**Control Algorithm**

The paper does not explicitly discuss a control algorithm; it focuses primarily on the design and characterization of soft pneumatic bending actuators without detailing any specific control strategies employed.

**Actuator**

* **Type**: Soft pneumatic bending actuator
* **Materials Used**:
  + Ecoflex® 00-30 (Young Modulus: 125 kPa, Shore Hardness: 00-30)
  + Dragon Skin® 20 (Young Modulus: 1.11 MPa, Shore Hardness: A-20)
* **Mechanism**: The actuator functions through inflation of embedded air chambers, which causes bending movement. A strain-limiting fabric is used to control strain during actuation.

**General Limitations**

* **Force Output**: The soft actuators produce limited force, which may not be sufficient to actuate stiffer joints, such as the metacarpo-phalangeal (MCP) joint.
* **Customizability**: High customizability is required due to the varying geometry and stiffness of patients' hands, which complicates the design.

**Response Time**

The paper discusses the step response of the bending actuator, indicating that it responds quickly initially but then reaches a steady state where further increases in input pressure yield diminishing returns in response.

**Safety**

The inherent compliance of soft actuators is noted as beneficial for biomedical applications, as it ensures a safer interaction with human body parts, minimizing the risk of injury during rehabilitation.  
  
  
<https://d1wqtxts1xzle7.cloudfront.net/34709753/MBEC_Yap2014-libre.pdf?1410519395=&response-content-disposition=inline%3B+filename%3DDesign_and_Characterization_of_Soft_Actu.pdf&Expires=1728928980&Signature=M2~QHKHR7lvl~Hq9xNczybGnxSYa9vHEJXYQb9cUHQkaN7qtPmgXAc~ADHeVpnw20d7SBH4gTK0meHKh6C2lpSQpHBGedx1ShxyVSjmEJMKMqV6~j8~9LCw8AO4aOR59mKikA9YjkQHxAZEi0wtmRalImGZ97SzPP~uAjlk5OZugMAfU1hLjS~bnInc8i6j0h79OHrZ-IKYQvXQTLgPH7DZcxRQYn3MbDYuQYjupkYYMGQhB3FQHVft1Ff4h0tHmeQ9gQ4gyWGIXxu2jsWvdb7ePErKpe3DxT1euq5Fo7n-2kjvh8~tqSps5vIFOqVfm-3QckiyZ2P65ijsBH94wDQ__&Key-Pair-Id=APKAJLOHF5GGSLRBV4ZA>

**Control Algorithm**

* **Type:** Proportional Integral Derivative (PID) control algorithm.
* **Control Frequency:** 200 Hz.
* **Model Type:** Force-position hybrid model.
* **Error Metrics:**
  + eθe\_\thetaeθ​: Error between designed and actual finger bending angle.
  + eFe\_FeF​: Error between designed contact force and actual contact force.

**Actuator**

* **Types**: Hybrid actuator composed of a soft actuator and an SMA spring actuator.
* **Soft Actuator**: Made with an expandable air cavity layer and a non-expandable confinement layer, 3D printed for rapid prototyping.
  + **Key Parameters**:
    - Width of the air cavity (B): 16 mm
    - Height of the air cavity (H): 15 mm
    - Intermediate radius (R1): 1.2 mm
    - Radius of the air cavity (R2): 3 mm
    - Material: Dragon Skin 30
* **SMA Actuator**: Nickel-titanium alloy with defined transformation temperatures.
  + **Characteristics**: Requires water-cooling for enhanced response speed.
  + **Diameter**: 4.75 mm
  + **Number of Coils**: 20
  + **Wire Diameter**: 0.5 mm
  + **Transformation Temperatures**:
    - Ms: 12 °C
    - Mf: 24 °C
    - As: 45 °C
    - Af: 64 °C
* **Number of Actuators:** 5 soft actuators.
* **Actuator Type:** Hybrid actuators (flexion and extension).
* **Material:** Dragon Skin 30.
* **Weight of Control System:** 1312.5 g.
* **Weight of Glove:** 317.7 g.
* **Power Requirements:**
  + Air pressure of soft actuator: P=U×KPP = U \times K\_PP=U×KP​ (when U>0U > 0U>0).
  + Current for SMA spring actuator: I=U×KII = U \times K\_II=U×KI​ (when U<0U < 0U<0).
* **Max Bending Angle:** 250° under 150 kPa.

**General Limitations**

* **Soft Actuator**: Balancing output force and bending angle due to material stiffness and dimensions.
* **SMA Spring Actuator**: Response times may not meet rehabilitation speed requirements without water cooling.
* **Cooling Structure**: Residual force affects the actuator's transparency.
* **Control Issues:** The force-position hybrid model cannot control force and position accurately simultaneously; tuning parameters are required for different operating modes.

**Response Time**

* **SMA Actuator Cooling**:
  + Water-cooled actuator: Transition from martensite to austenite in 7.5 seconds.
  + Conventional actuator: Transition takes 16.95 seconds.
  + The cooling structure reduces reaction time by 55.8%.
* **System Interaction:**
  + Force and position sensors for real-time feedback.
  + Adjustable parameters for different operating modes.

**Safety**

* **Material Selection**: The choice of materials (e.g., Dragon Skin 30) is essential to ensure comfort and safety for user wearability.
* **Experimental Results**: No significant increase in water temperature during prolonged operation indicates good thermal management.
* **Emergency Power Off:** Power switch available on control box for patient safety.
* **Sensor Placement:** Force and position sensors sewn inside the glove to enhance safety and reliability.
* **Patient Comfort:** Silica gel layer inside the glove to ensure adequate friction and comfort.

**Summary of Findings (from Section IV)**

* **Scope of Motion Assessment:**
  + Significant improvement in bending angles of affected fingers when using the bidirectional glove compared to no glove assistance, exceeding basic functional motion ranges necessary for ADLs.
* **Grip Strength Assessment:**
  + Maximum grip force improved significantly with glove assistance compared to unaided conditions.

<https://ieeexplore.ieee.org/abstract/document/10175575>

**Control Algorithm:**

* The control system for the soft rehabilitation gloves (SRGs) consists of a **PID controller** to improve performance due to the nonlinearity and complexity of the soft actuators.
* The incremental PID is used to reduce the processor's calculation amount, defined as: Δu(k)=u(k)−u(k−1)=Kp[e(k)−e(k−1)]+Kie(k)+Kd[e(k)−2e(k−1)+e(k−2)]\Delta u(k) = u(k) - u(k-1) = K\_p[e(k) - e(k-1)] + K\_i e(k) + K\_d[e(k) - 2e(k-1) + e(k-2)]Δu(k)=u(k)−u(k−1)=Kp​[e(k)−e(k−1)]+Ki​e(k)+Kd​[e(k)−2e(k−1)+e(k−2)]
* The control system implements both **position control** when worn by patients and **force control** when assisting grasping actions.
* A **force/position hybrid control strategy** is also employed for muscle training at specific angles.

**Actuator:**

* The SRGs consist of:
  + **Five bending actuators** (for flexion/extension) and **four rotating actuators** (for abduction/adduction) integrated into a fabric glove.
  + **Bending actuators** are designed using a curing and molding process with silicone and utilize compressed air for operation.
  + **Rotating actuators** are similar in design and serve to adjust angles between fingers, with varying air chamber configurations based on finger movement requirements.

**General Limitations:**

* Controlling soft actuators presents challenges due to:
  + **Material nonlinearity** and **large deformation**, complicating control and response predictability.
  + The efficiency of the system can decrease at higher air pressures due to energy being consumed in lateral deformation.

**Response Time:**

* The experimental data showed that:
  + Finger angle can reach **90° within 0.5 seconds** with a deviation of ±2°.
  + The desired force of **0.5 N** was achieved within **1 second**, stabilizing with a bias of 6% after contact with an object.

**Safety:**

* The design incorporates safety considerations by:
  + Limiting the range of motion of the actuators to prevent overexertion during rehabilitation.
  + Ensuring the system can adapt the control strategy based on the rehabilitation needs and the physical response of the user.

<https://www.mdpi.com/1424-8220/22/16/6294>

**1st Approach**

**Advantages:**

* **Material Selection**: The use of soft materials like Ecoflex® and Dragon Skin® provides compliance and safety, minimizing the risk of injury during rehabilitation.
* **Simplicity**: By not detailing a specific control algorithm, this approach allows for straightforward actuator design and characterization, focusing on the mechanics of the actuators themselves.

**Constraints:**

* **Lack of Control Algorithm**: The absence of a defined control strategy limits the actuator’s versatility and responsiveness, potentially affecting performance in dynamic rehabilitation scenarios.
* **Limited Force Output**: The soft actuators' inability to generate sufficient force may restrict their effectiveness in manipulating stiffer joints, limiting their application range.
* **High Customizability Required**: The necessity for custom designs based on individual patient needs complicates the manufacturing process and could lead to higher costs and longer development times.
* **Diminishing Returns in Response Time**: The actuator's response diminishes as it approaches a steady state, which could affect performance in applications requiring precise or quick movements.

**1st Approach**

**Advantages:**

* **Material Choice:** The use of soft materials (Ecoflex® and Dragon Skin®) makes the actuators safer and more flexible, reducing the risk of injury during rehabilitation.
* **Straightforward Design:** Since there’s no specific control algorithm mentioned, the focus is purely on the actuator design, making it simpler to understand and develop.

**Constraints:**

* **No Control Strategy:** Without a defined control method, the actuators may not be as adaptable or responsive, which can limit their effectiveness in varying rehabilitation situations.
* **Limited Force Generation:** These soft actuators might not produce enough force to move stiffer joints, which can restrict their usefulness.
* **Need for Customization:** Each patient may require a different design, making manufacturing more complicated and potentially increasing costs and time.
* **Decreasing Response Over Time:** The actuator may slow down as it reaches its limit, which could be an issue for tasks needing quick and precise movements.

**2nd Approach**

**Advantages:**

* **Hybrid Control Algorithm**: The use of a PID control algorithm allows for improved accuracy in controlling both position and force, which is beneficial for rehabilitation tasks requiring precision.
* **Rapid Prototyping**: The 3D printing of the soft actuator allows for faster iteration and customization, facilitating more responsive design changes.
* **Improved Response Time with Cooling**: The incorporation of water cooling enhances the SMA actuator's response speed, significantly improving the system's overall efficiency.
* **Safety Features**: The inclusion of emergency power off and careful sensor placement enhances patient safety during operation.

**Constraints:**

* **Complex Control Issues**: The hybrid model can lead to difficulties in accurately controlling both force and position simultaneously, requiring careful tuning for different operating modes.
* **Cooling Dependency**: The need for water cooling for optimal SMA performance may limit portability and introduce additional complexity in the design.
* **Material Stiffness Constraints**: Balancing the soft actuator's output force and bending angle with material stiffness and dimensions may complicate the design process.
* **Weight Considerations**: The weight of the control system and glove may affect user comfort and mobility.

**2nd Approach**

**Advantages:**

* **Precise Control:** Using a PID control algorithm improves the ability to accurately manage both the position and force of the actuators, which is important for rehabilitation exercises.
* **Fast Prototyping:** 3D printing allows for quick changes in design, making it easier to adjust the actuator as needed.
* **Faster Response with Cooling:** Adding a water cooling system helps the actuators respond more quickly, making them more efficient.
* **Enhanced Safety Features:** Features like an emergency power switch and well-placed sensors help ensure patient safety during use.

**Constraints:**

* **Complex Control Management:** The combined control system can be challenging to fine-tune for both force and position at the same time, requiring careful adjustments.
* **Cooling Requirements:** The need for water cooling can make the design more complex and less portable.
* **Material Limitations:** Designing the actuator to balance flexibility and strength can be tricky, as different materials have different properties.
* **Weight Impact:** The overall weight of the glove and control system may affect how comfortable it is for users to wear.

**3rd Approach**

**Advantages:**

* **Incremental PID Control**: This method reduces computational load while effectively handling the nonlinearity of soft actuators, improving performance during dynamic rehabilitation tasks.
* **Hybrid Control Strategy**: The ability to switch between force and position control allows for versatile applications, such as muscle training and grasping assistance.
* **Quick Response Time**: The experimental results show rapid achievement of desired finger angles and forces, which is critical for effective rehabilitation.

**Constraints:**

* **Challenges in Control**: The nonlinearity and large deformation characteristics of soft actuators can make control unpredictable and complicate response accuracy.
* **Energy Consumption Issues**: Higher air pressures may lead to decreased efficiency due to lateral deformation, which can affect overall performance.
* **Complex System Design**: The integration of multiple actuators with different functions may complicate the design and implementation process, potentially leading to increased development time and costs

**3rd Approach**

**Advantages:**

* **Efficient PID Control:** This method reduces the processing load while effectively managing the complexities of soft actuators, which helps performance during rehabilitation.
* **Versatile Control Options:** The ability to switch between controlling force and position allows for a variety of uses, such as training muscles and assisting with grasping.
* **Fast Response Times:** The actuators can quickly achieve the desired movements and forces, which is essential for effective rehabilitation.

**Constraints:**

* **Control Challenges:** The flexible nature of the actuators can make it hard to predict their behavior, complicating control accuracy.
* **Energy Use Issues:** Operating at higher air pressures might reduce efficiency because of unintended lateral movements, affecting overall performance.
* **Complex Design:** Integrating various actuators with different roles can complicate the overall design and implementation, potentially leading to longer development times and higher costs.