Assistive Arm Enhancement Exoskeleton

EE 4OI6 Project Proposal - Group 9
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● Abstract

To design Assistive Arm Enhancement Exoskeleton(AAEE), a wearable device that aids individuals with limited arm strength or mobility, enhancing their ability to perform daily tasks. The customer base will be individuals with physical disabilities, elderly individuals with weakened arm strength, rehabilitation centers assisting patients in regaining arm functions, and workers with a heavy workload on their upper limbs. The need it will fill would be to help people with limited arm strength or mobility carry heavy items, to reduce the harm to the body and minimize the risk of work-related musculoskeletal disorders (WMSDs). The AAEE will provide assistance in raising and holding heavy items for the users. It will utilize sensors and actuators to sync with the user's natural movements and provide the necessary support. The platform would be an arm exoskeleton powered with software control systems, paired with a software interface. The major resources would be light-weight materials for the frame, powerful actuators, sensors, battery power systems, and software interface and control systems.

● Description

a. Background

Work-related musculoskeletal disorders (WMSDs) is a wide range of painful disorders of muscles, tendons, and nerves [1]. It was mainly caused by repetitive motion, heavy overload on joints, some specific awkward postures, and so on. Common risks involving upper arm musculoskeletal disorders in workload are repeating motions on shoulder joints, lifting heavy loads above the head or shoulder, and bending arms for long working hours. By introducing our project idea, Assistive Arm Enhancement Exoskeleton, extra force will be generated with the movement of the upper arm to reduce the load on joints and muscles. We expect to minimize the exposure of WMSDs to shoulders and upper arms by using our exoskeleton.

Current existing exoskeleton can be classified as active or passive [2]. Active exoskeletons involve some actuated device like an electric motor, whereas passive exoskeletons are non-actuated like using only materials and springs for supporting. Exoskeletons are also classified based on the body part it is assisting. Based on these definitions, this project will be a single-joint active exoskeleton for shoulders and upper arms.

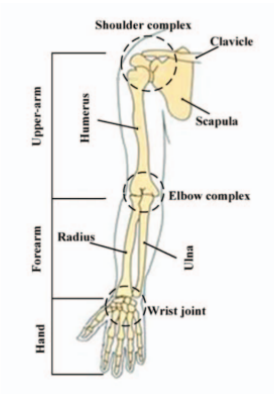

Fig 1: The human upper limb anatomy structure

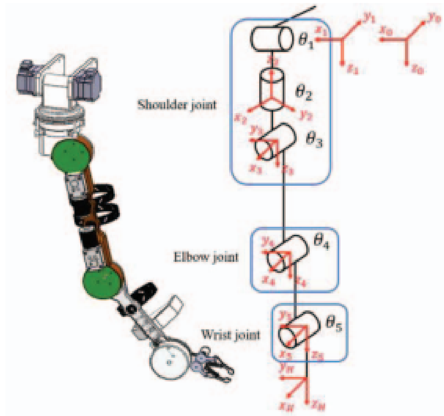

Fig 2: The distribution of DOF in upper limb

Current design of arm electrical active exoskeleton has two main obstacles, comfortability of mechanical design and electrical control system. The first concern of comfortability is the number of degrees of freedom needed to mimic the full motions of arms. According to Fig 1, the shoulder joint has a sphere shape mechanic. It requires at most 3 DOF to achieve all movement of the shoulder joint shown in Fig 2. The second concern is the total weight. There are some existing exoskeleton designs for neural rehabilitation. For example, this coble-driven exoskeleton for neural rehabilitation [3] is too large to carry along with people for doing working tasks, which is not suitable for our scenario. The third concern is safety. Since this mechanism works on the human body, it has to be harmless to human health.

In terms of control system, it can be divided into three main parts, sensors, processing methods, and actuators. Some available sensors used for exoskeletons are, bending sensors, torque sensors, accelerometers, EMG/EEG sensors, and so on [4]. Each of them has pros and cons, but different sensors can work together to get the best outcome. The same article also lists a few motor options like brushless motor, torque motors and stepper motors. In terms of processing methods, current exoskeleton use mostly PID/PD control [5]. Machine learning may also be used as an assistive decision making method.

b. Specifications

1. Essential Specifications (rank from the most important to least important):

- Assist customers to perform repetitive arm movement on 3 degrees of freedom with vertical, horizontal, and rotary degrees.
- Assist customers to lift loads more than 10lb with minimized efforts due to the powerful motors.
- Safe, reliable, and comfortable to use and wear, with weight load less than 30 lb on shoulders due to the low density of aluminum alloy.
- Auto detect malfunctions and self-check for system situation, including temperature sensing device, to warn users for safety operations with at least 50% accuracy.
- Detects and follows arms movement with responding time less than 1000ms by using the high speed processor and sensors.

2. Optional Specifications (rank from the most important to least important):

- Rechargeable independent power supply to allow users operating without AC power supply for at least 30 mins.
- Modular design for easy replacement or upgrade of parts.
- Adjustable size to suit users for different body shapes.
- Solar panel integration for extended battery life and increased green energy usage.

3. Lower Limits

- The exoskeleton shall help the user raise at least 10 lb items.
- The whole system shall weigh at most 30lb.
- The exoskeleton shall not harm users or put human health at risk

c. Concepts

- Available Concepts:

Material

	Pros	Cons
3D Printing Plastic	Easy to obtain and build	Fragile
Aluminum Alloy	Cheap; High strength	Heavy
Carbon Fiber	Lightweight; Strong	Expensive; Hard to customize

Actuator

	Pros	Cons
Electric Brushed Motor	Low price	Require more maintenance and longer response time; Energy consuming
Electric Brushless Motor	Less response time	High price and limited torque
Electric Hydraulic Pump	Larger torque	Large size; not accurate

Power Supply

	Pros	Cons
AC Power	Unlimited working time	Limited working distance
Battery Power	Portable	Limited working time

Control System
Either full PID methods or partial methods (PD, PI only). It is mostly impossible to tell which performs better without investigation and verification.

- Selected Concept:

a. Design the frame using aluminum alloy. Considering the cost and the material strength, the aluminum cost less and also has good strength.

b. Using brushless motors as actuators. The motors are easier to control accurately

c. Power supply using AC power for prototyping and bronze level deliverable, as it is each to implement and maintain. Batteries will be optional for future optimization. Batteries are more portable and easy to control.

- Available Resources:

  a. Hardware Component: Aluminium Alloy, ABS 3D Print, Processing ICs, Dynamic Motion Sensors, Thermometers, Electric Motors, Power Supply Cords, and other circuit components.

  b. Simulation Software: Keil, Cadence, Autodesk Inventor.

  c. Electrical Production Equipment: Digital Multimeters, Soldering Stations.

  d. Mechanical Production Equipment: 3D printer for ABS Printing Materials, Common Process Tools (Screw driver, drill press, etc.), Mechanical Designing Software (e.g. Autodesk Inventor, Fusion 360, Prusa Slicer), Tables of Mechanical Properties of Aluminum Alloy and ABS Material

e. Design and Planning

Components

1. Mechanical Structure

Fig 3: Mechanical Structure Design, Front & Back View

   a. Material
   The framework of the exoskeleton system will be mainly implemented using 3D printed ABS materials, with enhancement joints consisting of aluminum alloy material. ABS-printed body contributes to achieving a lightweight overall frame while aluminum alloy joints ensure essential performances involving loading-bearing actions.

   As a buffer layer between the framework and human body, soft materials will be used to reduce the discomfort while the user carries the exoskeleton system. For example, to increase comfortability of the user’s shoulders carrying the system, the rigid bodies can be embedded in spacer mesh straps and foam materials which have direct contact with the user's body.

   b. Degrees of Freedom
   The workspace of a human upper arm is determined by a shoulder joint, which is a purely rotational joint that can rotate in any direction, thus it should tolerate three

degrees of freedom at both joints of the system.

However, from the three degrees of freedom, only two degrees, which allow planar movements, will be actuated by the motors.

c. Safety Concerns
As the targeted group of customers suffer from WMSDs, the AAEE system should particularly focus on relieving the pain while assisting users to perform the same action, with or without loads in hand, whereas extra strains should be prohibited from the user's upper limb muscles.

The system should follow the natural mechanism describing a human upper arm, where the range of workspace should be physically restricted so that the user is protected from harm due to motor errors.

2. Control System

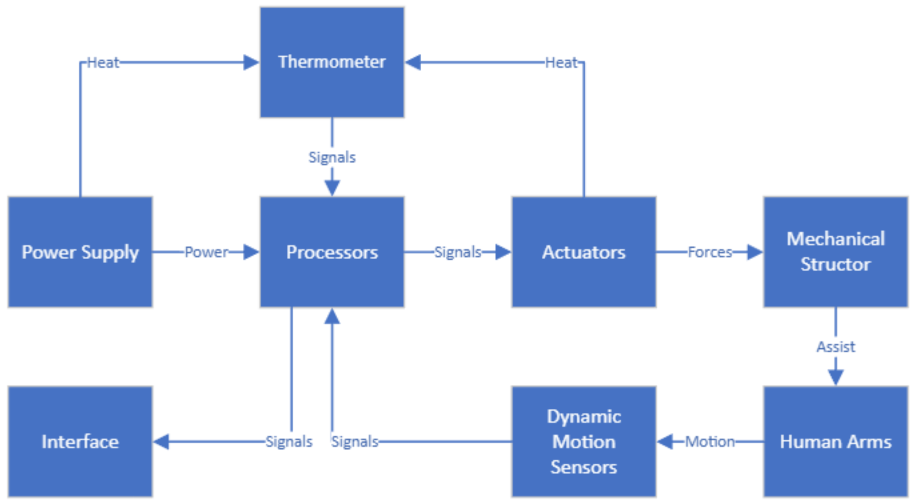

Fig 4: Control System Working Flow Chart

a. Sensors
Gyroscopes are used to detect, record and predict the real-time position of the user's upper arm and determine the direction of support provided.

Accelerometers are used to activate the assistance process to the user's upper arm, which helps with actions such as lifting, holding, pushing, etc.

Thermometers are used to measure real-time temperature near the motors, in order to determine whether the system is overheating and should be shut down for safety and maintenance purposes.

b. Processors
The main processor unit should at least be a 32-bit microcontroller IC (STM32, MSP32 ect). It is used to receive sensor signals, processing data, and sending signals to actuators.

The main control method will be PID control, with the inputs from gyroscope and accelerometer. PD or PI control may also be used and tested, so the control method with best performance will be the final processing method. If different types of sensor are needed, the control system will also need to be updated in the processor.

Processors are also used to handle other information like interface data and error detections.

c. Actuators
Brushless DC Motors are chosen since they offer enough torque and response quickly. They are used to convert electrical energy into mechanical motion and are responsible for assisting the movement of the upper limbs.

d. Power Source
Rechargeable batteries are used to provide electrical energy to other electronic components of the exoskeleton.

e. Interface
To show the user the status of the system, warning of overheating and noticing system power-off.

Milestones & Deliverable

Each milestone shall meet all essential specifications with the following metrics:

Deliverable\Standard	Bronze	Silver	Gold
System mass (lb)	30	17	15
Max. battery temp. (℃)	50	40	30
Max. motor temp.(℃)	50	40	30
Avg. response delay (ms)	1000	100	10
Max. bearable load (lb)	30	40	50
Total cost ($)	1000	800	600
Hazard warning accuracy (%)	50	75	100
Power Supply	AC power supply	Battery Power Supply for 30 mins	Battery Power Supply for 1 hour
Confortability	Universal Size	Ajustable size	Replaceable and Adjustable parts
Durability	Frequently maintained	Fewer maintenance needed	No maintenance needed
Circuit Layout	Physical Wires	PCB	PCB

- Project Management

a. Task Assignment

Yuying Lai	Embedded System Programming PID Design & Implementation Control System Verification
Xuanzhou Ma	Reliability Testing, Circuit Design & Electrical Device Implementation, PID Control System Design & Implementation, Output Interface Design & Implementation, Materials purchasing
Shangkun Zhuang	Mechanical Structure Design/ Build/ Verification
Yu Pan	Circuit Design & Electrical Device Implementation, Embedded System Programming & Testing, Output Interface Design & Implementation, Analog Signal Processing, Assembly

b. Scheduling

Start from 2nd Oct (Each two weeks)	Week 1-2	Week 3-4	Week 5-6	Week 7-8	Week 9-10	Week 11-12	Week 13-14	Week 15-16	Week 17-18	Week 19-20	Week 21-22	Week 23-24	Week 25-26	Week 27-28	week 29
Brainstorming	All Members														
Background Reserch		All Members													
Preliminary Concept Generation		All Members													
Testing and Selection of Concept		All Members													
Project Design			All Members												
Mechanical Implementation					SZ										
Control System Implementation					YL & YP										

Electrical Implementation					XM										
Mechanical Verification/Optimization									SZ						
Control System Verification/Optimization											YL & YP				
Electrical Verification/Optimization											XM				
Reliability Testing					XM						XM				
Final Deliverable Optimization													All Members		
Project Launch															All Members

c. Assumptions and Risks

i. The exoskeleton will be worn on the user's back, the design should be ergonomic and lightweight, preventing the system from causing overload or harm to the user's body.

ii. The exoskeleton will raise heavy items so that the power of the actuation system should be large enough. However, the more powerful the dynamic system is, the shorter the battery life would be.

iii. Assumptions for the actuation system: If an electrical motor is the source of the dynamic system, the torque of the motor may not reach the requirement. If using an air pump as the source of the dynamic system, the speed of rising would be very slow.

iv. The AAEE system is deployed for assistance purposes only. For users that wear the exoskeleton system over a certain period of time, the risk of muscle deterioration should be taken into account. Therefore, users should be advised and instructed so they are aware of the potential risk.

v. Due to the presence of actuation units and rigid body in the mechanical design, potential risks exist where the aluminum alloy parts may be heated to cause discomfort when installed on users.

- Reference

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[2] M. P. de Looze, T. Bosch, F. Krause, K. S. Stadler, and L. W. O’Sullivan, “Exoskeletons for industrial application and their potential effects on physical work load,” *Ergonomics,* vol. 59, no. 5, pp. 671– 681, 2016.

[3] Ying Mao and Sunil Kumar Agrawal. “Design of a cable-driven arm exoskeleton (CAREX) for neural rehabilitation,” 28(4):922–931. Publisher: IEEE.

[4] Tiboni M, Borboni A, Vérité F, Bregoli C, Amici C. “Sensors and Actuation Technologies in Exoskeletons: A Review. Sensors” (Basel). 2022 Jan 24;22(3):884. doi: 10.3390/s22030884. PMID: 35161629; PMCID: PMC8839165.

[5] J. N. Quispe, D. C. Solis, J. H. León and L. M. Ccopa, "Performance comparison between PD and PID Controller in an upper limb Exoskeleton by analyzing an arm trajectory modeled with Image Recognition," 2020 IEEE Engineering International Research Conference (EIRCON), Lima, Peru, 2020, pp. 1-4, doi: 10.1109/EIRCON51178.2020.9254082.