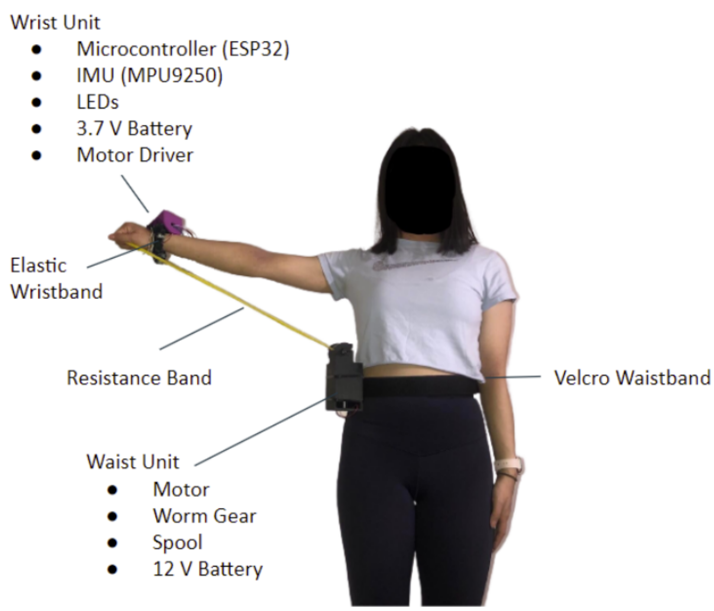

Fig. 6. The device is interfaced with the user through a velcro waistband and elastic wristband.

the device. Although we have completed CITI training, we would need approval of the Internal Review Board before running any of these suggested studies or tests.

Although the device currently only supports shoulder abductions, we hope to eventually expand to support other exercises such as adduction, horizontal abduction, horizontal adduction, extension, and flexion to target all of the muscle groups that contribute to full shoulder mobility (see 7). We ultimately aim to strengthen the shoulder muscles along different axes, including the middle deltoid, trapezius muscle, rhomboid muscle, supraspinatus muscle, supraspinatus muscle, teres muscle, etc.

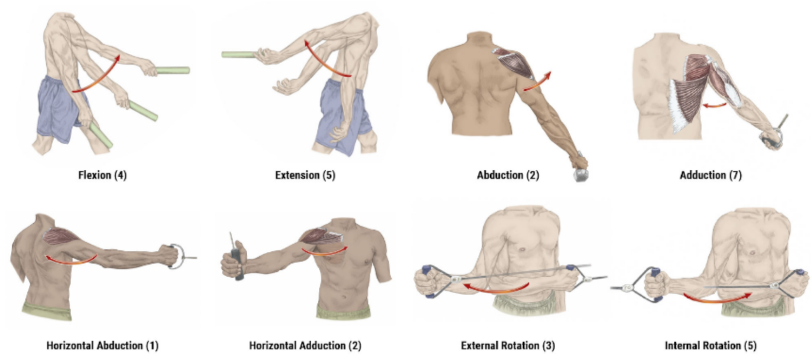

Fig. 7. Common exercises for regaining shoulder range of motion. Figure from [6].

IV. Intellectual Merit

This physical therapy device is novel in its specific target audience and adaptive feedback. As a result, this will influence the scientific community in this field to cater their research to young professionals working full time. Our device was intended to be comfortable and easy to use during the work day so it would be easier to fit into our need-knower's busy schedule. In later publications, it would be useful to test the device's efficacy with multiple working professionals in various fields and gather user feedback. New designs centered around making physical therapy more accessible would also be beneficial. Finally, this new device may be used as a testbed to evaluate how smart devices motivate users to perform physical therapy.

V. Broader Impact

There is a large focus on older populations with proximal humerus fractures in academia. However, our interview with the need-knower demonstrates that younger populations with this type of fracture also undergo a physically, emotionally, and mentally tasking experience in different ways. For those who go the noninvasive route of recovery, physical therapy is difficult to maintain, especially for working professionals. With this device, we hope to make the road to recovery easier and promote noninvasive procedures for proximal humerus fractures.

References

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Appendix A
Discovery Decomposition

Topic of the interview: assessment of proximal humerus fracture.

1) Management of Proximal Humerus Fractures in Adults: [1].

- Background/Hypothesis: The aim of this review is to develop a concise collection of treatments for proximal humerus fractures in adults that takes into account an individual patient's unique fracture configuration, health history, and recovery expectation.
- Methods: The literature review looks at the range of treatments available, ranging from non-operative, reconstructive, and prosthetic options.
- Results: Non operative treatments work best in minimally displaced, stable fractures while reconstructive and prosthetic treatments are better suited for less severe fractures and severe fractures in elderly patients respectively.
- Conclusion: Proximal humerus fracture recovery is a process highly dependent on careful evaluation of the fracture and the patient's health history.
- Test Hypothesis: The compilation of various proximal humerus fracture treatment methods and their advantages/disadvantages is meant to assist in the decision making process.

2) Four-part Fracture Dislocations of the Proximal Humerus in Young Adults: Results of Fixation: [2].

- Background/Hypothesis: Four-part fractures dislocations of the proximal humerus in young adults can produce a series of difficult complications.
- Methods: 39 patients younger than 40 years old and with four-part fracture dislocations were treated using two different methods, K-wires or a proximal humerus plate, to assist in healing.
- Results: After 26 months, the condition of the patients was observed, resulting in 36 patients that had achieved union and three patients that still had nonunion as well as 26 patients that were pain free and the rest experiencing some level of pain.
- Conclusion: Anatomical reduction and fixation combined with surgery leads to satisfactory patient recovery
- Test Hypothesis: Prosthetic replacement should be reserved for older patients because of the difficulty to maintain the prosthetic in a young individual.

3) Nonoperative Treatment of Proximal Humerus Fractures: A Systematic Review: [3].

- Background/Hypothesis: Proximal humerus fractures can often be treated nonoperatively and have various long-term effects on the patients
- Methods: By using the PubMed search engine and EMBASE database, literature within the inclusion criteria: proximal humerus fractures from trauma, patient age greater than 18 years, greater than 15 patients in the study, greater than 1 year follow up, and at least one quantitative outcome scoring, was found
- Results: 12 studies with 650 patients with a mean age of 65 years with varying severity of fracture collected data on rate of radiographic union, complication rate, forward flexion, external rotation, internal rotation, Constant score, and common complications
- Conclusion: This literature review shows high rates of radiographic healing, good functional outcomes, and a modest complication rate associated with nonoperative treatment of proximal humerus fractures.
- Test Hypothesis: Few studies evaluate the long term outcomes of nonoperative treatment of proximal humerus fractures and should be compiled together.

4) The Reliability of Concurrent Validity of Shoulder Mobility Measurements Using a Digital Inclinometer and Goniometer: A Technical Report: [5].

- Background/Hypothesis: The intrarater reliability (consistency of an individual's measurements for a particular phenomenon) and validity of shoulder mobility measurements with the use of a digital inclinometer and goniometer were determined.
- Methods: A goniometer and digital inclinometer were used for measuring several shoulder movements (flexion, abduction, internal and external rotation) on thirty participants using blinded repeated measures.
- Results: Both methods showed good results for measuring shoulder mobility, as presented using the Intraclass Correlation Coefficients (ICC).
- Conclusion: This paper supports the use of goniometers and digital inclinometers for shoulder mobility measurements but notes that there is a limit to the agreement between both measurements, so they should be used with caution.
- Test Hypothesis: After participants were tested on their dominant arm, it was determined that inclinometry and goniometry were valid methods for measurement.

5) A scoping review of the proximal humerus fracture literature: [7].

- Background/Hypothesis: Older adults are more likely to get proximal humerus fractures which severely impacts their independence.
- Methods: By looking through electronic databases, literature on proximal humerus fracture literature was classified into eight main categories.
- Results: The main categories consisted of surgical treatment studies, biomechanical fracture models and less common categories consisted of the outcome of non-operative treatment.
- Conclusion: A summary of proximal humerus fracture literature highlights multidisciplinary collaboration and unexplored areas of knowledge.
- Test Hypothesis: A compilation of proximal humerus fracture literature can help guide proximal humerus fracture management.

6) Operative versus non-operative treatment for 2-part proximal humerus fracture: A multicenter randomized controlled trial: [8].

- Background/Hypothesis: Surgical treatment of displaced 2-part proximal humerus is used to aid in healing.
- Methods: A study of 88 patients 60 years or older with displaced 2-part proximal humerus fractures tested operative treatment with a locking plate versus non-operative treatment.
- Results: The success of both treatments was measured with Disabilities of Arm, Shoulder, and Hand (DASH) score and the Constant-Murley score, a visual scale of pain, resulting in a DASH score of 18.5 for the operative treatment group and 17.4 for the non-operative group.
- Conclusion: After two years, there was no obvious benefit in the operative versus non-operative treatment of the proximal humerus fracture.
- Test Hypothesis: Effectiveness of surgical treatment of displaced 2-part proximal humerus fractures has not been proved.

Appendix B
Investigational Device Details

A. Interview

A chart depicting the needs identified from the interview can be found in Figure 8.

Question/Prompt	Need-Knower Statement	Interpreted Need
Current Difficulties	I have trouble reaching above my head.	She needs a method of reaching objects over her head.
	I have trouble doing my hair and basic hygiene stuff like showering.	She needs a full range of motion in her arm.
	I have trouble sleeping or lying on my right side.	She needs a comfortable way to lay down.
	I still can't drive myself because it's dangerous; instead, I have to take Ubers to work, which is very costly.	She needs a safe and affordable method of transportation that allows her to be independent.
Likes - Current Therapy	I saw a lot of progress in the first few weeks of PT but feel that my progress has plateaued.	She needs to see continuous progress in her physical therapy.
	Massages really help with loosening the muscle, but they all hurt	She needs a way to both relax and stretch her muscles that aren't painful.
Dislikes - Current Therapy	I have a lot of pain during exercises, which can be unmotivating, causing me to skip physical therapy some days.	She needs either new strengthening or recovery exercises that are more comfortable during and post exercise that will motivate her to want to do them at home.
Likes - Current Devices/Tools	I don't have the right tools at home to perform the exact exercise I do in physical therapy. I only have a broom which is uneven in weight on both sides which is kind of uncomfortable.	She needs tools to properly perform her physical therapy exercises.
	The exercise where I lie on the foam roller or lay on the medicine ball are good exercises	She needs more exercises like this that aren't painful and still correct her injury
Dislikes - Current Devices/Tools	The broom is not ideal for the physical therapy exercise compared to what is available at the physical therapy center.	She needs a more effective tool that simulates what she does at the physical therapy center.

Fig. 8. Identified needs from the interview.

B. System Circuit

See Figure 9 for a diagram of the circuit connecting the ESP32, IMU, motor driver, motor, and 12 V battery. LEDs may be added to any GPIO pins on the ESP32.

C. Wrist Unit

An image of the hardware for the wrist unit is depicted in Figure 10.

D. Waist Unit

Renderings of the CAD models for the waist unit design can be found in Figure 11. Images of the assembled device and how it is interfaced with the resistance band and velcro waistband are seen in Figure 12.

E. Code

The Arduino Sketch for the device can be found at the link below:
https://github.com/ingridkshan/shoulderROM.git

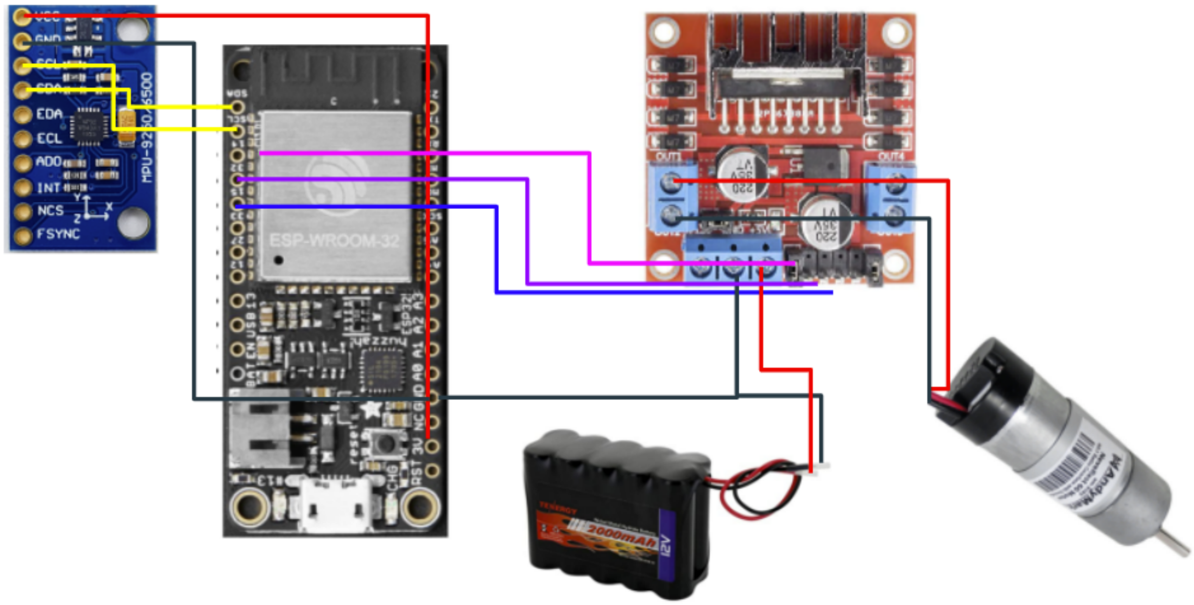

Fig. 9. The IMU (MPU9250) and motor driver (L298N) are connected through the I2C communication pins (SCL and SDA) of the ESP32 and GPIO pins respectively.

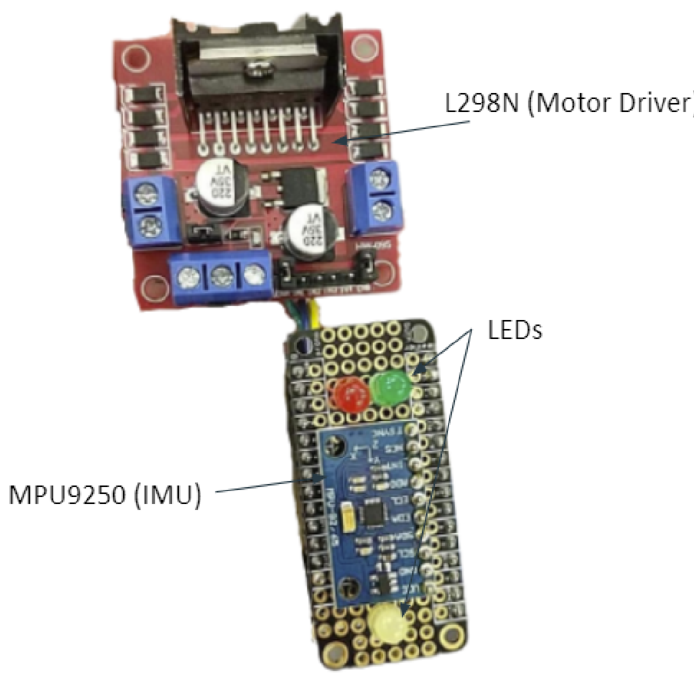

Fig. 10. Sensing and computing unit. The proto board for the LEDs and IMU are soldered on top of the ESP32.

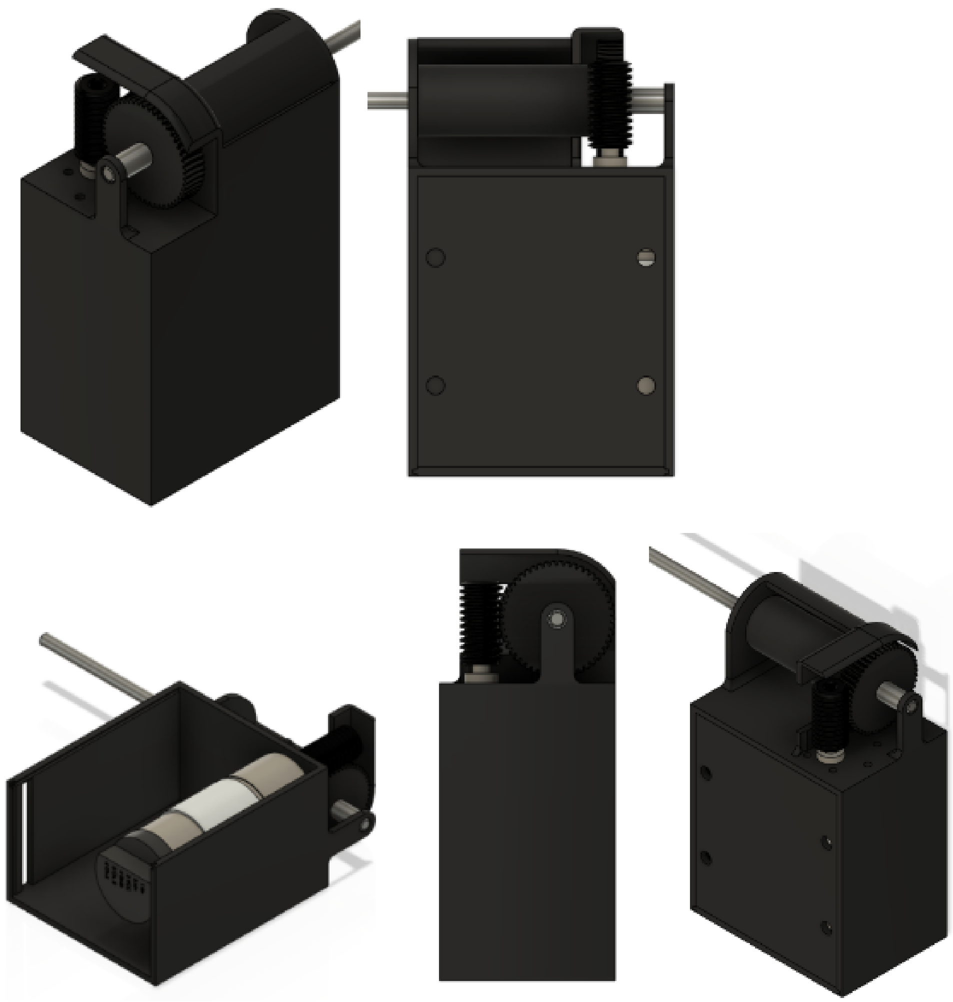

Fig. 11. Top, side, and isometric views of the waist unit produced on Fusion360.

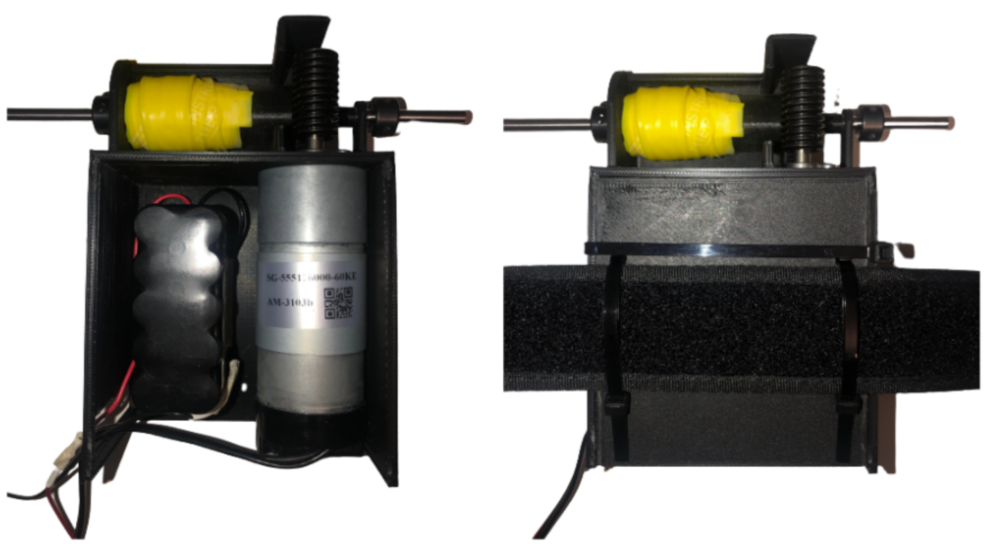

Fig. 12. Housing for waist unit open and closed. The velcro waistband is attached to the housing via zipties. The resistance band feeds through the spool and exits through a slot.