DESIGN AND DEVELOPMENT OF SPINAL POSTURE CORRECTOR USING MCKIBBEN ARTIFICIAL MUSCLES

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Abstract: With the rise of sedentary lifestyles, millions of people suffer from poor posture, particularly due to long hours spent sitting at desks. This poor posture, often referred to as kyphosis, is commonly characterized by slouching and an increased curvature of the upper spine, leading to discomfort and, in severe cases, long-term spinal damage. In this project, we present a novel back posture corrector that uses two air-controlled pneumatic artificial muscles to automatically adjust the user's posture. The device is designed to gently pull the shoulders into an optimal position by applying a controlled force through pneumatic actuators. These artificial muscles are powered by air pressure, which allows for smooth and adjustable adjustments to the back posture. The system is integrated with a lightweight frame, padded shoulder harness, and a controller unit that ensures accurate adjustment based on timer code. When the user's shoulders begin to slouch, the air pressure in the muscles is adjusted to pull them into the correct alignment, helping prevent further spinal misalignment and promoting good posture. The device offers a non-invasive and flexible solution for individuals suffering from poor posture, with the potential to improve spinal health and reduce the need for corrective surgeries in the future.
Keywords: Posture corrector, Control, McKibben muscles, Pneumatic, Wearable active device.

1. Introduction

Poor posture is a common issue in modern society, often leading to musculoskeletal discomfort, chronic pain, and spinal misalignment. Prolonged sitting, improper posture habits, and lack of corrective feedback exacerbate these conditions. Conventional posture correction devices, such as rigid braces, tend to be uncomfortable and limit mobility.

There is a need for an adaptable, dynamic solution that can provide real-time posture correction without restricting natural movement.

Postural misalignment has become a widespread issue due to lifestyle changes driven by technological advancements and modern work habits. Prolonged periods of sitting, often with improper spinal positioning, contribute to musculoskeletal disorders such as kyphosis, lordosis, and scoliosis. Research by the Centers for Disease Control and Prevention (CDC) shows that one in four Americans spend more than eight hours sitting [1]. These issues, if left untreated, can lead in the long term to reduced mobility, chronic pain or other complications. Traditional solutions, such as posture braces and ergonomic furniture, offer passive correction but fail to provide adaptive, personalized intervention.

Moreover, individuals with poor posture often lack the awareness needed to self-correct throughout the day. While some wearable posture correction devices exist, many rely on vibratory feedback, which may not be sufficient for lasting behavioral change. The introduction of an active, pneumatic-assisted system presents a promising alternative for improving postural health dynamically and comfortably.

A pneumatic-based system offers distinct advantages over conventional correction devices. Artificial muscles, driven by air pressure, provide a lightweight, flexible, and adjustable means of support that does not restrict movement. Unlike rigid exoskeletal designs, which can be uncomfortable and cumbersome, pneumatic actuators allow a more natural correction process. By using controlled inflation and deflation cycles, the system applies gentle but firm guidance to realign the user's posture without causing discomfort. The integration of a gyroscopic sensor enhances the device's effectiveness by allowing real-time posture monitoring.

The proposed pneumatic back correction device is designed for individuals suffering from poor posture, particularly those who spend extended hours in sedentary activities such as office work or studying. The choice of pneumatic actuation over traditional motors and rigid structures ensures higher flexibility and adaptability. This method provides a more organic feel, mimicking natural muscle movement while reducing the risk of strain or discomfort associated with mechanical solutions.

To enhance user comfort and effectiveness, the device is designed with a padded harness that distributes pressure evenly across the back and shoulders. The system prioritizes wearability, ensuring that users can wear it for extended periods without discomfort.

2. Design of Posture Corrector

2.1. State of the Art Design

The posture corrector is developed as a cost-effective solution to improve spinal alignment using artificial muscles. Existing solutions in the field employ various approaches, including water-driven McKibben actuators, motor-driven exoskeletons, and sensor-based feedback systems.

A number of research articles analyzing this area of wearable devices have been identified in the literature, they fint reviewed on shield below. Also, review articles analyzing wearable devices for spinal column correction have been identified such as the article by Lauren Simpson et al. [2].

A notable example is presented in [3], where the authors have developed an active spinal column correction device actuated by pressurized water to generate forces for spine realignment using artificial McKibben muscles. This system demonstrates effective correction capabilities but requires a bulky water pump and tubing system, which may not be practical for continuous use. Additionally, the response time of water-driven actuators is slower compared to pneumatic systems, limiting their real-time adaptability [3].

Another approach involves motor-driven corrective devices, such as Kevlar cable-based actuators powered by DC motors, which apply mechanical force to pull the shoulders back. While these devices provide strong correction forces, they tend to be heavier, less flexible, and may cause discomfort over extended periods [4].

The device consists of two pneumatic artificial muscles mounted on a padded harness, extending from the shoulders to the center of the spinal cord. These muscles contract and relax based on input from a gyroscopic sensor (GY-521) placed on the shoulder, which detects deviations from an optimal posture. An Arduino Uno microcontroller processes the sensor data and actuates the muscles using an air pump, electrovalve, and TIP121 transistors. The system can operate in two modes: a timer-based mode for periodic posture correction and an automatic mode triggered by sensor readings.

Pneumatic actuators function by utilizing compressed air to produce movement in a controlled manner. In the proposed system, artificial muscles contract when air is pumped into them, generating a pulling force that gently corrects posture. When the air is released, the muscles relax, allowing natural movement without restriction. The response time and pressure levels are carefully calibrated to ensure gradual correction rather than abrupt force application, making the system both effective and comfortable for the user.

2.2. Artificial Muscle Construction

The artificial muscles in our system are composed of two McKibben-type pneumatic muscles like shown in Figure 1, selected for their high contraction force and flexibility. These muscles consist of a rubber inner tube enclosed in a braided sheath that contracts when pressurized, mimicking natural muscle function [5]. A solid hose is used to connect the muscles to the air pump, ensuring consistent pressure distribution. These muscles are then securely attached to the corset using high-strength textile bands sewn into the structure, providing stability while allowing flexibility for daily use.

Fig. 1. McKibben-type pneumatic muscles.

The inflation and deflation cycles of the muscles are controlled via electrovalves, allowing precise regulation of contraction force. The positioning of the muscles on the corset has been optimized based on anatomical research, ensuring maximum efficiency in correcting forward-leaning postures.

To model the behavior of the McKibben artificial muscles, we use the fundamental force equation (1):

$$F = P\pi r_0^2(a(1-\epsilon)^2 - b) \tag{1}$$

where:

- F is the contraction force,
- P is the internal air pressure,
- r_0 is the initial muscle radius,
- ϵ is the contraction ratio,
- a and b are experimentally determined coefficients.

This equation highlights the nonlinear nature of the McKibben muscle, where the force decreases as contraction progresses [5]. The initial braid angle and material properties play a significant role in determining the efficiency of the contraction. These properties allow our posture corrector to exert controlled and smooth corrective forces without causing discomfort. McKibben-type artificial muscles are part of the field of soft robotics, where there are a plethora of applications in the field of medical recovery [6], [7] or neuro-fuzzy control methods [8].

3. Assembly and Control System Development

3.1. Gyroscopic Sensors and Control Mechanism

The posture corrector incorporates gyroscopic sensors (GY-521) to monitor spinal alignment. These sensors detect deviations from the predefined posture threshold and relay data to the Arduino Uno microcontroller. This sensor detects deviations from an ideal spinal alignment and triggers corrective actuation accordingly [9]. The adaptability of this approach ensures that users receive immediate and proportional assistance based on their specific posture deviations, making it a viable tool for both corrective and preventive applications. The microcontroller processes the data and activates the air pump and electrovalves accordingly to inflate the artificial muscles and apply corrective force.
To enhance system reliability, the electronic components are powered by a 12V DC power source, converted from a standard 220V AC supply using a transformer. A start/stop button is included for manual operation, ensuring user control over activation when necessary.

3.2. Circuit and Pneumatic System

The pneumatic system consists of:

- **Air Pump (12V DC)** shown in Figure 2 – Supplies pressurized air to inflate the artificial muscles. The compact and portable pump features two airways: one designated for air intake and the other for output. It operates using a 12V motor with a specific current rating, which converts rotational motion into an airflow mechanism. This process ensures the maintenance of an approximate pressure of 3 bar.

Fig. 2. Air Pump (12V DC).

- **Electrovalve (12V ND - Normally Open)** – Controls airflow out of the artificial muscles. The electrovalve incorporates a plastic seal designed to provide sufficient resistance to withstand a pressure of 3 bar. It operates at a voltage of 12V and is actuated via a transistor, ensuring efficient and precise control of its function.
- **Flexible Tubing** – Connects the air pump to the artificial muscles.
- **Pressure-Regulating Fittings** – Ensures uniform air distribution across the muscles.

A schematic diagram of the electrical system, shown in Figure 3, illustrates the interconnection of these components. The electrovalves are controlled using NPN TIP121 transistors, allowing the microcontroller to switch airflow on and off effectively.

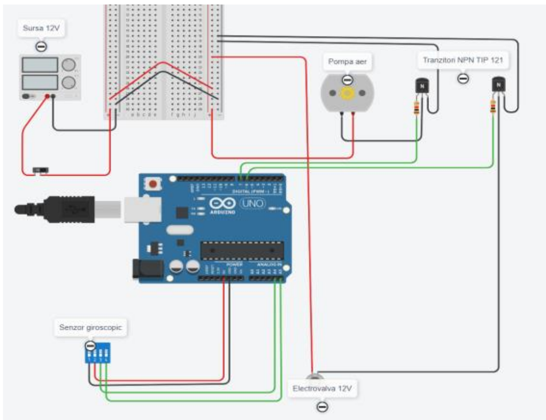

Fig. 3. Schematic diagram.

3.3. Control Logic and Operation

The system follows a simple yet effective control loop shown like below in Figure 4:

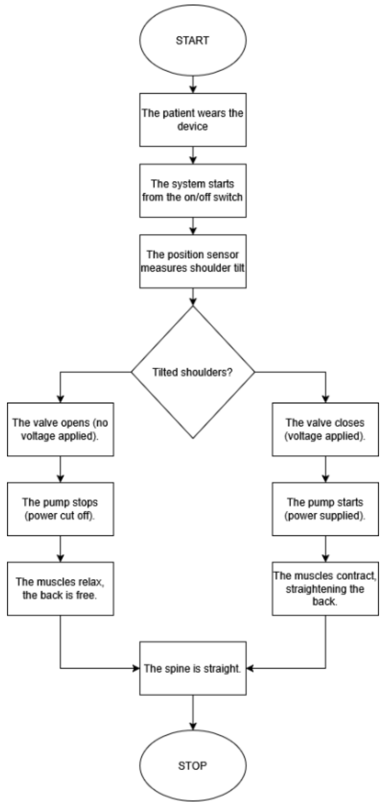

Fig. 4. Logic scheme of decision.

1. The gyroscopic sensors continuously monitor the user's posture.
2. If an excessive forward-leaning angle is detected beyond the preset threshold, the microcontroller

triggers the air pump and closes the electrovalves to inflate the muscles.
3. The muscles contract, pulling the shoulders back into an upright position.
4. Once proper posture is achieved, the electrovalves open, releasing the air and resetting the muscles.
5. The cycle repeats as needed, ensuring real-time correction.

The system is designed with future improvements in mind, including wireless data transmission to reduce the number of wires around the corset and battery operation for enhanced portability. The integration of additional sensors will further refine accuracy and responsiveness.

By implementing this assembly and control system, we provide an efficient, low-cost, and comfortable posture corrector that actively assists users in maintaining a healthy spinal alignment throughout daily activities.

4. Results and Discussion

4.1. System Performance and Testing

The developed posture corrector, shown in Figure 5, was tested under various conditions to evaluate its effectiveness in correcting spinal misalignment.

A series of trials were conducted with different healthy users to measure muscle contraction efficiency, response time, and comfort level. The gyroscopic sensors provided accurate posture deviation readings, triggering the artificial muscles effectively when necessary.

The air-driven system demonstrated a smooth and controlled correction mechanism. The muscles contracted efficiently, applying the necessary force to realign the user's posture without causing discomfort. The correction time varied between 2 to 4 seconds depending on the severity of misalignment, ensuring a prompt response to improper posture. The correction device with the two artificial muscles is shown in Figure 5.

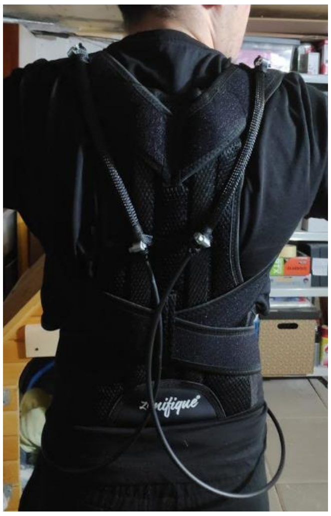

Fig. 5. Developed system for posture correction.

4.2. Pressure and Force Analysis

During testing, the air pressure within the artificial muscles was monitored to assess the force exerted on the user's back. The pressure ranged between 50 and 120 kPa, generating sufficient force to maintain correct spinal alignment. The readings indicated a stable operation, with pressure levels adjusting dynamically based on posture deviations detected by the sensor.

4.3. User Feedback and Comfort

Participants reported improved posture awareness and comfort during prolonged use. The textile corset provided adequate support without restricting movement, and the adjustable straps allowed for a customized fit. Users also appreciated the automatic nature of the system, reducing the need for constant manual adjustments [10], [11].

Minor adjustments were suggested to enhance user experience, including the implementation of a quieter pump and a more compact power source. These improvements will be considered in future iterations of the device.

5. Conclusion

The development of the air-driven posture corrector has successfully demonstrated an effective and affordable solution for improving spinal alignment. Through testing, the system has proven to be efficient in detecting and correcting improper posture using artificial muscles and gyroscopic sensors. The controlled inflation and deflation mechanism ensures a smooth and comfortable correction process, making it suitable for daily use.

User feedback highlights the comfort and practicality of the device, while minor improvements, such as noise reduction and battery operation, are planned for future iterations. Overall, the project presents a significant advancement in wearable posture correction technology, offering an accessible and innovative solution to posture-related health concerns. Future improvements include optimizing the artificial muscle response time, integrating machine learning algorithms for personalized correction patterns, and exploring wireless connectivity for data logging and real-time monitoring. Additionally, miniaturizing the power supply and components would enhance portability and usability. Clinical trials are necessary to validate the long-term effectiveness of the device in posture correction and rehabilitation.

6. References

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