report.

Rehabilitation and Assisted Living - Rehabilitation and Wearable Robotics (MA-MT-23)

Concept for a Post-Surgery Elbow Rehabilitation Device

Master Medical Technologies

1. semester

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Abstract

Elbow joint surgery poses a significant challenge to patients, necessitating a careful and controlled rehabilitation process to ensure optimal healing and minimise the risk of re-injury and elbow stiffness. In response to this clinical need, the project focuses on the development of a Post Elbow Surgery Rehabilitation Device. This device integrates cutting-edge technology, including electromyography (EMG) sensors and a Unity application, to monitor and control the degree of elbow flexion during rehabilitation.

1 introduction

1.1 BACKGROUND

The elbow joint has a normal range of motion from 0° to 145°, with a functional range of 30° to 130° for daily activities. Stiffness, defined as flexion less than 120° and loss of extension greater than 30°, can limit functional capacity.In figure 1 is the normal flexion and extension shown. Elbow stiffness often results from mechanical blocks caused by soft tissue or bone issues, with trauma being a common cause (3-20 percent incidence). Posttraumatic elbow stiffness is challenging to estimate due to its multi-factorial nature and variable manifestation time. Displaced fractures around the elbow, typically treated with internal fixation, can lead to stiffness influenced by both the initial and surgical trauma. Predicting the presence and degree of stiffness after elbow trauma is challenging in individual cases. [3]

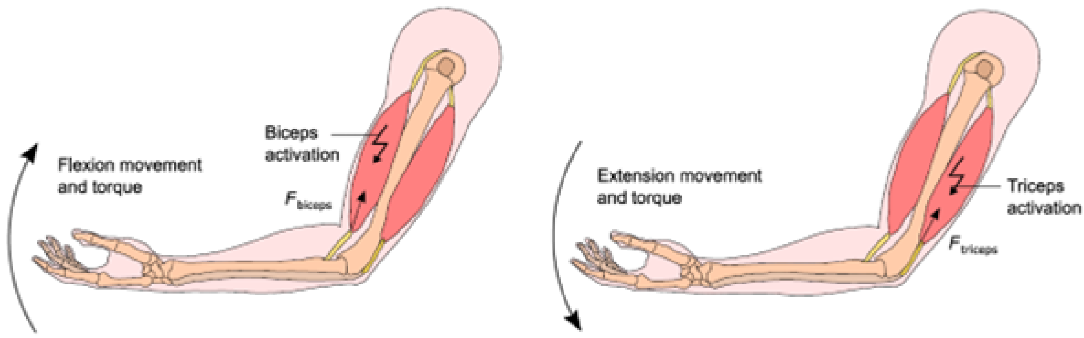

Figure 1: Left: activation of the biceps muscle indicates an elbow flexion movement or torque. Right: triceps activity indicates an elbow movement or torque in the extension direction. [1]

The treatment of a stiff elbow can be challenging, emphasising the importance of prevention. Stiffness following surgery or joint injury is postulated to progress through stages of bleeding, edema, granulation tissue, and fibrosis. Key preventive measures include early surgical intervention for fractures or joint instability and active mobilisation, which helps prevent edema and increased viscosity of inflammatory exudates, reducing the risk of adhesion formation.

Studies, such as one by Rafai et al., demonstrated the benefits of early mobilisation in posterior elbow dislocations. Patients treated with early mobilisation showed better recovery of elbow function (96 percent vs. 81 percent with immobilisation) and lower stiffness (4 percent vs. 19 percent with immobilisation). The FuncSiE trial also supported early mobilisation, showing better outcome scores at 12 months for stable simple elbow dislocations. Early active mobilisation was deemed safe and effective, leading to a faster return of functional range and a quicker return to work. [4]

1.2 IMPORTANCE

Addressing arm functionality loss, especially after elbow surgery or injury, is of paramount importance. It not only accelerates the recovery process but also helps prevent re-injury and complications. Proper rehabilitation ensures that patients regain optimal range of motion, strength, and functionality in their elbow joint. This leads to improved quality of life, reduced pain, and enhanced independence in daily activity.

2 problem definition

Elbow joint surgery constitutes a complex medical intervention often necessitated by conditions such as fractures, dislocations, or degenerative diseases. The recovery process following such surgeries is multifaceted, requiring a delicate balance between promoting healing and preventing complications. The proposed solution addresses the unique challenges associated with the post-surgery rehabilitation of the elbow joint, focusing on three key aspects: the user group, the medical problem, and the anticipated abilities or disabilities of the intended patients.

Understanding the diverse needs, challenges, and aspirations of this user group is foundational to the success of the rehabilitation device. By considering the intricacies of the medical problem and the temporary disability resulting from surgery, the solution aims to offer a tailored rehabilitation experience that goes beyond mere physical recovery, fostering a sense of empowerment and independence in patients on their journey to restored elbow function.

2.1 CLINICAL NEED

The primary target user group for the rehabilitation device comprises individuals who have recently undergone elbow joint surgery. This includes a diverse range of patients, spanning various age groups, medical histories, and lifestyles. Understanding the heterogeneity within this user group is vital for tailoring the rehabilitation device to meet the specific needs and capabilities of each individual, ensuring a personalised and effective recovery process.

2.2 MEDICAL PROBLEMS

Many different medical problems lead to the need of an elbow surgery. These issues include lateral and medial epicondylitis, triceps tendon tears, and biceps tendon tears.

- Lateral and Medial Epicondylitis: Commonly known as tennis elbow and golfer's elbow respectively, these conditions involve tendon problems at the elbow, particularly affecting the extensor and flexor tendons (see Figure 2). The majority of patients with these conditions recover without intervention, but surgery may be considered if conservative measures fail after an extended period. The postoperative rehabilitation for both conditions is similar, involving the use of a removable static splint and encouraging the patient to mobilize the elbow from the first postoperative day. Full recovery is expected within three to six months, although good function often returns before this time frame[5]
- Triceps Tendon Tears: This is a relatively rare condition that can involve tendinitis or partial or complete tears of the triceps tendon. Surgical intervention is usually reserved for symptomatic partial or complete tears. The postoperative protocol includes the application of a cast in mild extension, followed by a dynamic brace. This protocol allows for gradual increased flexion over time, with full flexion permitted after six weeks and strengthening beginning at three months. [5]
- Biceps Tendon Tears: These injuries significantly impact supination and flexion power of the forearm. Surgical reinsertion of the tendon is the common treatment for acute ruptures, while chronic lesions might require augmentation with a graft. The postoperative rehabilitation encourages immediate mobilisation of the elbow, with no limitations on range of motion and gradual increase in weight-bearing activities. [5]

In conclusion, the management of these medical issues following elbow surgery emphasises early mobilisation and specific postoperative care tailored to the type of injury and surgical intervention. The goal is to restore functionality and strength while minimising the risk of complications or re-injury.

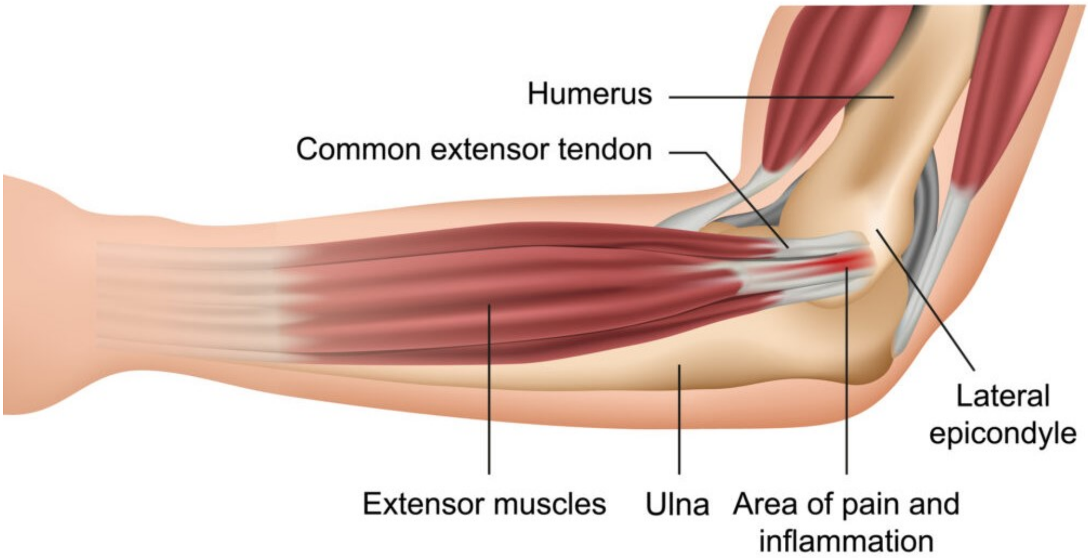

Figure 2: Tennis elbow injury affects the muscles and tendons located in the forearm that facilitate the extension of the wrist and fingers. [2]

3 meaningful training exercise

3.1 LEARNING OBJECTIVES

Rehabilitation after elbow surgery is a high priority, as elbow complaints, especially tennis elbow problems, are widespread and of considerable importance. A wide range of exercises, such as push-ups on the wall or on the floor, as well as exercises with a bar or on the traction apparatus, are routinely used. The point at which the elbow is able to bear weight, as stated in the medical report, should be noted. As a rule, this is only the case after 6-8 weeks with normal healing progress, whereby initially only active exercises without resistance are permitted. At a later stage, strength exercises with increasing weights follow, depending on the patient's age.

The focus of rehabilitation measures is on restoring strength and mobility, whereby both aspects must be fully restored. This is always an important therapeutic goal in physiotherapy. One medical problem that often occurs after elbow surgery is limited mobility in the elbow joint. Flexion, i.e. the bending of the elbow, is often limited to 130°, whereas normal flexion is 145°. This restriction can impair everyday activities such as brushing ones teeth or bringing a fork to the mouth. At the same time, extension of the elbow is often not possible up to 0°. The elbow remains in a 90° flexion or bent position, which makes it difficult to get the wallet out of a trouser pocket, for example.

Basic exercises are particularly important with regard to rehabilitation. The choice of these exercises depends on the patient's individual findings. It should be noted that movements involving force are not permitted after elbow surgery or a fresh fracture.

3.2 THERAPIST'S ROLE

The therapist's support for the patient is not limited to the correct execution of movements, but also includes feedback and motivation. The therapist assumes a supportive role on a mental and physical level (50 percent) through therapy and expertise. The remaining 50 percent requires the active participation of the patient in the realisation of the acquired knowledge.

4 user needs and technical requirements

These requirements are formulated with the clinical problem in mind, ensuring that the rehabilitation device aligns with the identified user needs and technical challenges associated with post elbow surgery rehabilitation.

4.1 USER NEEDS

Users express a fundamental need for precise monitoring and control over the elbow's flexion angle, essential for promoting optimal healing and facilitating rehabilitation that is uniquely suited to each individual's condition.

A crucial aspect of meeting user needs involves the incorporation of a robust feedback mechanism. This mechanism seamlessly integrates real-time visual, audio, and haptic cues, serving as a comprehensive guide throughout rehabilitation sessions. This user-centric approach not only enhances engagement but also significantly contributes to the overall effectiveness of the rehabilitation process.

The ability to track and record a patient's progress over multiple sessions addresses a key user need. By developing a sophisticated system for progress tracking, healthcare professionals can gain valuable insights into the effectiveness of the rehabilitation process. This feature serves as an essential tool for informed decision-making and allows for personalised adjustments based on individual progress.

Adaptability and penalisation are identified as critical user needs. The Arm Exoskeleton application, in recognition of diverse patient requirements, allows for adjustments tailored to each individual's progress and specific needs. This flexibility ensures a personalised and accommodating approach to rehabilitation, aligning closely with the expressed needs of users.

Safety emerges as a paramount user need, and the implementation of features such as resistance mechanisms directly addresses this concern. These safety measures come into play when users exceed predefined target angles, providing an additional layer of protection and control throughout the rehabilitation process. This commitment to safety underscores the user-centred approach in designing an Arm Exoskeleton that priorities both effectiveness and user well-being.

4.2 TECHNICAL REQUIREMENTS

The Arm Exoskeleton represents a meticulously crafted solution tailored to meet precise technical requirements, ensuring its effectiveness in various rehabilitation scenarios. Its design integrates a range of key features to address specific needs in providing optimal support and control for users.

At the core of its functionality is the integration of a reliable Electromyography (EMG) sensor. This sensor plays a crucial role in accurately detecting applied force during pinching motions, offering vital input for the Unity application. This user-friendly application, enriched with visual, audio, and haptic feedback, guides patients seamlessly through rehabilitation exercises.

Guidance and control are facilitated through the use of a stepper motor and angle sensor. The stepper motor directs the arm to specific angles, ensuring a controlled and targeted approach to rehabilitation. Power is conveniently supplied by a normal battery, enhancing the device's mobility and usability.

Continuous monitoring of the joint angle is achieved through a motor encoder, providing real-time feedback on the patient's performance. Customise settings empower therapists to adjust parameters based on individual patient needs and progress, reflecting the device's adaptability to diverse user requirements.

In conjunction with its software sophistication, the Arm Exoskeleton optimises user interaction and control. This includes seamless integration with the Unity application, supporting customisation and providing a user-friendly interface enriched with visual, audio, and haptic feedback. The sophisticated software further includes a robust data logging system, allowing healthcare professionals to track and analyse patient progress over time.

Safety remains a top priority in the Arm Exoskeleton's design. Advanced safety features, such as resistance mechanisms triggered when users exceed predefined target angles, ensure a controlled and secure rehabilitation experience. These safety measures add an extra layer of protection, fostering a secure environment for users throughout their rehabilitation journey.

In summary, the Arm Exoskeleton stands as a comprehensive and effective solution, combining precision, adaptability, and safety features to meet the diverse technical requirements for rehabilitation needs.

5 translation to exo arm functionalities

The rehabilitation device is designed to address this temporary disability by offering a structured and monitored environment for patients to regain optimal elbow function. The intended outcome is to empower patients with the ability to gradually and safely restore their elbow's range of motion, strength, and functionality.

5.1 REQUIREMENTS

To achieve this goal, the Exo Arm must meet the following technical specifications:

- Stepper Motor for Movement Control: The Exo Arm is equipped with a stepper motor that controls joint angles during rehabilitation exercises. Through a motor encoder the continuous monitoring of the joint angle is possible (see Figure 3). This feature allows for gradual and targeted improvement in joint mobility.

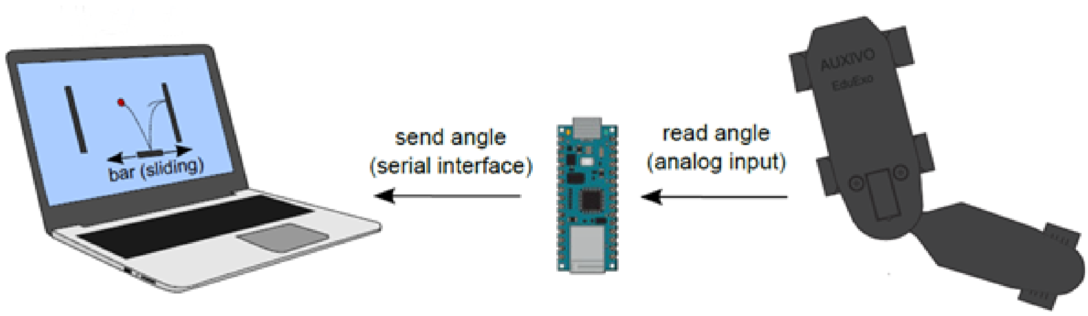

Figure 3: The setup and the data exchange between the devices. The Arduino reads the motor angle and sends it to the Unity game, where it is used to control the position of the selected ball.[1]

- EMG Sensor for Muscle Activity Monitoring: The system incorporates an Electromyography (EMG) sensor to detect and measure the patient's muscle activity. This information is crucial for monitoring movement quality and exerted force.
- Unity Application for Engagement and Feedback: Integrated with a Unity application, the Exo Arm offers a gamified rehabilitation experience. Real-time visual feedback guides and ensures correct exercise execution, effectiveness and patient engagement.
- Adaptive Resistance Mechanisms for Safety: Resistance mechanisms activate when the patient exceeds the prescribed range of motion, promoting safety and controlled exercise.
- Adjustment Capabilities and Data Integration: Therapists can adjust settings based on patient progress. The system also logs session details, providing insights into rehabilitation effectiveness.
- User-Friendly Interface: The Unity application features an intuitive interface with clear instructions, progress indicators, and motivational elements, enhancing the rehabilitation experience.

5.2 SOLUTION DESCRIPTION

The solution comprises a custom rehabilitation device equipped with an integrated Unity application. The primary mechanism of operation involves force detection through an EMG sensor, virtual object manipulation within the Unity application, guidance provided by a stepper motor, continuous monitoring of joint angle through a motor encoder (see Figure 3), and resistance application if the patient exceeds the target angle.

6 arduino implementation

The Arduino-based program is designed to interface with a Unity application. The code demonstrates intricate control of a servo motor and the processing of Electromyography (EMG) signals. Utilizing the versatile capabilities of the Arduino platform, the program is structured to receive commands from Unity, execute servo movements, perform calibration routines, and transmit EMG data back to the Unity application. Key components of the code include the initialization of serial communication, real-time handling of Unity commands, dynamic adjustment of servo position, and accurate reading of EMG signals. The breakdown of the program into logical sections provides clarity on each functionality, showcasing how Arduino can be effectively used in interactive hardware-software integration.

The full implementation of the code can be seen on the GitHub.

7 unity implementation

The core mechanics and interactive elements of a Unity-based game are described in the following, specifically focusing on the GameManager class. The Unity engine, renowned for its versatility in game development, is utilised here to create a dynamic and engaging gameplay experience. The code encompasses essential aspects such as the initialisation of game objects, handling player inputs, managing game states, and the visual representation of these elements. Through the GameManager class, we explore how Unity facilitates complex functionalities like object spawning, movement control, and collision detection, which are central to the game's interactivity and user experience. The code sections offer a comprehensive view into the intricate workings of game development within the Unity framework.

The full implementation of the code can be seen on the GitHub.

The general idea of the ball manipulation game (described in more detail in section 9) was to develop a game, where the user is motivated to engage in the rehabilitation activity and can regain the full extension and flexion angle in a playful way. An important aspect we focused on was that the movement of the arm should be reflected in the game, in this case the up and down and no left/right movement with the by the EduExo controlled element in the game. This way playing the game is more intuitive and confusion of the patients and unaware movements of the forearm to the side can be avoided.

8 outline of implementation

The current implementation tackles a wide range of functionalities and establishes the foundation for further development. The code includes several key components on both sides, ensuring comprehensive control and monitoring capabilities.

The implemented features are as follows:

- Steering of the motor and application of resistance.

- Limitation of the range of motion in terms of angles.
- Configuration settings for the EMG Sensor.
- Continuous monitoring of the EMG Signal and the Motor Encoder.
- Serial connectivity for real-time data transmission.
- Visual feedback system for user interaction and status indication.
- Adaptive algorithms for personalized training regimes.
- Data logging for performance tracking and analysis.
- User interface for real-time feedback and control.
- Safety features to prevent overexertion and injury.

While all these building blocks are implemented, not every component is currently utilised in the context of the implemented game. This structure allows for future expansions and the integration of additional functionalities.

9 demonstration and video recording

The developed game serves to rebuild the arm angle. The aim is to relearn the movement of the arm. The arm is either stretched (Figure 4(a)) or bent (Figure 4(b)) for interaction with the game.

((a)) Arm stretched

((b)) Arm bend

Figure 4: Range of movement of the arm during the game

Start your gaming adventure by launching the game (Figure 5). Immerse yourself in a captivating experience where your actions directly influence the gameplay. Start with a simple, intuitive gesture by clenching your hand into a fist to grab a ball in play.

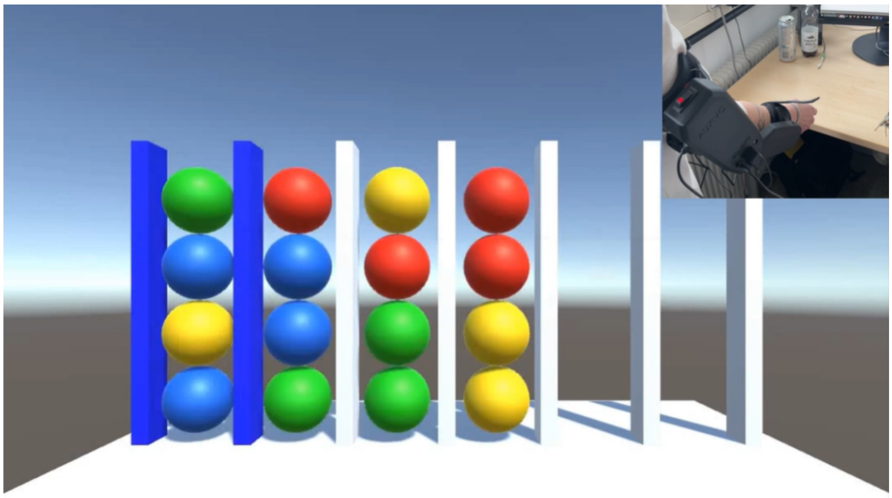

Figure 5: Starting point of the game

The next step in the game is to raise your arm to lift the ball at the same time (Figure 6). While moving your arm upwards, a natural and seamless movement transfers your physical movement into the virtual world. Watch as the ball rises and follows your command.

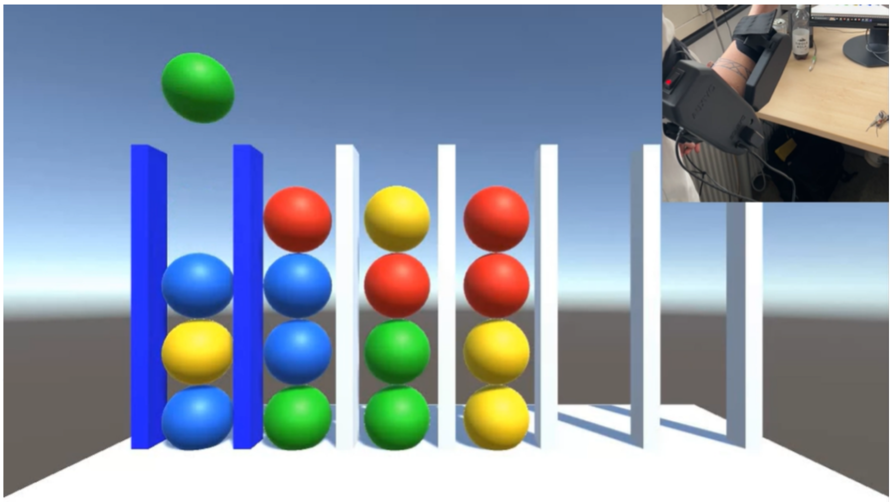

Figure 6: A column is selected and the ball is lifted

Now you need to think strategically. Your objective? To skilfully stack balls of the same colour in a single column. Think carefully and use the arrow keys to select a column (Figure 7). This decision determines where your lifted ball will be positioned in.

Ready for the next interaction step? Clench your hand into a fist again to release the ball from its elevated position. Execute this with precision and watch as the ball descends into the chosen column (Figure 8).

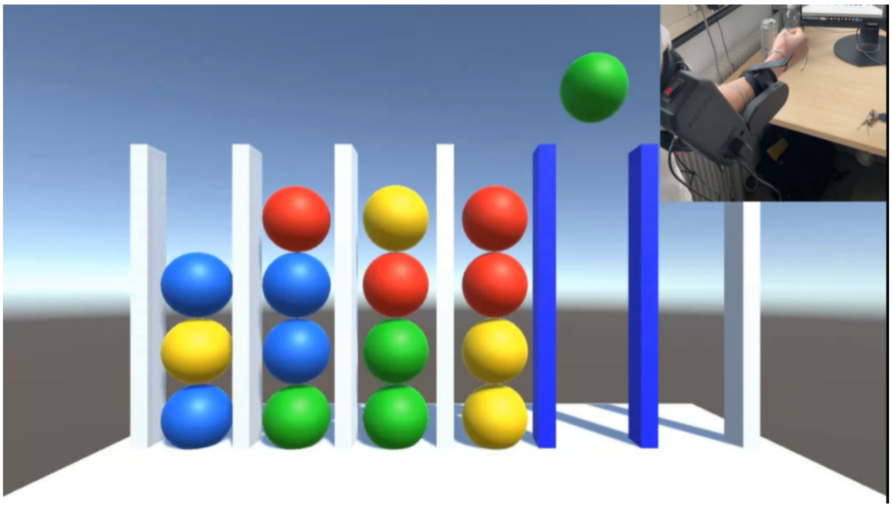

Figure 7: The ball is moved across the target column

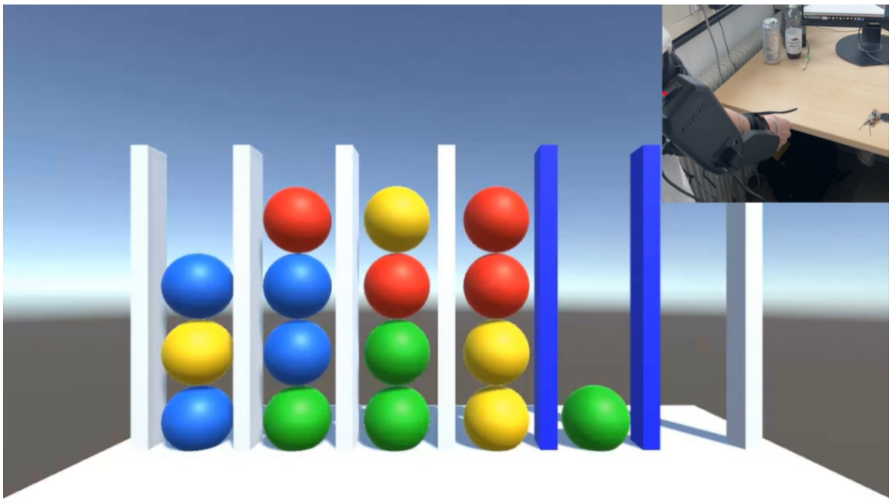

Figure 8: The ball is dropped in the column

Continue the game by selecting columns using the arrow keys. Each press of the arrow keys and the following manipulating of a ball brings you one step closer to your goal. Achieve it, and you'll be rewarded with a spectacular visual effect, highlighting your success in this engaging and interactive game (Figure 9).

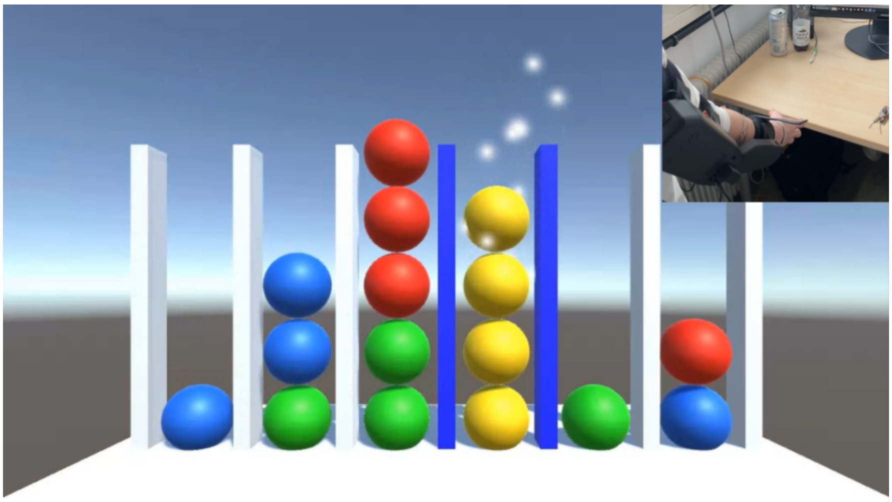

Figure 9: A series of bales in the same colour was completed. An animation to illustrate the success appears.

10 conclusion

10.1 LIMITATIONS

The current design and implementation, while quite robust, encounter certain limitations that could be addressed in future iterations for enhanced performance and usability. These limitations span across various components and design aspects, as detailed below:

- **Stepper Motor Power and Type:** The choice of stepper motor affects both power efficiency and control precision. The current motor type may limit the device's capability to handle varying resistance levels and movements smoothly, trough wich the restriction of movement is only possible to a certain degree.
- **EMG Sensor Precision and Stability:** The accuracy and consistency of the EMG sensor are crucial for reliable signal interpretation. Current limitations in precision and stability could impact the effectiveness of muscle activity monitoring.
- **Serial Connection Cables:** The existing cable setup for serial connections poses restrictions on the user's range of motion. This limitation can hinder the natural movement and overall experience.
- **General Movement Hindrance and Kinematic Mismatch:** Constraints in allowing full-range motion while maintaining focused actuation due to design limitations and potential misalignment with user's anatomy.
- **Size and Weight:** Challenges with adaptability to different user physiques and weight distribution, impacting user comfort and movement.
- **Potential for Collisions with Environment:** Increased risk of collisions due to the size and bulkiness of the exoskeleton.
- **Heat Dissipation and Ventilation:** Managing heat close to the body to prevent user discomfort or overheating.
- **Complexity of Control Systems:** The requirement for extensive user training due to complex controls.
- **Energy Efficiency and Power Requirements:** Limitations related to energy consumption and operational time.

- **Noise and Vibration:** User discomfort due to operational noise and vibrations.
- **Durability and Wear-and-Tear:** Maintenance needs arising from regular use and component wear.
- **Unity Game:** Playing only one single level, may be boring after a certain time, even if the balls spawn in a random setup and therefore create different possibilities for reaching the goal each time.

Addressing these limitations will be pivotal in advancing the device's functionality, user comfort, and overall application effectiveness. Future design enhancements should aim to optimise motor performance, sensor accuracy, physical flexibility, and customisation to user anatomy.

10.2 SUGGESTIONS FOR IMPROVEMENT

Given the outlined limitations of the current design and implementation, several improvements are suggested to enhance functionality, user experience, and overall performance. These suggestions aim to address the specific challenges and constraints identified:

- Improve motor selection by considering more powerful and efficient stepper motors for smoother operation and better handling of resistance variations, to improve the restriction of variable angles to provide a more secure rehabilitation process.
- Enhance the precision and stability of the EMG sensor to ensure more reliable muscle activity monitoring and interpretation.
- Redesign the cable arrangement to reduce movement restrictions, exploring options like more flexible cable management or transitioning to a wireless system, such as Bluetooth, for enhanced freedom of movement and operational ease.
- Optimise the exoskeleton design for a better balance between freedom of movement and focused actuation, while ensuring kinematic compatibility with the user's anatomy.
- Incorporate adjustable sizing mechanisms to accommodate a wider range of user physiques, particularly in the forearm and upper arm areas.
- Implement lightweight materials and better weight distribution strategies to reduce user fatigue and improve ergonomic comfort.
- Introduce advanced heat dissipation and ventilation systems to manage and reduce heat buildup close to the body.
- Simplify the control systems to reduce the learning curve, possibly through more intuitive interfaces or automated adjustments.
- Explore energy-efficient solutions and alternative power sources to extend operational time and improve overall energy management.
- Utilise materials and components that reduce noise and vibration to enhance user comfort during operation.
- Focus on durable materials and modular designs for easier maintenance and longer lifespan of the exoskeleton components.
- To enhance motivation to continue the rehabilitation it is possible to unlock more different levels, and increase the mind activity and the degree of difficulty by providing a varying amount of columns or more different colours of balls. Additionally it could be possible to implement a certain weight of the ball - simulated by resistance of the motor - to provide the user also with strength training to enhance muscle formation after the restoring of the full angle.

These suggestions are aimed at addressing the current limitations while paving the way for more advanced, user-friendly, and efficient design iterations in future developments.

10.3 CONCLUSION

The document comprehensively addresses critical aspects including user needs, technical requirements, and the implementation of the exoskeleton system using Arduino and Unity.

Beginning with the selection of a typical arm or elbow handicap, the work centers on its rehabilitation, necessitating an understanding of arm anatomy and the clinical presentation of the chosen condition, particularly tennis elbow in this case.

The rehabilitation process is elaborated upon, emphasizing the restoration of strength and mobility in the elbow joint through a graduated series of exercises, tailored to individual needs.

User needs are meticulously considered, focusing on precise monitoring, real-time feedback, and progress control. Technical requirements for the arm exoskeleton are then clearly defined, encompassing features such as EMG sensors, adaptive resistance mechanisms, and a user-friendly interface. Simultaneously, a game concept is developed to be implemented in Unity, intended to incentivize rehabilitation exercises.

Details of the implementation with Arduino and Unity demonstrate sophisticated integration of hardware and software, facilitating a gamified rehabilitation experience. The ball manipulation game not only mimics real arm movements but also seeks to engage and intuitively guide the user through the rehabilitation process.

Acknowledging limitations in the current design, insightful suggestions for improvement are proposed, spanning motor selection, sensor precision, cable redesign, and enhancements for user comfort and adaptability.

In summary, the thesis presents a holistic approach to rehabilitation post-elbow surgery, leveraging advanced technology to address both physical and psychological aspects of recovery. The outlined suggestions for improvement pave the path for future iterations, aiming for a more efficient, user-friendly, and adaptable arm exoskeleton to achieve superior rehabilitation outcomes.

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