PRO 3: Progress Report 2

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I. Project Information

Title	Name	Role	Date
Assisted Function Exoskeleton	Irini Provatidis	Software Leader	2023-11-27
	Albin Gustafsson	Hardware Leader	
	Jalal Taleb	Software Developer	
	Sebastian Ahlström	Hardware Developer	
	Moritz Schmidt	Hardware Developer	

II. Project Progress Summary

The progress of Assisted Function Exoskeleton (AFE) project is concluded as follows.

A. Hardware Progress:

During this period, the objective was to design (WP3.1-WP3.4), machine and construct (WP5.2, WP5.3) the required hardware parts to build the exoskeleton. The team was able to order and receive all parts that had to be bought and have everything else machined or printed.
During this development of the motor controller was also completed (WP2.5.2, WP4.4).
Lastly, a testing stand has been built to hold the exoskeleton during testing (WP5.4).

B. Software Progress:

During this phase, our main objectives were twofold: completing extensive research and implementing a robust decision-making method for the Exoskeleton. The initial step involved the creation of a specialized dataset derived from Electromyography (EMG) sensors, crucial for supervised learning. We successfully gathered, filtered, and computed the necessary features, essential for training our AI classification model to adeptly recognize muscle contractions. Our customized dataset encompasses a variety of features extracted from filtered EMG signals, paired with labels denoting muscle contraction (represented by ones) or no contraction (represented by zeros) (WP2.5.1).

Furthermore, our team dedicated efforts to exploring diverse AI algorithms to pinpoint the one with the highest accuracy for an online application. We meticulously investigated and implemented four algorithms: Support Vector Machine (SVM), Linear Regression (LR), K-Nearest Neighbor (KNN), and Artificial Neural Network (ANN). Currently, SVM, and KNN have showcased the most promising and accurate results (WP2.5.3, WP4.3). Looking ahead, our immediate focus for the upcoming week centers on integrating various code implementation sections into a unified system. This integrated system is designed to receive user input from EMG sensors, process it, pass it through a classification model, and generate an output indicating relaxation or flexing of the bicep muscle. Achieving this involves managing sensor data, merging code segments for data processing and classification, and collaborating closely with the hardware team to ensure safe motor control without potentially harmful rotations for the user.

Simultaneously, the software team will study into uncovering correlations between the amplitude of EMG signals and the user's current physiological status. Factors such as fatigue or heightened adrenaline levels will be meticulously analyzed. This experiment aims to unravel the information conveyed by the signals and their variations based on the subject's situation.

To validate our implementations and propel the code forward, enhanced communication between software and hardware team members is imperative. Our ultimate goal is to activate the exoskeleton motors based on streamed data online from the EMG sensor.

C. Project Progress Summary:

The Exoskeleton team is working collaboratively to achieve a common goal. Effective communication and collaboration among team members have been key to our success. The hardware team has successfully designed the Exoskeleton, overcoming challenges in sourcing the right components while adhering to budget constraints. Simultaneously, the software team has completed the necessary code for initiating online trials and testing.

Looking ahead, the focus of the Exoskeleton team in the upcoming weeks will be on delivering a comprehensive prototype. Concurrently, preparations for the project presentation and the final report are underway. This marks a crucial phase as we consolidate our efforts to showcase the culmination of our hard work and advancements in the project.

III. Work Package Status

The following section provides the current status of work packages from Week 44 to Week 48.

WP2.5.1: Research - Decision making methods (Implementation of the control system.)

Author: Irini Provatidis

- **Planning Status:** Off-track
- **Completion Status:** Completed

- **Accountability:** Irini Provatidis & Jalal Taleb & Moritz Schmidt
- **Recovery Plan:** -
- **Current Progress:** Research about control system used for exoskeletons. Developers tend to use Proportional-Integral-Derivative (PID) control, Impedance control and Fuzzy logic control depending on the specification of their application.
- **Issues Encountered:** Difficulty in determining which controller may be most efficient for our application.
- **Next Steps:** The immediate plan is to develop and implement an initial control system utilizing logical if statements. The primary objective is to establish its functionality, and subsequently, efforts will be directed towards enhancing its performance and functionality further.

WP2.5.2:Research-Decision making methods (Communication between the Raspberry Pi and motor controllers)

Author: Moritz Schmidt & Irini Provatides

- **Planning Status:** Off-track
- **Completion Status:** Completed
- **Accountability:** Moritz Schmidt
- **Recovery Plan:**-
- **Current Progress:** The communication is set up and the motor control is functional.
- **Issues Encountered:** -
- **Next Steps:** Test functionalities in combination with real sensor data.

WP2.5.3: Research-Decision making methods (Artificial Intelligence (AI) & Machine Learning (ML))

Author: Irini Provatidis & Jalal Taleb

- **Planning Status:** Off-track
- **Completion Status:** Completed
- **Accountability:** Irini Provatidis & Jalal Taleb
- **Recovery Plan:**-
- **Current Progress:** Ongoing research with alternative approaches have been found. Testing different algorithms to find the one with best classification accuracy. It was decided that the Support Vector Machine algorithm was the best choice.
- **Issues Encountered:** Different classification models can be used with good accuracy levels according to the state of the art. However, this application is online and the goal is avoid delays in the system, a pre-trained and non-computational heavy model shall be used.
- **Next Steps:** -

WP3.1: Elbow joint design

Author: Sebastian Ahlström & Albin Gustafsson

- **Planning Status:** On-track
- **Completion Status:** Completed
- **Accountability:** Sebastian Ahlström & Albin Gustafsson
- **Recovery Plan:** -
- **Current Progress:** The final iteration has been made with the intention of being made out of plastic.
- **Issues Encountered:** As seen in the last status report this package was off-track. There was multiple issues with how to connect this part, which material it needs to be (which affects the design) etc.
- **Next Steps:** -

WP3.2: Lower arm design

Author: Sebastian Ahlström & Albin Gustafsson

- **Planning Status:** On-track
- **Completion Status:** Completed
- **Accountability:** Sebastian Ahlström & Albin Gustafsson
- **Recovery Plan:** -
- **Current Progress:** The final iteration has been made. Additionally, an additional connector part has been made which is design in a way that ensures better durability when made in plastic.
- **Issues Encountered:** As mention in the last status report this package was off-track. There was multiple issue design wise, which have now been overcome.
- **Next Steps:** -

WP3.3: Shoulder joint design

Author: Sebastian Ahlström & Albin Gustafsson

- **Planning Status:** On-track
- **Completion Status:** Completed
- **Accountability:** Sebastian Ahlström & Albin Gustafsson
- **Recovery Plan:** -
- **Current Progress:** By a thorough discussion it has been decided to include the shoulder joint. Also a design has been decided on, which is a direct copy of the elbow joint design.
- **Issues Encountered:** -
- **Next Steps:** -

WP3.4: Upper arm design

Author: Sebastian Ahlström & Albin Gustafsson

- **Planning Status:** On-track
- **Completion Status:** Completed
- **Accountability:** Sebastian Ahlström & Albin Gustafsson
- **Recovery Plan:** -
- **Current Progress:** The final iteration has been made.
- **Issues Encountered:** -
- **Next Steps:** -

WP3.5: Upper body design

Author: Sebastian Ahlström & Moritz Schmidt

- **Planning Status:** On-track
- **Completion Status:** In progress
- **Accountability:** Sebastian Ahlström & Moritz Schmidt
- **Recovery Plan:** -
- **Current Progress:** We have made the decision to connect the exoskeletons shoulder directly to a testing stand to allow it to move freely during testing.

- **Issues Encountered:** This solution of course isn't a permanent one. A reasonable solution, that allows the exoskeleton to be worn by an user needs to be developed by the next team.
- **Next Steps:** Testing the support structure with the completed hardware.

WP3.6: Electronics design
Author: Sebastian Ahlström & Albin Gustafsson & Moritz Schmidt

- **Planning Status:** Off-track
- **Completion Status:** Not started
- **Accountability:** Sebastian Ahlström & Albin Gustafsson & Moritz Schmidt
- **Recovery Plan:** With the final assembly of the exoskeleton completed, the hardware team can now focus on this package. Since the team considered the electronics when designing the hardware and similar circuits have been used during testing, a quick completion is to be expected.
- **Current Progress:** -
- **Issues Encountered:** -
- **Next Steps:** Work on this package will be started once the entire exoskeleton has been constructed.

WP4.1.1: Development-Stream sensor data -More than one EMG channel
Author: Irini Provatidis & Jalal Taleb

- **Planning Status:** Off-track
- **Completion Status:** Ongoing
- **Accountability:** Irini Provatidis & Jalal Taleb
- **Recovery Plan:**-
- **Current Progress:** Ensure that data can be streamed online to Python for two input sensors
- **Issues Encountered:** The type of EMG sensors can only stream one channel at the time. This requires more than one sensor if muscle activity from different muscles is analysed.
- **Next Steps:** To to stream sensor data into Python API from more than one sensor at the time.

WP4.3: Development-Decision making methods(AI & ML)
Author: Irini Provatidis, Jalal Taleb

- **Planning Status:** On-track
- **Completion Status:** Completed
- **Accountability:** Irini Provatidis & Jalal Taleb
- **Recovery Plan:**-
- **Current Progress:** Our current progress involves testing models such as SVM, LR, KNN and ANN. If time permits, we aim to explore additional methods for further testing.
- **Next Steps:** Try different approaches and state the accuracy. Collect more sensor data with higher variance in motion and way of lifting weights.

WP4.4: Development-Motor control (Implementation of the control system.)
Author: Irini Provatidis

- **Planning Status:** On-track
- **Completion Status:** Completed
- **Accountability:** Irini Provatidis & Jalal Taleb & Moritz Schmidt
- **Recovery Plan:** Start with the implementation of a basic control system as soon as possible.
- **Current Progress:** The control system is set with if statements deciding when the motor should rotate and in what speed.
- **Issues Encountered:** We faced challenges with the serial connection between the Raspberry Pi 4 and the motor controller.
- **Next Steps:** Our immediate goal is to resolve this connection issue to ensure the transmission of output commands to the motor controller.

WP5.1: Gearbox construction
Author: Sebastian Ahlström & Albin Gustafsson

- **Planning Status:** Off-track
- **Completion Status:** In progress
- **Accountability:** Sebastian Ahlström & Albin Gustafsson
- **Recovery Plan:** Once all the materials have arrived and been constructed, focus will be shifted to quickly building it together.
- **Current Progress:** Currently waiting for materials to arrive. The other parts are currently being constructed.
- **Issues Encountered:** Waiting for materials.
- **Next Steps:** -

WP5.2: Elbow joint construction
Author: Sebastian Ahlström & Albin Gustafsson

- **Planning Status:** On-track
- **Completion Status:** Completed
- **Accountability:** Sebastian Ahlström & Albin Gustafsson
- **Recovery Plan:** -
- **Current Progress:** The parts have been printed out in plastic and can be used for the final construction.
- **Issues Encountered:** -
- **Next Steps:** -

WP5.3: Shoulder joint construction
Author: Sebastian Ahlström & Albin Gustafsson

- **Planning Status:** On-track
- **Completion Status:** In progress
- **Accountability:** Sebastian Ahlström & Albin Gustafsson
- **Recovery Plan:** -
- **Current Progress:** The parts have been constructed.
- **Issues Encountered:** -
- **Next Steps:** -

WP5.4: Testing stand construction
Author: Sebastian Ahlström & Moritz Schmidt

- **Planning Status:** On-track
- **Completion Status:** Completed
- **Accountability:** Sebastian Ahlström & Moritz Schmidt
- **Recovery Plan:** -

- **Current Progress:** The stand was constructed with given materials from the university and additional 3D printed parts are to serve as a connector between the pole and the exoskeleton.
- **Issues Encountered:** -
- **Next Steps:** Once the exoskeleton is fully constructed it will be connected to this structure.

WP6.1: Testing-Testing Protocols-Software implementations
Author: Irini Provatidis & Jalal Taleb

- **Planning Status:** On-track
- **Completion Status:** Ongoing
- **Accountability:** Irini Provatidis & Jalal Taleb
- **Recovery Plan:** -
- **Current Progress:** The emphasis is on achieving a high-accuracy output th the commands sent to the motor controller, through the classification model
- **Issues Encountered:** The accuracy of the model is decreased when trying to obtain classified data from sensor data that is streamed online even though the streamed data is undergoing all the pre-processing needed.
- **Next Steps:**
  - Increase the dataset size for improved training.
  - Standardize the collection process for streaming data, ensuring consistency.
  - Emphasize maintaining a clean surface where electrodes are placed, and minimize the length of wires for optimal results.

IV. Completed Work

The following section summarizes the completed work so far and also provides with a preview of upcoming work.

A. *Completed work packages:*

- WP2.5.1: WP2.5.1: Research - Decision making methods (Implementation of the control system)
- WP2.5.2:Research-Decision making methods (Communication between the Raspberry Pi and motor controllers)
- WP2.5.3: Research-Decision making methods (AI & ML)
- WP3.1: Elbow joint design
- WP3.2: Lower arm design
- WP3.3: Shoulder joint design
- WP3.4: Upper arm design
- WP4.3: Development-Decision making methods(AI & ML)
- WP4.4: Development-Motor control (Implementation of the control system)
- WP5.2: Elbow joint construction
- WP5.3: Shoulder joint construction
- WP5.4: Testing stand construction

B. *Upcoming work packages:*

- WP6.1: Testing protocols
- WP6.2: Data processing and decision making online testing
- WP6.3: Durability of Exoskeleton design
- WP6.4: Calibration
- WP6.4: Reliability of prototype product

V. Issues, Blockers and Risk Status

In the following section, current issues, blockers and risk status will be explored. Hardware will be discussed first, before moving on to software.

A. *Hardware*

- Since it was necessary to rely on 3D-printing for most of the structural parts, stability and durability will eventually become an issue. No intervention is necessary since, for now, the parts will only be used a few times for demonstration purposes.
- Not all the required parts have arrived yet. While everything is supposed to arrive in time, as long as it has not, a certain risk / potential blocker continues to exist.
- Due to safety concerns as well as time constraints, the team is not able to build a wearable prototype. Therefore, a model of a human shoulder will be used. While this works for demonstration purposes, it is a weakness of the overall model.
- Due to miscommunication, the wrong gear size was ordered and therefore does not fit the axle. As a workaround for the time remaining, a fitting will be designed and printed.

B. *Software*

- Ensuring prompt motor rotation is critical for the proper functioning of the system. When the user contracts the bicep muscle, the motor should rotate without significant delays between instances. Prolonged delays would make the Exoskeleton uncomfortable for the user, undermining its intended purpose of enhancing stamina and aiding in lifting objects effectively.
- Potential connectivity issues may arise in the online application, specifically related to Bluetooth. The transmission of data from the EMG sensor to the Raspberry Pi relies on Bluetooth technology. If connectivity is disrupted at any point during Exoskeleton use, the entire system automatically shuts down for safety reasons.
- Insufficient data has been acquired for training purposes, posing a challenge for the AI models. Increasing the volume of data is crucial for enhancing the accuracy of classification results, as is commonly observed in these types of models. While certain models like KNN can perform adequately with smaller datasets, others, such as SVM, commonly used in applications like ours, may demand more extensive sensor data for optimal accuracy.
- Inconsistencies in the output commands to the motor can lead to undesired motor behavior, causing it to rotate and abruptly stop, resulting in unintended vibration patterns. This issue arises when executing motor commands and can impact the overall performance of the system.
- Incorrect classifications may arise from the AI model. Despite the initial training of the model for the online

application, the accuracy of the output diminishes when presented with new streamed sensor data. This reduction in accuracy can significantly impact the performance of the online demonstration involving the Exoskeleton.
- Enhance the data streaming capabilities to accommodate multiple sensors simultaneously. Presently, the code allows streaming data from one sensor at a time, limiting the analysis to a single muscle group, such as the bicep. Consequently, the current implementation only utilizes muscle data to control the exoskeleton for lifting objects, lacking the utilization of muscle data to enable the arm's return movement. This limitation hinders the system's ability to leverage multiple muscular inputs for comprehensive control and operation of the exoskeleton

VI. Individual Contribution

In this section, each team member briefly summarizes their contributions to the project so far.

- Irini Provatidis: During this period, I focused on the development of AI algorithms and the collection of sensor data using the Shimmer sensor. The goal was to determine which algorithms provided the highest accuracy for the Exoskeleton's online application. Collaborating with Jalal Taleb, we implemented code to enable online functionality, specifically for rotating the motors. Additionally, I am currently engaged in collaborative efforts with the University of Panama. Our upcoming meeting will involve a discussion of their progress in the project, allowing us to compare results and share insights.
- Albin Gustafsson: Designing the structure, 3D-printing the parts for the arm and construction of the arm so far. Contacting suppliers and ordering parts. Making renders of the 3D-model for advertisement purposes.
- Jalal Taleb: I have been actively involved in developing various AI solutions for our system to operate online. Currently, my focus is on ensuring the accurate output from classification models to both the Raspberry Pi and motor control. In the upcoming week, we plan to implement and test our solutions, aiming to achieve the successful rotation of the motor using EMG signals. This step is crucial for our project and represents a significant milestone in our progress.
- Sebastian Ahlström: I have been actively engaged in the design process of components for the exoskeleton, including the creation of 3D-printed parts for both the testing stand and the exoskeleton itself. Additionally, I have successfully constructed the testing stand and made progress in assembling the arm.
- Moritz Schmidt: I was mostly tasked with designing the motor controller and communication software. I worked together with the software team on combining the all code parts on the Raspberry Pi.

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PRO 2: Progress Report 1

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I. Project Information

Title	Name	Role	Date
Assisted Function Exoskeleton	Irini Provatidis Albin Gustafsson Jalal Taleb Sebastian Ahlström Moritz Schmidt	Software Leader Hardware Leader Software Developer Hardware Developer Hardware Developer	2023-10-30

II. Project Progress Summary

The progress of Assisted Function Exoskeleton (AFE) project is concluded as follows.

A. Hardware progress

During this period, our primary objective in hardware development initially revolved around researching components such as motors and gears that would not only align with our budget constraints but also meet as many project requirements as possible. Later on, our main focus shifted to the development of the Computer Aided Design (CAD) for the complete exoskeleton. To simplify the design process, the exoskeleton has been broken down into as many parts as feasible. Additionally, the development of the motor control system was initiated, in the scope of which the motor controller to Raspberry Pi connection and first control functions have been established.

B. Software progress

To begin with, the main goals during this period of time were to develop a script in Python3 that will be able to stream data online from the Electromyography (EMG) sensors, develop code that filters the raw EMG signal and extracts features from time domain (TD), frequency domain (FD), and time-frequency domain (TFD), and use these features as input for a Machine Learning (ML) algorithm in order to detect muscle contraction. It is important that the code provides steps and comments on why specific approaches are chosen. Further, it was necessary to collect EMG data and store it on the Secure Digital (SD) card of the used sensors. The data can then be properly extracted and used for analysis purposes. Additionally, ongoing research about different Artificial Intelligence (AI) approaches is made. Lastly, research about how to control the exoskeleton is also made in parallel.

C. Concluded progress of the project:

The team has done huge amounts of research on the state of the art for exoskeleton applications. The main focus has been to understand how an exoskeleton is built, controlled, and used in safe manners. Research about what type of input data is usually used and processed for applications related to the goal application of our project has been performed.

The construction of the exoskeleton is designed in such a way that it is comfortable and safe for the user. The hardware team has started designing the arm, more specifically the elbow joint, the lower arm, and the gearbox design. Components have been ordered and await delivery.

The software team has completed the tasks mentioned earlier and will continue testing alternative methods to classify data, collect more data from the EMG sensors, and further look into an effective way to control the exoskeleton with respect to the safety of the user. The project is currently slightly behind schedule, but no outstanding issues have arisen.

III. Work Package Status

The following section will summarize the current work packages and analyse their progress to the project schedule.

WP1.1: Initial hardware research
Author: Sebastian Ahlström

- **Planning Status:** On-track
- **Completion Status:** Completed
- **Accountability:** Sebastian Ahlström & Albin Gustafsson & Moritz Schmidt
- **Recovery Plan:**-
- **Current Progress:** Researched into existing exoskeleton, their general design and functionality.
- **Issues Encountered:**-
- **Next Steps:**-

WP1.2: Sensor hardware research
Author: Sebastian Ahlström & Moritz Schmidt

- **Planning Status:** On-track
- **Completion Status:** Completed
- **Accountability:** Sebastian Ahlström & Albin Gustafsson & Moritz Schmidt

- **Recovery Plan:-**
- **Current Progress:** Researched into existing EMG sensors, contacted companies about these sensors. Had to settle with sensors provided by the university.
Researched and ordered temperature sensors.
Researched torque sensors as a feedback tool. Decided, due to the price of torque sensors, to use the motor controllers inbuilt current sensor instead.
- **Issues Encountered:** The researched EMG sensors and torque sensors were not within the budget of the project.
- **Next Steps:-**

WP1.3: Processor hardware research
Author: Sebastian Ahlström

- **Planning Status:** On-track
- **Completion Status:** Completed
- **Accountability:** Sebastian Ahlström & Albin Gustafsson & Moritz Schmidt
- **Recovery Plan:-**
- **Current Progress:** Researched into existing processors for EMG control. Obtained processor from the university.
- **Issues Encountered:**
- **Next Steps:-**

WP1.4: Motor & drive-train hardware research
Author: Sebastian Ahlström & Moritz Schmidt

- **Planning Status:** On-track
- **Completion Status:** Completed
- **Accountability:** Sebastian Ahlström & Albin Gustafsson & Moritz Schmidt
- **Recovery Plan:-**
- **Current Progress:** Researched into existing motors and a corresponding drive-train for its control.
Researched a motor controller.
- **Issues Encountered:-**
- **Next Steps:** Ordered motors, gears and a motor controller.

WP2.1: Initial software research.
Author: Jalal Taleb

- **Planning Status:** On-track
- **Completion Status:** Completed
- **Accountability:** Irini Provatidis & Jalal Taleb
- **Recovery Plan:-**
- **Current Progress:** Research into different scientific approaches towards exoskeleton and look into their software working structure and implementation.
- **Issues Encountered:-**
- **Next Steps:-**

WP2.3: Research-Data acquisition
Author: Irini Provatidis, Jalal Taleb

- **Planning Status:** On-track
- **Completion Status:** completed
- **Accountability:** Irini Provatidis & Jalal Taleb
- **Recovery Plan:-**
- **Current Progress:** Research into different ways of collecting and streaming data from EMG sensors efficiently and with limited artifacts.
- **Issues Encountered:-**
- **Next Steps:-**

WP2.4.1: Research-Signal processing methods (raw EMG signal)
Author: Irini Provatidis, Jalal Taleb

- **Planning Status:** On-track
- **Completion Status:** Completed
- **Accountability:** Irini Provatidis & Jalal Taleb
- **Recovery Plan:-**
- **Current Progress:** Research into different processing methods that can be applied into the raw EMG signal.
- **Issues Encountered:-**
- **Next Steps:-**

WP2.4.2: Research-Signal processing methods (Feature Extraction)
Author: Irini Provatidis, Jalal Taleb

- **Planning Status:** On-track
- **Completion Status:** completed
- **Accountability:** Irini Provatidis & Jalal Taleb
- **Recovery Plan:-**
- **Current Progress:** Research into different Feature Extraction methods which could be in time domain or in frequency domain.
- **Issues Encountered:-**
- **Next Steps:-**

WP2.5.1: Research - Decision making methods (Implementation of the control system.)
Author: Irini Provatidis

- **Planning Status:** On-track
- **Completion Status:** Ongoing
- **Accountability:** Irini Provatidis & Jalal Taleb & Moritz Schmidt
- **Recovery Plan:** -
- **Current Progress:** Research about control system used for exoskeletons. Developers tend to use Proportional-Integral-Derivative (PID) control, Impedance control and Fuzzy logic control depending on the specification of their application.
- **Issues Encountered:** Difficulty in determining which controller may be more efficient for our application.
- **Next Steps:** Implement an initial and basic control system, ensure it functionality and further improve it.

WP2.5.2:Research-Decision making methods (Communication between the Raspberry Pi and motor controllers)
Author: Moritz Schmidt & Irini Provatides

- **Planning Status:** On-track
- **Completion Status:** Ongoing
- **Accountability:** Moritz Schmidt

- **Recovery Plan:**-
- **Current Progress:** The communication is set up and the motor control function is in development.
- **Issues Encountered:**-
- **Next Steps:** Complete motor control function.

WP2.5.3: Research-Decision making methods (AI & ML)
Author: Irini Provatidis

- **Planning Status:** On-track
- **Completion Status:** Ongoing
- **Accountability:** Irini Provatidis & Jalal Taleb
- **Recovery Plan:**-
- **Current Progress:** Ongoing research with alternative approaches have been found. Testing different algorithms to find the one with best classification accuracy.
- **Issues Encountered:** Different classification models can be used with good accuracy levels according to the state of the art. However, this application is online and the goal is avoid delays in the system, a pre-trained and non-computational heavy model shall be used.
- **Next Steps:** Try different approaches and state the accuracy.

WP3.1: Elbow joint design
Author: Sebastian Ahlström & Albin Gustafsson

- **Planning Status:** Off-track
- **Completion Status:** In progress
- **Accountability:** Sebastian Ahlström & Albin Gustafsson
- **Recovery Plan:** Focus will be shifted to the design of the joint. The team will consult with experienced product designers and take notice of common design practices to improve the current design and speed up the design process.
- **Current Progress:** The first iteration of the design is made. However, changed are needed to make the design lighter/simpler and make the design in sheet metal instead. Two sub models of the gearbox and the motor are fully done.
- **Issues Encountered:** -
- **Next Steps:** Remodel the design and change it into sheet metal.

WP3.2: Lower arm design
Author: Sebastian Ahlström & Albin Gustafsson

- **Planning Status:** Off-track
- **Completion Status:** In progress
- **Accountability:** Sebastian Ahlström & Albin Gustafsson
- **Recovery Plan:** The team will consult with experienced product designers and take notice of common design practices to improve the current design and speed up the design process.
- **Current Progress:** The first iteration of the design is made. However, changed are needed to make the design lighter/simpler.
- **Issues Encountered:** -
- **Next Steps:** Remodel the design.

WP3.3: Shoulder joint design
Author: Sebastian Ahlström & Albin Gustafsson

- **Planning Status:** On-track
- **Completion Status:** Not started
- **Accountability:** Sebastian Ahlström & Albin Gustafsson
- **Recovery Plan:** A meeting will be held to decide if the project will include the shoulder or if it is acceptable to disregard the shoulder joint.
- **Current Progress:** Other than No progress has been made.
- **Issues Encountered:** -
- **Next Steps:** Discuss the scope of the project.

WP4.1: Development-Stream sensor data
Author: Irini Provatidis, Jalal Taleb

- **Planning Status:** On-track
- **Completion Status:** completed
- **Accountability:** Irini Provatidis & Jalal Taleb
- **Recovery Plan:**-
- **Current Progress:** Collection of data by saving on SD card of sensor, used for analysis. Ensure that data can be streamed online to Python.
- **Issues Encountered:** The type of EMG sensors can only stream one channel at the time. This requires more than one sensor if muscle activity from different muscles is analysed.
- **Next Steps:** To to stream sensor data into Python API from more than one sensor at the time.

WP4.2.1: Development-Data processing algorithm (raw EMG signal)
Author: Irini Provatidis, Jalal Taleb

- **Planning Status:** On-track
- **Completion Status:** Completed
- **Accountability:** Irini Provatidis & Jalal Taleb
- **Recovery Plan:**-
- **Current Progress:** The raw signals are filtered to obtain the muscle activity without external noise and artifacts.
- **Issues Encountered:** The filtering process is now set, but if the subject using the sensors to collect data is located somewhere else and in different environmental conditions, this process may need to be altered.
- **Next Steps:** Investigate how to manage the filtering process in different environments.

WP4.2.2: Development-Data processing algorithm (Feature Extraction)
Author: Irini Provatidis, Jalal Taleb

- **Planning Status:** On-track
- **Completion Status:** completed
- **Accountability:** Irini Provatidis & Jalal Taleb
- **Recovery Plan:**-
- **Current Progress:** The features used now are obtained from TD such as Mean Average Value (MAV), Root Mean Square (RMS), Wavelength (WL), Zero Crossing

(ZC) and for the FD such as most dominant frequency component and power spectral density.
- **Issues Encountered:** The features are used as an input to the classification model predicting contraction or no-contraction of the muscle, fatigue level, etc. Depending on the wanted outcome of classification models, the features shall be chosen accordingly.
- **Next Steps:** Ensure that the extracted features are mostly relevant for our application

WP4.3: Development-Decision making methods(AI & ML)

Author: Irini Provatidis

- **Planning Status:** On-track
- **Completion Status:** Ongoing
- **Accountability:** Irini Provatidis & Jalal Taleb
- **Recovery Plan:**-
- **Current Progress:** Support Vector Machine (SVM) and Linear Regression (LR) are the models tested during this period. More methods will be tested
- **Issues Encountered:** Need of more data for training.
- **Next Steps:** Try different approaches and state the accuracy. Collect more sensor data with higher variance in motion and way of lifting weights.

WP4.4: Development-Motor control (Implementation of the control system.)

Author: Irini Provatidis

- **Planning Status:** Off-track
- **Completion Status:** Not started
- **Accountability:** Irini Provatidis & Jalal Taleb & Moritz Schmidt
- **Recovery Plan:** Start with the implementation of a basic control system as soon as possible.
- **Current Progress:** Research about possible solutions.
- **Issues Encountered:**
- **Next Steps:** Implementation of the control system.

IV. Completed Work

The following section summarizes the completed work so far and also provides with a preview of upcoming work.

A. *Completed work packages:*

- **WP1.1: Initial hardware research**
- **WP1.2: Sensor hardware research**
- **WP1.3: Processor hardware research**
- **WP1.4: Motor & drive-train hardware research**
- **WP2.1: Initial software research**
- **WP2.3: Research-Data acquisition**
- **WP2.4.1: Research-Signal processing methods (raw EMG signal)**
- **WP2.4.2: Research-Signal processing methods (Feature Ex- traction)**
- **WP4.1: Development-Stream sensor data**
- **WP4.2.1: Development-Data processing algorithm (raw EMG signal)**
- **WP4.2.2: Development-Data processing algorithm (Feature Extraction)**

B. *Upcoming work packages:*

- **WP2.5.1: Research - Decision making methods (Implementation of the control system.)**
- **WP2.5.2:Research-Decision making methods (Communication between the Raspberry Pi and motor controllers)**
- **WP2.5.3: Research-Decision making methods (AI & ML)**
- **WP4.3: Development-Decision making methods(AI & ML)**
- **WP4.4: Development-Motor control (Implementation of the control system.)**

V. Issues, Blockers and Risk Status

A. *Hardware*

- Selecting materials for hardware models is currently a challenge. There is uncertainty regarding the choice of materials for each specific part in the exoskeleton design. While certain components with minimal stress can be manufactured from plastic, others must be constructed from metal to withstand the necessary loads. The current issue lies in the fact that transitioning to metal components requires a complete redesign of each part. The current solution would be to consult with experienced product designers and take notice of common design practices to be able to make the remodeling precise and possible for construction.
- The fulfillment of all the requirements seems to not be possible. Therefore, the decision on which requirements to fulfill and which to break proves to be an issue. To solve this, a priority is assigned to each requirement.

B. *Software*

- EMG sensors provide only one channel output: The current sensors provide only one channel for measuring muscle activity, which creates synchronization problems when signals from more than one muscle are needed for the system. The solution is to take into consideration the delay this generates for the system's output and determine if more sensors can be used in the system.
- Limited accuracy of sensor: The sensors used for this application are wired, and that is a common factor that generates artifacts when the sensors are embedded into a system. The solution is to keep the length of the electrode cables as short as possible and not to place them in positions that bend and move at high levels on the arm.
- Bluetooth and interpolation of the signal: The sensor data is transmitted through Bluetooth to the brain of the system, the Raspberry Pi. This creates package loss during transmission. The solution for this is to use interpolation on the signal.

- Low accuracy in classification model when classifying new incoming streaming data: The classification model to detect muscle contraction will be pre-trained on specific datasets. However, the outcome sensor data is following specific patterns to easily recognize the contraction of the bicep muscle holding weight/no weight and the surrounding environment is controlled so that no external artifacts are included. When streaming data in a different surrounding environment, the accuracy of the model will decrease. To solve this, different type of data sets will be recorded and used for training purposes.

VI. Individual Contribution

In this section, each team member briefly summarizes their contributions to the project so far.

- Irini Provatidis: Research about the state of the art of exoskeletons. Deepened the research into the sensor data needed to control the device, the signal processing, the AI algorithms mostly using in such application implemented code in Python 3. Investigated the possibility of obtaining sponsorship and contacted companies that may be interested to support the project. Started up the communication with Panama university by requesting a "kick-off" meeting.
- Albin Gustafsson: Researched into motors, gears/gearboxes, sensors, pre-study of existing exoskeletons. Designed CAD models for the exoskeleton, that is gearbox model and the general structure of parts connecting to the arm.
- Jalal Taleb: Researched about Data Acquisition, Feature Extraction and Machine Learning that are used in other pre-study of existing exoskeletons. Writing python3 code for the parts mentioned before and looking into different methods that can be used in the AI implementations and investigate which method gives the heights accuracy. Also fixed code that let the user stream data direct from Shimmer sensor into python3 script.
- Sebastian Ahlström: Researched into motors, gears/gearboxes, sensors, pre-study of existing exoskeletons. Designed CAD models for the exoskeleton, that is gearbox model and the general structure of parts connecting to the arm.
- Moritz Schmidt: Researched state of the art of exoskeletons, torque sensors, motors and gears. Set up motor controller to Raspberry Pi connection and began development of the motor control function.

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Project plan

Project name	Client / Sponsor	Project manager
Assisted Function Exoskeleton (AFE)	Mälardalens University	Mikael Ekström & Pontus Sundkvist

1 Executive Summary

The Assisted Function Exoskeleton (AFE) project aims to create a prototype of a practical upper-body exoskeleton designed to aid individuals in diverse sectors, including agriculture (e.g., fruit and berry picking), industrial applications (e.g., assisting in heavy lifting), and healthcare technology (e.g., providing support during surgeries or heavy lifting tasks and decrease muscle fatigue). This effort will involve comprehensive background research and embody the latest advancements in exoskeleton technology to gain an understanding of the concept. This knowledge will guide the project's development process, ensuring agreement with all relevant regulations and safety standards during the exoskeleton's construction. The project encompasses the following generalized tasks: The exoskeleton design and structure, determining the materials used in the construction of the exoskeleton to ensure reliability, functionality, and durability. The project will incorporate electronics to control the exoskeleton, utilizing Electromyography (EMG) sensors, force sensors, temperature sensors and motors as the actuators of the device. Enabling a logical fusion of information through data processing and developing a safe system that will control the torque on the exoskeleton motors and assist the user.

In an effort to enhance project completion and organization, specific roles and responsibilities have been assigned to individuals. The Exoskeleton project team includes Albin Gustafsson as the Hardware Team Leader, with Sebastian Ahlström and Moritz Schmidt serving as Hardware Developers. Furthermore, Irini Provatidis has taken on the role of Software Team Leader, while Jalal Taleb is responsible for software development. During this time, a collaboration with students from the Technological University of Panama is held, to gain additional ideas.

The hardware team is responsible for integrating electronics and mechanical components into the Exoskeleton. They are tasked with designing the Exoskeleton, selecting suitable materials and components to ensure its robustness and safety, and ensuring compliance with the project manager's requirements.

The software team handles data processing, analysis, and the development of the Exoskeleton's control system. Their responsibilities include accurately acquiring sensor data, filtering and detecting motion patterns using Artificial Intelligence and Machine Learning. They focus on designing a stable control system that not only collects critical feedback but also effectively estimates system errors to provide precise force commands to the Exoskeleton's motors.

2 Background

Human-robot collaboration systems have a wide range of applications, and currently they are entering the daily lives of humans. The development of sensor technology is establishing an interaction between humans and robots, which makes it possible to communicate, predict, and understand the current state of each partner of the system in a shared environment. Human-robot research is applied in diverse areas such as entertainment and education, robot-assisted surgery, intelligent vehicles and aircraft, assisted and rehabilitation technology, etc. Some of their basic aims are to enhance the quality of tasks, improve productivity, reduce the workload of humans, and help with the rehabilitation process after trauma.

To facilitate communication between humans and robots, predict intentions, categorize data, and develop control systems using sensor data input, researchers have used various signals that are non-biological and/or biological over the years. Biological signals are electrical signals that travel between our brain, skin, organs, glands, and muscles and are generated by the nervous system. The human body generates various biological signals: Electrooculogram (EOG), Electrocorticogram (ECoG), Electroencephalogram (EEG), Magnetoencephalography (MEG) and EMG. On the other hand, examples of non-biological signals are kinematic parameters such as force/torque sensor data, velocity, or signals generated from temperature sensors, etc[1].

Exoskeleton control systems are applications reflecting assistive robotic technologies. The research and state of the art of this project are limited to the assistive technology of exoskeletons. In general, exoskeletons are categorized as upper-limb exoskeletons, lower-limb exoskeletons, or full-body exoskeletons. The majority of designed and developed exoskeletons are still in the experimental stage of clinical testing, and more research and effort are essential to bring them out of the laboratory.

Controlling any exoskeleton requires sophisticated technologies and methods. The main requirements of accuracy, long-term reliability, and safety are vital for the control system of exoskeletons. EMG is frequently used in the controlling methods of exoskeletons and prosthetics since it reflects the motion intention or muscle activity of the user. Furthermore, sensory data from temperature and force/torque sensors is also utilized as feedback control information in EMG-based control systems for exoskeleton applications. Even though EMG is one of the most efficient signals to utilize in the control method of an exoskeleton, muscle fatigue introduces variations in the EMG amplitude and frequency, which influence the input data to the control system. Senarath et al. researched hybrid EMG-EEG-based control approaches aimed at exoskeleton applications. Their paper includes a review of EMG-based methods proposed for assistive robot control. One of the aspects they aim to explore is related to muscle fatigue in EMG-based control systems. Their proposed method included training multiple fuzzy-neuro modifiers to adapt to the muscle fatigue conditions to compensate for the effects of muscle fatigue on EMG-based control, and the effectiveness of the results was experimentally validated. The results of their experiments indicated that an EMG amplitude feature such as EMG Root Mean Square (RMS) alone is not adequate as an input signal for an effective EMG-based control during muscle fatigue conditions. It is essential to use frequency domain EMG features as additional input features to identify muscle fatigue conditions and use them in EMG-based control systems[2].

The broad range and diversity of approaches available for the development and control of robots using surface Electromyography (sEMG) poses a significant challenge for researchers, prompting them to explore the optimal ways to design such systems. Song et al. present and provide a comprehensive overview of techniques and methods for controlling robots using sEMG. The article provide an overview of sEMG-based robot control concluding two important aspects:

1. sEMG signal processing and classification methods.
2. Robot control strategies and methods based on sEMG.

To detect limb movement or to control the system of an exoskeleton, raw sEMG signals cannot be used directly This is to obtain a higher signal-to-noise ratio (SNR). The signals need to be processed through correct data acquisition, pre-processing, feature extraction, dimensionality reduction (if necessary), and pattern recognition. The selection of feature sets extracted by the processed signal is an important factor for the accuracy of the classifiers, which is the core of pattern recognition. They present a variety of sources related to sEMG and data processing methods as well as a statistical analysis to know the level of success of each attempt depending on the purpose and goal of the project. Numerous approaches have been explored and developed over the years. The filtering of raw EMG signals remains relatively consistent across many applications. However, when it comes to extracting features from EMG signals and implementing Artificial Intelligence (AI) algorithms, a wide array of approaches has emerged, each offering distinct solutions. Extracted features can be represented in the time domain (TD),frequency domain (FD), and time-frequency domain (TFD) of the EMG signal. The choice of features is heavily dependent on the specific application's objectives, and the same holds true for selecting the appropriate AI algorithm. Researchers have explored and used diverse approaches to classify data and achieve accurate predictions[3].

Most research on exoskeletons primarily focuses on rehabilitation purposes, aiming to support individuals with conditions such as spinal cord injuries, strokes, or other neurological issues. The control system of an exoskeleton application is one of the most important aspects of its development since it must be designed with respect to the needs of the patient. Delgado et al. have achieved a significant milestone by developing a simulated model that demonstrates effective human-exoskeleton synergy, particularly for individuals with weakened muscle activation. Their proposed strategy centers around an adaptive Fuzzy Sliding Mode Control, designed to manage the inverse dynamics of a nonlinear 4-degrees-of-freedom (DOF) exoskeleton, allowing for the estimation of muscle activation and effort. The system utilizes signals from the biceps brachii muscle, and the error in exoskeleton position serves as input for a fuzzy inference system. This system generates an output to adjust the sliding mode control law parameters, thus providing the correct assistive motor force to the actuators. The simulation model has successfully equipped users with the necessary support they require[4].

3 Purpose

The AFE project aims to assist healthy individuals with high workloads, demonstrating its feasibility and serving as a foundation for future research at Mälardalens University (MDU). By investigating its potential, we hope to inspire future students and researchers to further develop this concept and maximize its impact.

4 Goal

The project's objective is to establish the foundation for designing and developing a prototype single-arm AFE. This involves comprehensive research, including a thorough review of the current state-of-the-art, to validate the project's relevance in today's context. The exoskeleton will harness electrical impulses generated by muscular activity, which will be measured by sEMG sensors. These electrical signals, produced through muscle conduction, will undergo processing to generate commands that will activate the appropriate motors. Further on, the development of a stable control system and the utilization of the commands in combination with feedback sensor data will provide the necessary assistive force to facilitate the lifting of objects.

5 Scope

The scope of the project provides a general overview of the project's composition, outlining the responsibilities and tasks of each team. Each of these sections contains sub-tasks related to specific aspects of the project

5.1 Work-Breakdown-Structure (WBS)

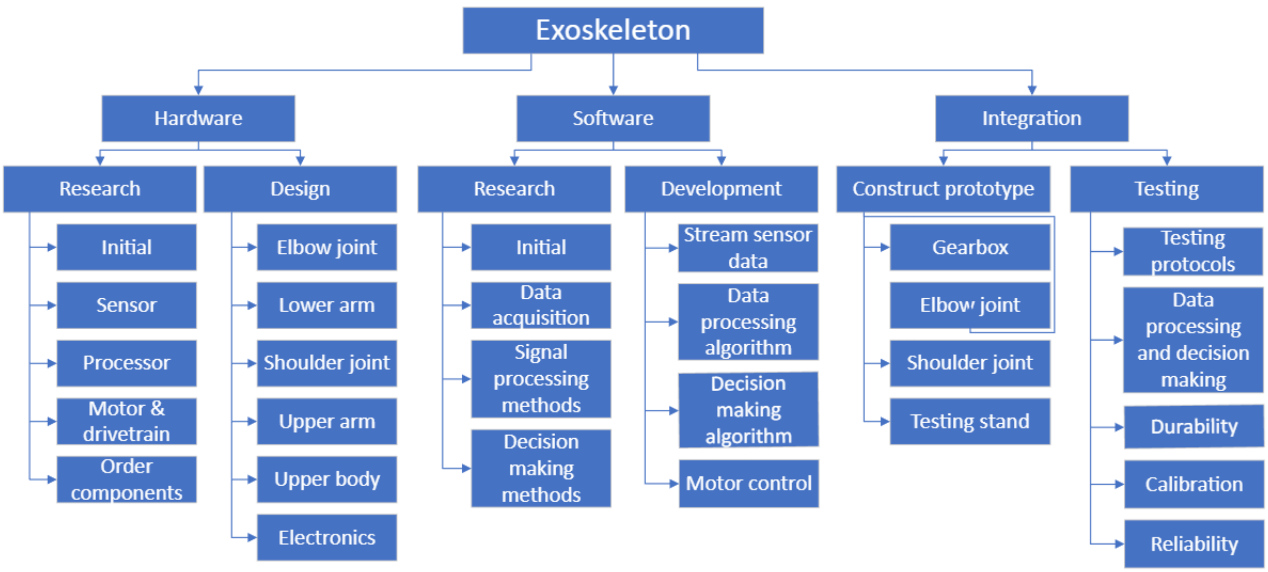

Figure 1: Work-Breakdown-Structure for each team. The basic responsibilities and tasks are illustrated.

6 Project Schedule

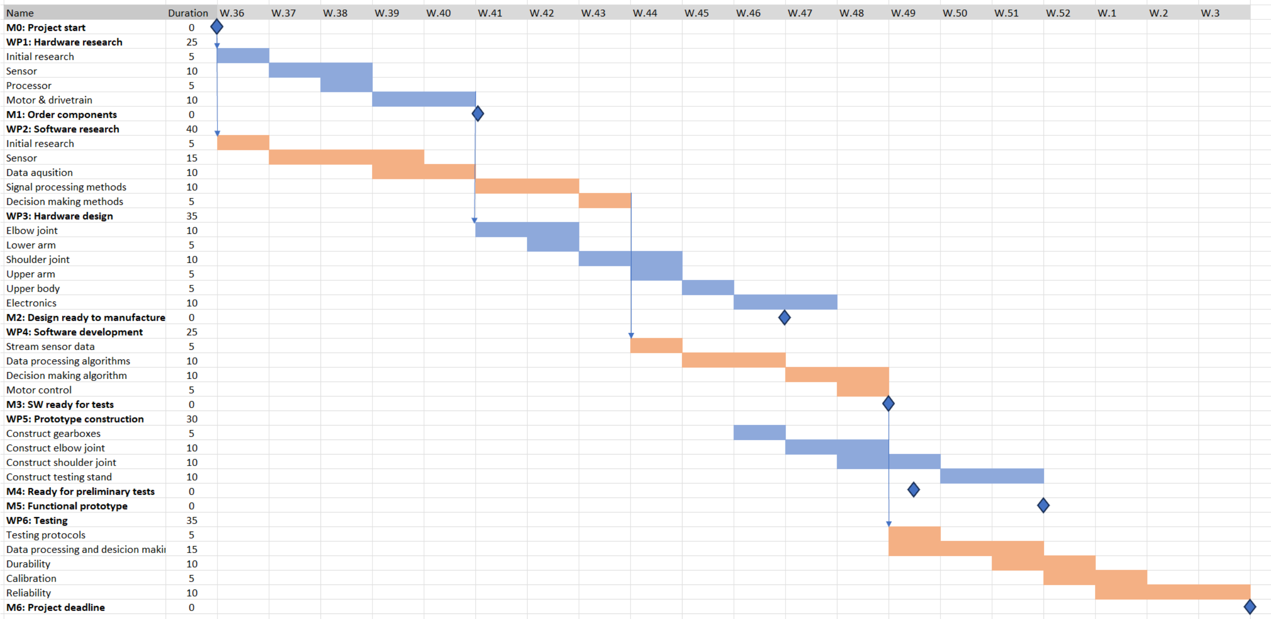

Figure 2: A GANTT chart showing the current project plan, including work packages and milestones that will be completed before the end of the project.

The project runs from the 4th of September 2023 until the 12th of January 2024, the project has several stages and assignments that need to be done in order to finish the project. The first stage is research and will last for 5 weeks, this period is used to find current research to serve as a basis to guide the design and development of the project. During this period two assignments also have to get done, this project plan is one and a preliminary poster to advertise the project is the second.

The next stage is the development stage, this is the stage where the design is made, and the software needed for the project is developed. It overlaps with the research stage and the construction stage and lasts for 8 weeks, during this time two progress reports are written as a reminder of what has been done and what needs to be done.

The third stage is construction, during this period the exoskeleton is being manufactured and at the end there will be a functional prototype. This stage overlaps not only with the development stage but also the testing stage and will last for 6 weeks. During this period the second progress report is being written and the final project poster will be made to advertise the project.

The final stage is testing, during this period of 3-4 weeks the prototype will be tested and tweaked to measure and improve the performance of the system. The last milestone to be done is the final project report which will be a summary of all of the work on the project and will contain the results and conclusions of the project.

7 Project and Product Requirements

This section provides a closer look at the project and product requirements. These requirements serve as the fundamental building blocks of successful project management and development, underpinning the entire project planning process, and ultimately guiding the project towards the successful attainment of its objectives.

7.1 Product requirements

The following section categorizes the given product requirements into two sections. That is non-functional and functional requirements. The non-functional requirements contain performance, scalability, security, usability and maintainability requirements, while functional contains input, output, data handling, processing, user interface and error handling requirements.

7.1.1 Non-functional requirements

1. The EMG sensors shall be Electromagnetic Compatibility (EMC) resistant.
2. The exoskeleton, and all the parts of it, shall share a common electrical ground.

3. Sensors shall be assigned a corresponding motor.
4. Sensors shall be assigned to a motor in such a way that they are not interchangeable.
5. A temperature sensor shall be placed on the battery pack.
6. Temperature sensors shall be present on each motor.
7. The Central Processing Unit (CPU) shall have a pre-coded emergency shutdown sequence.
8. The pre-coded shutdown of the medical device shall be executed in a controlled manner.
9. All maintenance-authorised investigators/engineers shall be provided with an individual "key" (access code) used to access the system.
10. All wireless communication shall be encrypted.
11. The medical device shall not be connected to any external wireless network (outside its own data processing network).
12. System code maintenance shall only be possible through physical connection to a system data port.
13. The system shall have a maximum of three (3) actuators per unit (arm).
14. The system shall have a maximum of three (3) motors per unit (arm).
15. The device shall shutdown in a controlled manner if the signal from the EMG sensors is zero or lost for a duration of more than 3 seconds.
16. The EMG sensors shall be fastened to the exoskeleton structure in such a way that they may only be placed correctly on the subject's body when wearing the medical device.
17. Structural parts of the system shall be capable of handling 40 kg without experiencing plastic or elastic deformation (breaking or deflecting).
18. The medical device shall weigh a total maximum of 20 kg.
19. The actuators shall be capable of handling a weight of 40 kg.
20. The subject shall be shielded from the battery pack.
21. The battery compartment/attachment point shall have vibration dampening rubber insulators.
22. The battery pack compartment shall be protected against inertia shock of 2000 J.
23. The system shall be able to operate normally between -20*C and 40*C.
24. The power supply shall consist of a Lithium ion battery pack.
25. The battery pack shall be a 28 Volt system
26. The structural parts of the medical device shall be of a non-conductive material (electricity) or completely electrically insulated.
27. The battery pack shall have a capacity equalling to four (4) hours of use at maximum power consumption.
28. The battery pack shall be modular.
29. The motors shall be axial motors.
30. The structural parts of the exoskeleton shall include a stop not allowing movement beyond the arm being straight.
31. The structure attaching the two modules shall not hinder the movement of the subject's shoulder blades.
32. The strap connecting from the back to the front shall not interfere with the female breast if present.
33. Power cable connectors shall be keyed in such a way that they only allow for correct connection between both cables and connectors.
34. Data cable connectors shall be keyed in such a way that they only allow for correct connection between both cables and connectors.
35. The structural parts of the exoskeleton shall be able to withstand a physical shock of 2000 Joule without compromising the structural integrity of the structural parts.

36. The medical device shall issue an auditorial warning when an controlled shutdown is initialised.
37. The medical device shall issue a visual warning when a controlled shutdown is initialised.
38. The exoskeleton device shall only operate if all motors of a device unit (arm) is functioning.
39. The battery compartment shall protect the subject from a explosion and/or fire caused by the battery.
40. The subject shall always use two modules (a pair) of the system (one on each arm).
41. The medical device shall be rated for 25 kg (15kg below max).
42. The structural parts of the medical device shall be replaced if the medical device has experienced a physical shock greater than 2000 Joule (e.g. drop from height).
43. The battery shall be charged separate from the medical device and the subject.
44. The battery pack shall be charged in a controlled environment.
45. The battery pack shall be handled by a qualified and authorised investigator during the charging process.
46. System alterations shall be performed by a trusted investigator/engineer.
47. If the subject has experienced injuries to the arm resulting in a bone fracture, sprain, dislocation or strain usage of the device shall be avoided.

7.1.2 Functional requirements

1. The device shall always have a non-zero signal from the EMG sensors for assistive force to be applied by the device.
2. The temperature sensor shall monitor the temperature of the battery pack.
3. The temperature sensors of the motors shall monitor the temperature of the motors.
4. The minimum range of the EMG sensors shall be 3-80 Hz.
5. The EMG sensors shall take five (5) measurements every second.
6. All system maintenance shall be logged automatically with date and time as well as location in the code.
7. The individual "key" (access code) used during the maintenance shall be logged.
8. System code back-ups shall be performed every 80 hours of use.
9. The CPU block shall have a maximum failure rate of 10^{-3} faults/hour.
10. The CPU block shall have a maximum error rate of 10^{-4} errors/hour.
11. Each actuator shall have a maximum failure rate of $6 * 10^{-6}$ faults/hour.
12. Each actuator shall have a maximum error rate of $6 * 10^{-4}$ errors/hour.
13. Each motor shall have a maximum failure rate of 10^{-3} faults/hour.
14. Each motor shall have a maximum error rate of 10^{-4} errors/hour.
15. Each EMG sensor block (one block per measuring point) shall have a maximum failure rate of 10^{-3} faults/hour.
16. Each EMG sensor block (one block per measuring point) shall have a maximum error rate of 10^{-4} errors/hour.
17. The force sensor shall measure the force output to the exoskeleton from the actuators.
18. The force sensor shall have a minimum resolution of 1-220N of force.
19. Each force sensor block (one block per actuator) shall have a maximum failure rate of $2 * 10^{-3}$ failures/hour.
20. Each force sensor block (one block per actuator) shall have a maximum error rate of $3 * 10^{-4}$ errors/hour.
21. Every component of the system shall be compatible with a 28 volt power input.
22. The power supply shall have a maximum failure rate of 10^{-3} failures/hour.
23. The power supply shall provide correct amount of power to the system with a maximum error rate of 10^{-4} errors/hour.

24. The power supply shall not experience any errors that may impact its integrity with a maximum error rate of 10^{-7} errors/hour.

25. The structural parts of the system shall have a maximum failure rate of $4 * 10^{-6}$ failures/hour.

26. The structural parts of the system shall have a maximum error rate of $4 * 10^{-4}$ errors/hour.

27. The wires of the system shall have a maximum error rate of $2 * 10^{-3}$ errors/hour.

28. The fuses of the system shall have a maximum error rate of $7 * 10^{-4}$

29. Motors shall be able to provide a total maximum force of 200N.

30. The attachment points shall be capable of handling 400N of force in any direction without detaching and/or breaking.

31. Any maintenance shall be logged with a description of the change/-s made to the system.

7.2 Project requirements

1. To develop the prototype AFE
2. To follow stated Product requirements.
3. To respect budget constrain.
4. To respect time constrain.
5. To establish a collaborative partnership with Technological University of Panama

8 Limitations

Since the project is very complex, it will need to be limited to make it reasonable to achieve within the given time and budget. The limits can be categorized as both product limitations and project limitations; the limitations state what we aim to achieve and what we will not achieve at the end of the project.

8.1 Product functional limitations

The exoskeleton will offer a limited range of motion, specifically designed for safely lifting and raising boxes in compliance with safety regulations. It is important to note that this exoskeleton is intended as a proof of concept, featuring a single arm constructed from cost-effective materials. As a result, the final product will not be a fully functional upper-body exoskeleton for commercial use. The primary objective of this project is to assist in fruit picking and box handling by enhancing stamina, rather than solely increasing raw strength. Furthermore, our research aims to boost work efficiency, with a focus on productivity improvement rather than rehabilitation.

8.2 Project limitations

The project operates with a limited budget, which impacts the procurement of all the necessary components for constructing the device. Developing a prototype product under these constraints may affect the quality and final outcome of the exoskeleton. Additionally, the project faces time constraints. The design of a functional device may be affected by delays in component arrivals or the non-availability of components in manufacturers' stock. The project requirements, as provided by the project manager to ensure the safety of the medical device, pose a limitation. This is because the required components may not meet a specific requirement on the list, even though they fulfill all other specified requirements. At the end of the project, a prototype will have been constructed; it will consist of one arm that will respond to muscle activity. The motors of the arm will provide a force proportional to the muscle activity of the operator. The project will not provide a complete product, only a limited prototype to prove the concept. It will not be mounted to a person but to a stand so as not to endanger the person operating it.

9 Risk Analysis and Counteractions

As part of our project management, we carefully analyze risks. This involves identifying potential risks, rating their probability on a scale of 1 to 5 (from very unlikely to very likely), assessing their impact on a scale of 1 to 5 (from minimal to critical), and then calculating a risk score by multiplying the probability and impact ratings.
The risk score thresholds are interpreted as follows:

- 1-5: Low priority risks. These are monitored but may not require immediate action.
- 6-10: Medium priority risks. These require a mitigation plan and should be addressed as resources allow.
- 11-15: High priority risks. These require a detailed mitigation plan, and resources should be allocated to address these risks immediately.

- 16-25: Critical risks. These must be addressed immediately with a detailed and efficient mitigation plan to avoid severe project disruption.

Table 1 illustrates recognized risks, their evaluation, and planned responses. This includes mitigation techniques and reactions to these risks, ensuring that we are ready for unforeseen circumstances and can handle them successfully if they do occur.

Risk	Probability(1 to 5)	Impact(1 to 5)	Risk(P*I)	Risk Response
Team member absent during development	2	5	10	Develop a good communication plan, cross-train team members, have each development part be distributed in smaller groups.
Missed project deadlines	2	3	6	Multiple status meetings every week, one at the beginning to assign tasks, and one at the end to discuss progress and if needed relocate resources. Also, have biweekly meetings with stakeholders
Components breaking	2	4	8	Order extra components, Always be thorough in datasheets and do multiple checks before powering a newly build system.
Software bugs detected during tests	5	3	15	Thorough testing process, allocate resources for bug fixes.
Unexpected additional costs	2	5	10	Prepare a flexible budget that can withstand additional costs.
Incompatible hardware	1	5	5	Make proper research before hand, finding sources and guides supporting the current idea.
Scope creep & Communication issues	2	3	6	Multiple meetings every week to discuss current situation and plan progress according to the requirements.
Time and budget constrains	4	3	12	Allocate resources according to the budget plan.
Inadequate Testing	2	5	10	Follow a thorough predefined test plan, allocated resources and conduct peer reviews.
Health and safety risks of testing entire system	4	5	20	Follow safety tips [5], regular inspections, educate staff in protection and awareness.
System communication failure between components	3	5	15	If communication fails during use of device, immediate shot down and research of new communication protocols.

Table 1: Risk Analysis

10 Development Plan

This Development Plan serves as an encompassing guide for the project, accurately outlining the development process, our chosen methodologies, and the unique roles and responsibilities of each team member. Its design prioritizes a smooth integration process for newcomers, regardless of their entry point in the project's lifecycle. By immersing yourself in this plan, you'll gain essential insights into our operational procedures and project-related information, enabling you to contribute effectively and align with the team's overarching goals.

10.1 Development Methodology

In this project, our team strictly complies to the Waterfall development method [6]. This method follows a linear approach, comprising distinct phases, including requirements, design, implementation, verification, and deployment. The fundamental principle of this methodology is that each phase must be completed in its entirety before progressing to the subsequent one.

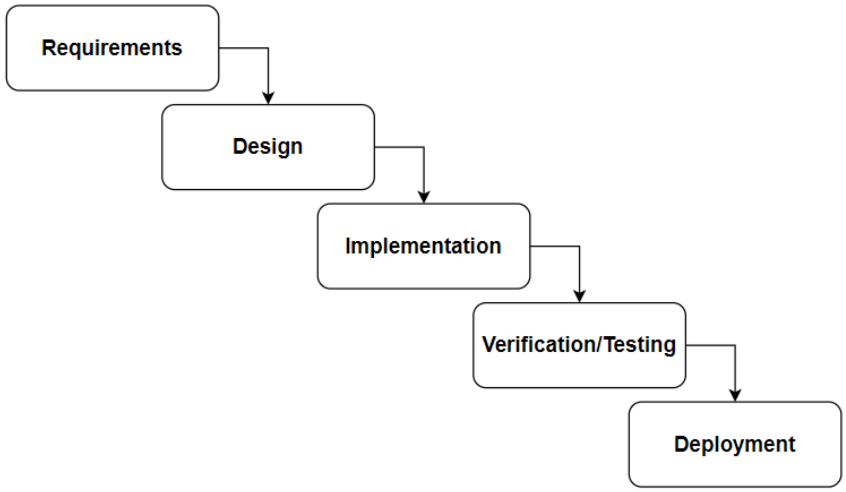

Figure 3: This image shows the Waterfall development method, which follows a step-by-step process where each phase must be completed before moving on to the next. For instance, you need to finish the requirements phase before starting the design phase. In simple terms, it is like water flowing down a set of stairs, taking one step at a time.

We chose this methodology due to its alignment with the initial project briefing, which provided a well-documented and clear list of requirements to be fulfilled. Furthermore, it suits our project exceptionally well, as this project demands thorough research and development. To provide a better understanding of this choice, we provide some of the advantages and disadvantages of this methodology below.
Advantages:

- Easy to manage and understand
- Clear objectives and requirements
- Greatly transfers information between sections

Disadvantages:

- Slow development
- Costly
- Hard to make changes
- Testing delayed to after completion

10.2 Team Structure and Roles

Our team comprises the following roles:

- **Hardware Team Leader:** Manages the hardware development process, coordinates with the software team, and ensures timely delivery while maintaining quality standards.
- **Software Team Leader:** Oversee the software development process, collaborate with the hardware team, and ensure the timely delivery of high-quality project milestones.
- **Hardware Developer:** Designs, develops, tests, and troubleshoots hardware components and collaborates with the software team.
- **Software Developer:** Develops, tests, and debugs software modules and coordinates with the hardware team.

10.3 Tools, Technologies, and Systems

We leverage the following tools, technologies, and systems in our project:

- **Project Management & Communication Tools:**

  For successful communication and management, the platform Microsoft Teams 10.4.7 is used. This can be acquired from [7]. Additionally, the add on tool for teams Microsoft Planner 1.18.0 is also utilized. For general file management Github is used which can be obtained from [8].

- **Software Development Tools:**

  The following software tools were applied for this development project, Arduino IDE 2.2.1 [9], Matlab R2023b [10], ConsensysBASIC v1.6.0 [11], Solidworks 2022 [12], Python 3 [13], Visual Studio Code [14].

10.4 Coding Standards and Guidelines

- **Hardware Tools and Software:**

  We utilize tools like a 3D printer Finder 3 [15] and the corresponding software for it FlashPrint 5.7.1 [16], Raspberry Pi 4 model B [17], PCB Design Software NI Ultiboard 14.2 [18].

Install the correct version numbers as specified for consistency and compatibility.

10.4 Coding Standards and Guidelines

To ensure high code quality and readability, we follow the google coding standard provided by *Styleguide* [19], which is a git directory. The site provides several guides for different languages, such as C#, C++, Python etc. Some of the basic universal guidelines can be viewed below:

- Code should be documented
- Each variable should have a descriptive and meaningful name
- Each identifier should be limited to one purpose if possible
- Proper indentation
- Limited use of global variables

For the rest of the guidelines see the given link.

10.5 Version Control

We utilize Github [20] as a code hosting platform for version control and collaboration. To keep track of our work and help us to easily explore the changes we have made while coding. GitKraken [21] is also used, which makes Git commands and processes easy, fast, and intuitive. For detailed guidance on using this system, please refer to *Version Control with Git* [22].

10.6 Testing and Quality Assurance

We adopt robust testing and quality assurance practices that are integrated into our development plan. For comprehensive insights into our testing process, please consult the section 12, Testing Plan.

10.7 Integration and Deployment

Our integration and deployment strategies are aligned with the goals assigned to each team (hardware and software). This requires individuals within each team to independently integrate and deploy their solutions to address the problem. Our integration strategy involves Continuous Integration, while the deployment process includes preparation, testing, and ultimately, deployment.

11 Documentation Plan

To have a structure in what, how, when, who and where to document files during a project is essential for its success. Therefore, the following section will in detail present this projects Documentation Plan and answers what needs to be documented, followed by how and when to document. Finally it will be outlined who is responsible for documenting and where data shall be stored to assure data is easily accessible. This section will also discuss the review and approval process for these documents.

11.1 What to Document

- Daily progress report
- Meeting protocols
- Data sheets
- Computer Aided Design (CAD) models and drawings, including iterations
- Code, including iterations
- Testing
- Research

11.2 How and when to Document

The rules listed below should be followed when documenting in this project.

11.2.1 Daily progress report

Daily progress shall be updated daily at the end of the workday by every member of the project group and shall reflect what the respective group member has worked an during that day.

11.2.2 Meeting protocols

Meeting protocols may be informal but should always include the following: date, participants, topic of the meeting. They shall be created during or right after the meeting and the completed protocol shall be stored as soon as possible but no later than the day after the meeting.

11.2.3 Data sheets

Complete data sheets as provided by the manufacturer should be documented if the described hardware might or has been chosen for the project. Data sheets of hardware which was not selected shall never be deleted to assure a complete documentation and decision history.

11.2.4 CAD models and drawings

Every iteration of model and drawing shall be documented and include the following: name, iteration number, date, author, revision. All files shall be stored in the appropriate location at creation.

11.2.5 Code

Code should be commented as it is written. Finished functionalities should be reviewed and different iterations documented separately. GitHub is used to structure and document all code including all iterations.

11.2.6 Testing

All tests shall be documented including at least setup description, expected outcome, collected data, results and conclusion. Description and expected outcome shall be documented before the test by the responsible group member in form of a short testing plan. Data and results shall be added after the testing. The conclusion shall be revised by at least another group member.

11.2.7 Research

All relevant researched scientific papers shall be documented as soon as possible.

11.3 Who is Responsible

- **Hardware Team Leader:** Oversees and approves hardware-related documentation and assigns hardware-related documentation tasks.
- **Software Team Leader:** Oversees and approves, and assigns software-related documentation tasks.
- **Hardware Developer:** Creates and updates hardware-related documentation as assigned.
- **Software Developer:** Creates and updates software-related documentation as assigned.

11.4 Where to Store Documents

Documents shall be stored in Microsoft Teams according to the provided structure to ensure availability, accessibility and data security. All document that might be important for the continuation shall also be uploaded to Github as formal documentation for the client.

11.5 Document Review Process

All design documents shall be reviewed by at least one other member of the respective group.

12 Testing Plan

This Test Plan offers a comprehensive overview of our project's testing strategy, methodology, and procedures. It serves as a framework for the validation and verification of both software and hardware components to ensure compliance with specified requirements. The document is structured to provide clarity to team members at any stage of the project's lifecycle.

12.1 Testing Methodology

- **Compatibility Testing (CT):** CT is a software and hardware testing method that assesses how a software application performs in various environments and configurations. Our team will adopt this approach to ensure the seamless operation of components and to verify their compatibility. This proactive measure helps prevent issues from arising during the integration of all components into the final product [23].
- **Requirements-Based Testing:**This is a software testing approach that focuses on ensuring that a system or software application meets its specified requirements. This is critical for the software and hardware teams and must be followed to successfully develop the Exoskeleton.
- **Functional Testing (FT):** This approach focuses on verifying that hardware components or systems perform their intended functions correctly. Test cases are designed to validate each hardware function, such as input/output ports, sensors, or buttons, to ensure they work as expected. This approach is upheld to ensure the safety and reliability of the final hardware component composition [24].
- **Reliability Testing (RT):** RT assesses the consistent performance of both software and hardware over an extended duration, aiming to minimize failures. This encompasses tests measuring parameters like MTBF (Mean Time Between Failures) and assessing performance under challenging conditions. It is a critical testing method, particularly since project requirements specify a specific acceptable failure rate for the Exoskeleton [25].
- **Endurance Testing(ET):** This involves subjecting the hardware to continuous operation for an extended period to identify any performance degradation, overheating, or other issues that may occur with prolonged use. The aim is to develop a prototype what is robust and stable [26].

12.2 Testing Team Structure and Roles

Our testing team includes the following roles:

- **Testing Team Leader:** Software and Hardware Team leaders are in charge of the testing strategies, as well as organize and ensure that tasks are assigned to each team members.
- **Testing Engineer:** Manage tests with respect to the chosen testing methodology (e.g, CI, compatibility testing, and requirement testing) as well as report all issues and problems that can occur in the testing stage and mention possible solutions.

12.3 Bug Reporting and Tracking

We use GitHub to log and track identified defects. Each testing team member is responsible for documenting and reporting bugs according to our bug reporting guidelines, outlined in GitHub repository [20].

12.4 Test Schedule

Our testing schedule aligns with the overall project timeline. The detailed test schedule can be found in this section 6.

13 Communication Plan

To facilitate the sharing of information among team members throughout the project lifecycle, a Communication Plan has been defined. Its purpose is to promote mutual understanding and foster cooperation among team members and stakeholders. The Exoskeleton Communication Plan is presented as follows.

- **Who (Target Audience):** Project team members such as the hardware and software developers, hardware and software team leaders, contribution team in Technological University of Panama , stakeholders, the examiner, the course responsible, and the supervisor.
- **Why (Purpose):** Project updates inform stakeholders about progress, task assignments, to manage deadline and potential issues and to share ideas with our contribution team in Technological University of Panama.
- **What (Type of Information):** Project updates, task assignments, meeting agendas, change requests, and risk alerts.
- **When (Timing):** Daily communication between team members, weekly communication with the stakeholders and biweekly meeting with our contribution team in Technological University of Panama.
- **How (Communication Channels):** Communication methods include email, direct communication, meetings and project management software and communication such as Microsoft Teams.
- **Responsible:** Hardware and Software Team Leaders.

Who	Why	What	When	How	Responsible
Project members	To discuss the progress of the ongoing plan and put goals for the coming days	Meeting agendas	Daily	Direct communication, meetings	HW,SW Team leaders
Project members	To address progress and issues, Plan for the next meeting with the Stakeholder	Meeting agendas	Weekly	Direct communication, meetings	HW,SW Team leaders
HW Team Leader	To keep updated on hardware status and needs, to know their responsibilities	New tasks, updates, changes	Everyday	Email, direct communication, meetings	Albin Gustafsson
HW Developer	To know their tasks and deadlines	Task Assignments	As needed	Email, direct communication, meetings, project management tools	Sebastian Ahlström and Moritz Schmidt
SW Team Leader	To keep updated on software status and needs, to know their responsibilities	New tasks, updates, changes	Everyday	Email, direct communication, meetings	Irini Provatidis
SW Developer	To know their tasks and deadlines	Task Assignments	As needed	Email, direct communication, meetings, project management tools	Jalal Taleb
Team members in Technological University of Panama	To share ideas and progress of the common project	Task Assignments	Biweekly	Email, project management tools	Project members
Stakeholder	To share our progress and to address any issues that may arise	Meeting agendas	Weekly	Email, direct communication, meetings, project management tools	Project members

14 Handover Plan

The following section describes this projects handover plan. It outlines the systematic process of transferring all documentation, results, reports and hardware to the project owner at the end of the project.

14.1 Handover Team Structure and Roles

Our handover team includes the following roles:

- **Handover Team Leader:** Coordinates the handover process, ensuring that all project deliverables and documentation are transferred wholly and accurately.
- **Handover Specialist Hardware:** Organises the handover of the hardware related documents.
- **Handover Specialist Software:** Organises the handover of the software related documents.

14.2 Handover Methodology

To ensure a complete and comprehensive handover process, the following methodology is employed.

- Handover specialists check inventory and itemize all deliverables
- Team members review itemization
- Deliverables are transferred to the project owner

These steps have been chosen to ensure a comprehensive and efficient handover process.

14.3 Handover Tools

We leverage the following tools, technologies, and systems during our handover process:

- **Inventory Management Tools:** We utilize Microsoft Teams 10.4.7 and GitHub to catalogue and track all project deliverables for handover.
- **Presentation Tools:** If necessary, we use PowerPoint 1808 to conduct presentations or demonstrations.

14.4 Handover Schedule

Our handover schedule aligns with the overall project timeline. See section 6 for the handover timeline.

14.5 Documentation

Comprehensive project documentation, including user manuals, technical documentation, and project reports, will be provided during the handover process. See section 11 for more information.

14.6 Presentation and Demonstration

Our team will conduct presentations and demonstrations where necessary to familiarize the stakeholders with the project's operation and results.

14.7 Final Sign-off

All deliverables will be handed over to the project owner at the 12.01.2024. The project owner will sign off, indicating successful handover and completion.

15 Individual Contributions

Chapter	Responsible	Contributor
1. Executive Summary	Irini Provatidis	
2. Background	Irini Provatidis	
3. Purpose	Irini Provatidis	Jalal Taleb
4. Goal	Irini Provatidis	Albin Gustafsson
5. Work-Breakdown-Structure (WBS)	Moritz Schmidt	
6. Project Schedule	Albin Gustafsson	
7. Project and Product Requirements	Sebastian Ahlström	Moritz Schmidt
8. Limitations	Sebastian Ahlström	Albin Gustafsson & Irini Provatidis
9. Risk Analysis and Counteractions	Sebastian Ahlström	Irini Provatidis
10. Development Plan	Sebastian Ahlström	Irini Provatidis
11. Documentation Plan	Moritz Schmidt	
12. Testing Plan	Jalal Taleb	Irini Provatidis
13. Communication Plan	Jalal Taleb	
14. Handover Plan	Moritz Schmidt	

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