Red: ARTICLE 1

Green: ARTICLE 2

Blue: <https://d1wqtxts1xzle7.cloudfront.net/34709753/MBEC_Yap2014-libre.pdf?1410519395=&response-content-disposition=inline%3B+filename%3DDesign_and_Characterization_of_Soft_Actu.pdf&Expires=1728211616&Signature=LWAneo3rTVi4ZjRAhFXUarJ11YtFQzUFvfIzZxmaJ-JrnVRw3v3l6NfKFduyAXVhxr6HL2PIF9p32Szq6a7o0-MTw67wO6xQC~r3xwI6PwpzYsYITVYQtWghv9KTv06g-bhxgeX-ulZ4kJw9KcqUOWjt8xX6aFvDVth6CrceCvN4OB4wK-6YRiNIvDc3UNTvk1bSVg0rdjOydypx4OgNmBLgglweObahzdFZ-Sulb0HbJSmJy3qCIHGBWj7H7xq5rFjoRJsuMXjEc3iV9inIqKPVoZSkbsdhYi-ncKPTJHhYpzcIlr9QoagtZl~DrEIaB1ujnaluV~2uRMziXiE0oA__&Key-Pair-Id=APKAJLOHF5GGSLRBV4ZA>

Pink Highlights: General Knowledge

Yellow Highlights: Unanswered

**1. Project Scope and Objective**

*- What is the primary objective of our rehabilitation device? Is it for specific conditions like stroke recovery, arthritis, or general hand therapy?*

Primary Objective: The primary objective of our rehabilitation device, based on the text provided, is to aid in hand rehabilitation for patients with impairments like those caused by stroke, spinal cord injuries, and degenerative diseases. The aim is to improve dexterity, strength, and range of motion through the use of soft robotics.

- What is the specific problem or need we are addressing in rehabilitation? (e.g., improving dexterity, strength recovery, range of motion)

Specific Problem: We are addressing the limitations of traditional rigid exoskeletons in rehabilitation (heavy, uncomfortable, expensive, restrict natural motion) by developing a soft, flexible glove that provides better motion assistance and comfort.

- Are we targeting specific user groups (e.g., age, injury type) in our design?

Target User Group: The device is intended for individuals with hand impairments caused by conditions such as stroke, spinal cord injuries, or degenerative diseases like Parkinson’s.

**2. Actuation and Control**

- What kind of soft actuation mechanisms are we planning to use (e.g., pneumatic, hydraulic, shape memory alloys, or electroactive polymers)?

Soft Actuation Mechanism: Soft pneumatic actuators are used for flexion and extension of fingers, combined with flexible rotating actuators for abduction/adduction.

Other designs incorporate shape memory alloy (SMA) springs for extension, enhancing the bidirectional motion capabilities.

We plan to use pneumatic or electroactive polymers due to their flexibility and adaptability in mimicking natural hand movements.

**EXPLANATION**

**Pneumatic Actuation**

* **How it works**: Pneumatic actuators use compressed air to generate movement. In soft robotics, soft pneumatic actuators are made from flexible materials that inflate or deflate, mimicking muscle motion. These actuators can be configured to bend, expand, or contract based on how the air pressure is controlled.
* **Practicality**:
  + **Pros**:
    - High flexibility and adaptability, allowing for smooth, natural motion, which is particularly useful in mimicking hand movements.
    - Safe for use in human-robot interaction because of their inherent compliance (i.e., they deform easily without causing damage).
  + **Cons**:
    - Requires an air compressor or pump, which adds to the system's bulk and energy consumption.
    - Air leakage can lead to loss of efficiency, and the system might need frequent maintenance.

**Best for**: Applications that need a high level of flexibility and adaptability, such as rehabilitation devices for hand therapy.

**2. Shape Memory Alloys (SMAs)**

* **How it works**: SMAs are materials that return to their pre-set shape when heated. In soft actuators, SMA springs can be used for extension or contraction. When an electric current heats the material, it "remembers" its original shape and moves accordingly.
* **Practicality**:
  + **Pros**:
    - SMAs are very lightweight and can generate a relatively strong force for their size.
    - Good for applications where silent and smooth motion is needed.
    - Can be compact, making them useful in miniaturized designs.
  + **Cons**:
    - SMAs generally have slower response times compared to pneumatic and EAP actuators due to the heating and cooling cycle.
    - Limited range of motion, which might restrict the types of movements that can be achieved.
    - Efficiency decreases if rapid cycling is required, as cooling can become a bottleneck.
* **Best for**: Small, simple actuators where space and weight are limited, and the speed of actuation is not the highest priority.

**3. Electroactive Polymers (EAPs)**

* **How it works**: EAPs are materials that change shape or size when an electric field is applied. This property allows them to act as artificial muscles in soft actuators. The deformation is typically reversible, making them a good candidate for repetitive motion tasks.
* **Practicality**:
  + **Pros**:
    - They offer precise control and can achieve very small, smooth movements, making them excellent for fine motor control, such as finger manipulation.
    - Lightweight and highly flexible, reducing bulk in the design.
    - Can operate silently without the need for pumps or compressors.
  + **Cons**:
    - Power consumption can be relatively high, particularly for large displacements.
    - Some EAPs require high operating voltages, which can limit their practical applications, especially in medical devices.
    - Durability and material fatigue are concerns, as EAPs may wear out more quickly than other actuation methods.
* **Best for**: Tasks that require precision and light weight, such as wearable rehabilitation devices that need to be compact and comfortable.

- How will we control the actuators (e.g., manual controls, sensors for real-time feedback)?

Control of Actuators: The device will likely use a hybrid PID control system for force and position control, allowing dynamic adjustment during rehabilitation.

The glove uses **button mode** for manual control via a mobile app and **mirror rehabilitation training** mode, which mirrors the movements of the healthy hand onto the impaired hand.

The actuators will be controlled via sensors that provide real-time feedback, allowing adjustments based on user needs.

**EXPLANATION**

1. **Hybrid PID Control System**:
   * **How it works**: A PID (Proportional-Integral-Derivative) control system is widely used in applications requiring precise control of dynamic systems. In your project, a hybrid PID controller will manage both force and position control of the actuators.
     + **Proportional (P)**: Adjusts based on the current error (difference between desired and actual positions or force).
     + **Integral (I)**: Corrects past errors by integrating them over time to reduce steady-state error.
     + **Derivative (D)**: Predicts future errors based on the rate of change, helping to prevent overshooting.
   * **Why it’s Practical**:
     + Offers smooth, continuous control for both force and position, which is critical for rehabilitation where subtle adjustments in hand movement are essential.
     + Allows the device to respond quickly and accurately to changes in input (e.g., muscle tension or hand position), ensuring safe and effective therapy.
2. **Manual Control (Button Mode via Mobile App)**:
   * **How it works**: The device will include a manual control mode, likely operated through a mobile app. Users or therapists can press buttons to control movements directly, adjusting the actuators in real-time.
   * **Why it’s Practical**:
     + Provides an easy-to-use interface, enabling users or healthcare professionals to tailor the therapy to individual needs.
     + Offers more control over the device during initial stages of rehabilitation, or when precise movements are required.
     + Ensures accessibility and user-friendliness for non-experts (e.g., patients themselves), as they can operate the system without needing to know the underlying mechanics.
3. **Mirror Rehabilitation Training Mode**:
   * **How it works**: In this mode, the healthy hand's movements are captured through sensors, and those movements are mirrored onto the impaired hand via the actuators. This type of training is known to enhance motor learning and recovery.
   * **Why it’s Practical**:
     + Facilitates rehabilitation by leveraging the healthy hand’s natural movement patterns to guide the impaired hand, encouraging brain plasticity and muscle reactivation.
     + Allows for more engaging and intuitive therapy, making the rehabilitation process smoother and more effective.
     + Reduces the cognitive load on the patient by using familiar movements instead of requiring new motion patterns.
4. **Real-Time Feedback Sensors**:
   * **How it works**: Sensors, possibly placed within the glove, will provide real-time feedback on the hand's position, force applied by the actuators, or muscle activity. This feedback can be used by the control system to dynamically adjust the actuators based on the user’s needs.
   * **Why it’s Practical**:
     + Ensures the actuators respond accurately to the current state of the hand, maintaining safety and comfort.
     + Helps adapt the rehabilitation exercises to the patient's specific progress, providing a personalized and responsive treatment approach.
     + Enables monitoring of performance metrics, allowing therapists to track improvements or modify the therapy plan in real time.

- What kind of feedback will the system provide to ensure correct motion (haptic feedback, visual cues)?

Feedback Mechanism: Force and strain sensors provide real-time feedback on finger positions and the amount of force exerted. This is crucial to ensure the correct range of motion and to avoid over-exertion.

Feedback is provided through real-time sensors and virtual reality interfaces, especially in the mirror training mode, allowing the patient to visualize their progress.

The system will incorporate haptic feedback and visual cues to guide users through exercises, ensuring correct motions are performed.

Explanation

**Force and Strain Sensors**:

* **How they work**: These sensors will monitor the position of the fingers and the force exerted by the actuators in real time. Strain sensors can detect stretching or compression in soft materials, while force sensors measure the load being applied.
* **Why it’s Practical**:
  + Ensures that the rehabilitation exercises stay within a safe range of motion, preventing over-exertion or injury.
  + Provides real-time data for the control system to adjust the actuators dynamically, ensuring smooth and accurate hand movements.
  + Useful for tracking patient progress by measuring improvement in strength and range of motion over time.

**Virtual Reality (VR) Interfaces**:

* **How they work**: VR or other visual interfaces can display a virtual representation of both hands, particularly in the mirror training mode, where the healthy hand's movements are mirrored onto the impaired hand.
* **Why it’s Practical**:
  + Provides patients with immediate visual feedback on their movements, helping them understand the alignment and motion of their hands.
  + Enhances engagement in the rehabilitation process, making it more interactive and motivating for patients to follow through with exercises.
  + Allows therapists to visualize data and make adjustments to treatment plans in real time, improving the overall effectiveness of rehabilitation.

**Haptic Feedback**:

* **How it works**: Haptic feedback involves delivering tactile sensations (such as vibration) to the user. In this case, the device can provide subtle haptic cues when certain thresholds are met (e.g., when the hand reaches the correct position or force).
* **Why it’s Practical**:
  + Helps the patient feel when the correct motion is achieved, without needing to constantly look at a visual display.
  + Reinforces the learning of correct movements, making rehabilitation exercises more intuitive and effective.
  + Can alert the user when they are over-exerting, protecting against injury and ensuring safe exercises.

 **Visual Cues**:

* **How they work**: The system will likely use visual indicators (such as on a mobile app or VR display) to show progress in real time. This could include color changes, graphics, or numerical data indicating the degree of movement or force.
* **Why it’s Practical**:
  + Helps users understand how well they are performing the exercises, making corrections easier to implement.
  + Assists therapists and patients alike in identifying any difficulties or inconsistencies in movements.
  + Encourages user engagement by showing immediate improvements or achievements.

**3. Biomechanics and Design**

- How will our device mimic or assist natural hand movements (e.g., flexion, extension, abduction)?

Mimicking Natural Hand Movements: The soft glove supports flexion, extension, abduction, and adduction to replicate natural hand movements. Pneumatic actuators bend to assist with flexion/extension, and rotating actuators enable finger separation (abduction/adduction).

The device will use a combination of soft actuators that flex and extend to mimic natural hand movements such as flexion and extension.

- What range of motion and strength are we aiming for?

Range of Motion and Strength: Zhu et al.'s design achieved a bending angle of 130°, sufficient for most rehabilitation exercises. Strength improvements are seen in grip strength as well.

The glove significantly enhances the range of motion, with the **PIP joint** bending from 6.8° to 68.3°, and **MCP joint** from 11.3° to 68.1°. It also improves **grip strength**, increasing force from 8.4 N to 21.34 N.

We aim for a range of motion that closely aligns with natural hand movement (e.g., 0 to 90 degrees of flexion) and sufficient strength to assist in lifting light objects.

- How will we account for different hand sizes and variations in user anatomy?

Adjusting for Different Hand Sizes: Soft materials (e.g., silicone) allow the glove to conform to different hand sizes and shapes, improving adaptability and comfort.

**4. Safety and Comfort**

- What safety measures are needed to prevent injury or overextension of the hand during rehabilitation?

Safety Measures: The hybrid control system ensures that excessive force is not applied to the hand. The use of soft materials reduces the risk of injury compared to rigid exoskeletons.

The glove's **water-cooling system** ensures safe operation of the SMA springs, preventing overheating and improving response time.

- How will we ensure the device is comfortable to wear over extended periods? Are there soft, ergonomic materials we should consider?

Comfort: Soft elastomers and flexible fabric ensure comfort, enabling prolonged use without discomfort. Ergonomic materials such as Dragon Skin silicone are optimized for both flexibility and strength.

- What mechanisms will we use to detect or prevent excessive forces on the hand?

Preventing Excessive Forces: Force sensors and the hybrid control system prevent over-pressurization or excessive force, making the device safer for users with fragile conditions.

The control system regulates the actuator force, preventing overexertion or injury by adjusting the applied force during rehabilitation.

**5. Clinical and User Input**

- Have we consulted with physical therapists or healthcare professionals to understand the key requirements for a rehabilitation device?

- How will we involve end-users in the design process to ensure usability?

User-Centric Design: Involving users in early testing phases can help identify usability issues and refine the design based on real-world feedback.

**6. Sensors and Feedback**

- What sensors will we use to track hand movements (e.g., force sensors, position sensors, EMG sensors)?

Types of Sensors: Flexible strain and force sensors are used to monitor the position and force applied to the fingers. These sensors enable accurate control and dynamic adjustment of the actuators.

The device uses a **Leap Motion sensor** to track the movement of the patient’s healthy hand, which is then mirrored on the impaired hand.

We will use a combination of force sensors and position sensors to track hand movements accurately.

- How will we provide feedback to both the patient and therapist on the progress of the rehabilitation (e.g., tracking data, performance metrics)?

Providing Feedback: Feedback could be provided to both the patient and therapist via performance metrics, real-time data on movement, and force application, allowing continuous monitoring of rehabilitation progress.

Through **virtual reality** and **mirror rehabilitation training**, patients and therapists can track the progress of rehabilitation exercises.

Feedback will be provided through an app that tracks data and performance metrics, accessible to both patients and therapists.

**7. Technology and Materials**

- What materials are best suited for soft actuation and repeated hand movements?

Material Suitability: Soft pneumatic actuators are made from elastomers like silicone for flexibility and durability. The materials chosen (e.g., Dragon Skin silicone) balance flexibility and strength for repeated use in rehabilitation.

Materials such as silicone for soft actuators and durable fabrics for the wearable part of the device are best suited for repeated movements.

- Are there limitations in durability, wear, or response time for the materials we're considering?

Durability: Materials need to be able to withstand repetitive motion, particularly actuators that will inflate and deflate constantly. Silicone casting techniques help optimize durability.

- How will the power source be integrated into the system? Will it be portable or stationary?

**8. Software and Control Algorithms**

- What kind of software or algorithms will we need for controlling the actuation? Are we implementing any machine learning or adaptive algorithms?

Control Software: The hybrid PID control system integrates real-time adjustments for both force and position control, ensuring that the glove can dynamically respond to the patient's needs. Machine learning could be implemented in future developments to further adapt to individual users’ progress over time.

We will need software that includes control algorithms for managing actuator movement, with potential integration of machine learning for adaptive control based on user performance.

- How will we integrate real-time adjustments for force and movement based on user feedback?

The system will utilize feedback loops for real-time adjustments of force and movement based on user activity and progress.

**9. Rehabilitation Effectiveness**

- How will we measure the success of our device in improving hand rehabilitation outcomes (e.g., hand strength, range of motion)?

Measuring Success: Success could be measured through improvements in hand strength, range of motion, and fine motor control. Specific benchmarks could include the angle of flexion and abduction achieved or grip strength improvement.

- Are there existing benchmarks or protocols that we can use to test the device?

Testing Protocols: Clinical trials can be used to test the effectiveness of the device, as seen in the second article where the glove improved joint angles and grip strength in stroke patients.

**10. Regulatory and Ethical Considerations**

- Are there any regulatory requirements for medical devices that we need to be aware of?

- How will we ensure that the device meets safety standards for medical use?

**11. Project Management and Timeline**

- What are the key milestones for our project, and how are we managing the division of tasks among the team?

- Do we have a prototype development schedule, and when can we begin testing?

**Biology behind Project**

**12. Hand Anatomy and Function**

- What specific muscles, tendons, and joints are involved in the hand movements we are trying to assist or rehabilitate?

Muscles, Tendons, and Joints: Hand movements like flexion, extension, abduction, and adduction are controlled by a complex system of muscles (like the flexor and extensor muscles), tendons (e.g., flexor tendons), and joints (e.g., DIP, PIP, and MCP joints). Rehabilitation aims to strengthen these components.

- How do nerves control hand movement, and what happens when these nerves are damaged or impaired (e.g., stroke, spinal cord injury)?

Nerve Control: Nerves such as the ulnar, median, and radial nerves control hand movement. When these nerves are damaged (e.g., after a stroke), the loss of motor control occurs. Rehabilitation exercises help retrain the brain to restore movement.

- How does the hand typically recover from injury or trauma, and what role do rehabilitation exercises play in that process?

Recovery Process: After an injury, recovery involves re-strengthening muscles and relearning movement patterns. Rehabilitative exercises help stimulate neural pathways through repetitive motions.

**13. Types of Injuries and Conditions**

- What are the common conditions that affect hand functionality (e.g., stroke, arthritis, carpal tunnel syndrome, nerve damage)?

Common Conditions: Stroke, spinal cord injuries, arthritis, and nerve damage can all lead to reduced hand functionality. These conditions often result in a reduced range of motion, weakened grip strength, and difficulty with fine motor skills.

- How does each of these conditions affect the hand’s range of motion, strength, or fine motor control?

Impact on Functionality: Stroke or nerve damage affects the hand’s motor control, making precise movements and tasks like grasping difficult. Rehabilitation can gradually restore these functions through repetitive exercises.

- What biological mechanisms are involved in the loss of hand function, and how can rehabilitation help restore it?

**14. Muscle Atrophy and Recovery**

- How does muscle atrophy occur in the hand after prolonged disuse or injury, and what is the biological process of muscle rebuilding during rehabilitation?

Muscle Atrophy: Prolonged disuse, such as after a stroke or injury, can lead to muscle atrophy in the hand. Rehabilitation exercises promote muscle rebuilding and regaining strength.

- What role do soft tissue, ligaments, and tendons play in recovery? How are these structures affected by injury?

Role of Soft Tissues and Tendons: Tendons and soft tissues play a critical role in hand movement and recovery. Injuries to these tissues can impair function, but rehabilitation exercises help stretch, strengthen, and restore flexibility

**15. Neuroplasticity and Motor Learning**

- How does neuroplasticity (the brain’s ability to rewire itself) factor into hand rehabilitation, particularly in cases of stroke or neurological damage?

Neuroplasticity: Neuroplasticity is the brain’s ability to form new neural connections. During rehabilitation, particularly after neurological injuries like stroke, repeated hand movements can help the brain rewire itself, improving motor control and restoring function.

- What biological processes occur in the brain and nerves during motor learning and rehabilitation?

Biological Processes: As patients engage in motor learning exercises, new neural pathways are formed or existing ones are strengthened, enhancing coordination and function in the hand.

**16. Circulation and Healing**

- How does blood circulation in the hand impact the healing and recovery process?

Blood circulation in healing: Blood circulation in the hand is critical for delivering oxygen and nutrients to injured tissues, promoting healing. Adequate blood flow also helps remove waste products and inflammatory substances, speeding up recovery. Poor circulation can delay healing and increase the risk of complications.

- Are there specific biological factors (e.g., inflammation, cell regeneration) that affect the pace of recovery?

Biological factors in recovery: Inflammation is the body's immediate response to injury, helping clear out damaged cells. Over time, cell regeneration (especially in skin, muscles, and tendons) is essential for restoring function. Growth factors and stem cells also play a role in tissue repair.

**17. Pain and Sensation**

- What are the biological causes of pain or loss of sensation in the hand during injury or after surgery?

Causes of pain and loss of sensation: Pain or loss of sensation can occur due to nerve damage, inflammation, or swelling. After surgery, scar tissue can compress nerves, leading to discomfort or numbness. In some cases, muscle or tendon injuries can cause referred pain due to the proximity of nerves.

- How can rehabilitation help address or mitigate pain, and what should we consider about nerve recovery and sensation?

Rehabilitation’s role: Rehabilitation can help by gradually restoring nerve function through controlled exercises and movements. It encourages nerve regrowth (nerve plasticity) and desensitizes painful areas. The rehabilitation process must account for nerve recovery time, avoiding excessive strain on healing nerves.

**18. Rehabilitation Effectiveness**

- What biological markers or signals indicate that the hand is recovering or improving during rehabilitation (e.g., increased strength, improved range of motion, nerve regeneration)?

Markers of recovery: Biological markers of hand recovery include improvements in grip strength, range of motion, and fine motor control. Other indicators include decreased pain, swelling, and regeneration of nerves (evidenced by restored sensation).

- How does repetitive motion in rehabilitation contribute to muscle memory and the recovery of hand function?

Repetitive motion in rehabilitation: Repetitive motion helps retrain the brain through neuroplasticity. Muscle memory improves as the same motions are repeated, which strengthens neural pathways that control movement. This practice helps regain control and coordination.

**19. Impact of Age and Health on Recovery**

- How does aging affect the hand’s ability to recover from injury or trauma? Are there any biological limitations?

Effect of aging on recovery: Aging slows down tissue regeneration, and older adults may have reduced blood circulation and lower muscle mass, which can limit the speed and extent of recovery. Joint stiffness and arthritis are also more common, potentially hindering flexibility and mobility.

- How do other health conditions (e.g., diabetes, cardiovascular issues) impact hand recovery and rehabilitation?

Impact of health conditions: Health conditions like diabetes can reduce circulation and slow healing, making it harder to regain full hand function. Cardiovascular issues can further limit recovery by restricting blood flow to injured tissues.

**20. Tendon Gliding and Joint Health**

- What is the role of tendon gliding (the ability of tendons to move smoothly) in hand rehabilitation?

Role of tendon gliding: Tendon gliding allows smooth movement of tendons through their sheaths, essential for normal hand function. During rehabilitation, ensuring that tendons can glide properly helps prevent stiffness and adhesions (scar tissue), which can limit movement.

- How do joint stiffness and synovial fluid affect hand motion, and how can rehabilitation improve joint health?

Joint stiffness and synovial fluid: Joint stiffness, often due to a lack of movement, can restrict motion. Synovial fluid lubricates the joints and allows smooth, pain-free movement. Rehabilitation exercises stimulate synovial fluid production, improving joint mobility.

**21. Muscle Fatigue and Endurance**

- What biological factors cause muscle fatigue in the hand during rehabilitation exercises, and how can we optimize our device to avoid overexertion?

**Causes of muscle fatigue**: Muscle fatigue during rehabilitation exercises can result from the depletion of energy stores (ATP) in muscles, lactic acid buildup, or poor circulation. Neurological fatigue may also occur when nerves struggle to send signals to the muscles after injury. **Optimizing to avoid overexertion**: To avoid overexertion, the device can be designed to monitor muscle fatigue using sensors that track force and movement. Gradual, controlled increases in exercise intensity help build endurance without causing strain or injury.