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Conceptual Design and Simulation of a Smart Posture Corrective Orthosis for Kyphotic Patients

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*Abstract***—** This project aims to design an innovative smart posture corrective orthosis that monitors, mitigates, and corrects the kyphotic spine. Kyphosis is a spine deformity of an abnormal excessive outward curve of the thoracic and sacral regions due to congenital disabilities, Scheuermann's disease, poor posture, or spine malformation overtime. Some moderate kyphosis cases continue to get more severe without being monitored continuously, causing back pain, spine stiffness, and muscle atrophy. The proposed system uses inertial measurement units for posture monitoring along with a designed electrical stimulation unit that is all embedded in a semirigid spinal orthosis. The results of the system simulation on LabVIEW software and NI Multisim software are presented in this paper. This system attains the need for accurate continuous telemonitoring and prevents deformity progression via a three-point pressure design that embeds electrical stimulators (ES) for muscle weakness and pain management.

*Keywords***— Kyphosis, electrical stimulation, corrective orthosis, garment, posture, monitoring.**

I. Introduction

Kyphosis is a spine deformity that increases the curvature in the cervical, thoracic, or sacral regions. A healthy cervical spine sustains the cervical lordosis within the normal range. Each person has some degree of curvature in their spine. However, a curve that exceeds 45° is considered excessive and the back appears more rounded. Maintaining cervical lordosis within the normal range is considered a clinical goal for chiropractic treatment, [1], [2], [3]. Kyphosis may occur due to malformation of the spine, neuromuscular disorders, degenerative disease, and systemic arthritis. These reasons affect muscle activity and muscle stiffness resulted in postural dysfunction. Gradually, the spine will suffer from degeneration of vertebrae and ligaments hardening [1]. There are several types of kyphosis; however, the three primary types are postural, Scheuermann's, and congenital kyphosis. This paper concerns Postural kyphosis due to its popularity. It is caused mainly by poor posture and muscle weakness that is associated with pain and fatigue symptoms.

Kyphosis ideal treatment is still a challenge, and the best possible treatment is yet to be found. Even though it is mainly a postural deformity, it has associated severe complications, including physical impairment, respiratory problems, back muscle weakness, and back pain [4].

To manage and treat kyphosis, the type, patient's age, and spine flexibility are all taken into consideration. Surgical treatment is usually recommended for severe cases, while mild and moderate postural kyphosis can be managed non-surgically [5], [6]. There are many effective non-surgical methods such as postural continuous monitoring, physical therapy (traditional and electrotherapy), anti-inflammatory medications, and bracing [7], [8], [9], [10].

Continuous monitoring of posture curvature indicates the progression of postural kyphosis, which improves the disease management and treatment plan. The use of electrical energy in the medical treatment of muscle is a particular type of physical therapy. This method targets stiff and weak muscles to reduce muscle spasms and atrophy. Research papers introduced many electrotherapy modalities including transcutaneous electrical nerve stimulation (TENS), electrical muscle stimulation (EMS), interferential current (IFC), and galvanic stimulation (GS). These techniques have been successfully applied in managing neck and back pain, and back muscle strengthening and pain management, [11]. The effectiveness of physical therapy has been clarified to improve muscle strength using different signal waveforms, frequencies, durations, and intensities. However, it requires regular clinic visits and long treatment plans. Moreover, it is limited by the patient's commitment and physical ability to regularly perform home-based exercises. Another practical treatment is bracing, which is one of the most popular in-home-based treatment options for kyphosis. As it alleviates the pain and significantly improves the curvature angle [4]. There are many types of orthosis, such as Milwaukee, Boston, and thoracolumbosacral (TLSO) orthosis. TLSO orthosis restricts the spinal flexion through a three-point pressure system by applying two posteriorly directed pressure, and one equal pressure directed in the opposite direction. Despite TLSO orthosis effectiveness, it significantly restricts the patient's motion and reduces patient compliance [12]. Although rigid orthoses provide a high degree of immobilization and motion control, they have several limitations such as discomfort, muscle atrophy with prolonged use, poor physical activity, and muscle pain [13]. Researchers started developing new flexible corrective orthosis as an alternative which was proven to be effective and have much fewer side effects [14]. Semirigid spinal orthosis is a type of orthoses made of both flexible and rigid stays. It provides postural correction using posterior metal supports integrated into the flexible orthosis [15].

Limited research has been done in the development of wearable electrotherapy devices that target kyphotic patients. In this project, an innovative device that aids in spine correction and reduces the kyphotic curve progression is designed. This can be achieved by designing a three-point pressure orthosis that embeds electrical stimulators along with a smart monitoring system. This provides a new approach for kyphotic management that combines the intensive rehabilitation program with orthotic and posture management which is a time saving painless method.

II. Materials and methods

The proposed design integrates spine correction, pain-relieving, and posture monitoring features into a three-point pressure orthosis as shown in Figure 1.

Fig. 1 The designed orthosis, (red: inertial sensors, dark gray: Electrodes)

The orthosis will be made of a synthetic rubber and a thermoplastic material, designed with an adjustable waistband, to ensure the end-user comfortability and ease of movement. The electrical stimulator electrodes are embedded in the orthosis to deliver current pulses to the targeted muscles. long with the mechanical pressure of the semi-rigid orthosis, it aids in posture correction. Two pairs of the electrical stimulator electrodes are placed on the pectoralis major muscle to release stiffness and pain, and another two pairs are placed on the middle and lower trapezius muscle to rebuild and restore muscle strength. All electrodes are placed parallel to the muscle's fibers with enough spacing in between to let the current pass through the desired muscles [16]. Additionally, two inertial sensors are placed on C5 and T7 vertebrates to continuously monitor the thoracic and cervical posture and provide feedback if any wrong posture is detected. The system is designed to be controlled by an ESP-32 (Espressif Systems, China) controller and connected wirelessly to a smartphone application as shown in Figure 2.

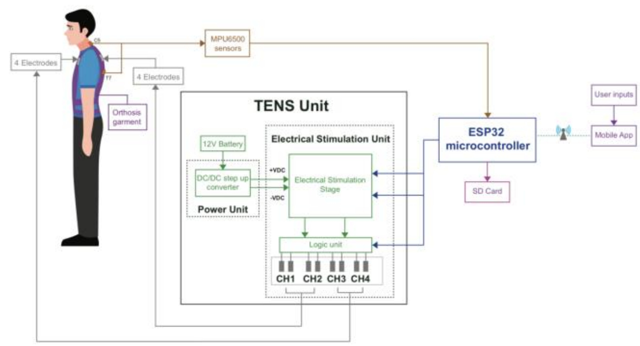

Fig. 2 Block diagram of the system.

A. System simulation

The whole system was simulated using *LabVIEW* software. It is divided into posture monitoring and electrical stimulation. The posture monitoring part depicted in Figure 3 consists of two MPU6500 (TDK InvenSense, US) sensors to detect spinal angle changes. The readings from the sensors are filtered by a complementary filter to get accurate, fast, and reliable angle measurements. Moreover, if the measured filtered angle exceeds the allowed range above the patient's reference angle, the patient will be notified to adjust his posture. The posture references are patient-dependent values that are measured by the MPU6500 (TDK InvenSense, US) sensors at the beginning of each wear of the orthosis while the posture is maintained at the most upright posture that the patient can achieve.

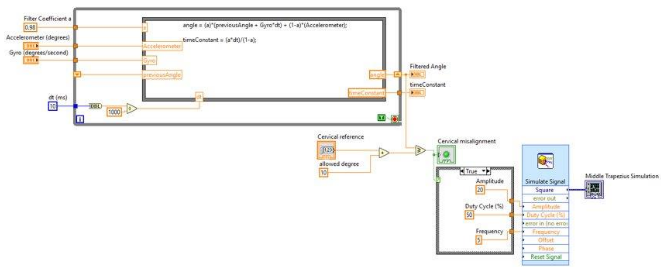

Fig. 3 Posture monitoring system simulation

For the electrical stimulator shown in Figure 4, a 4-channels square signal generator was used to stimulate the affected muscles. With the ability to alter the sessions effect and intensity by controlling the amplitude, pulse width, and frequency.

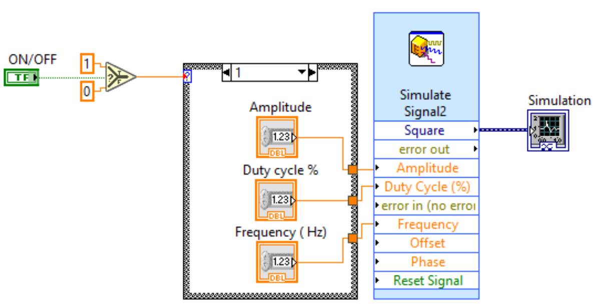

Fig. 4 Electrical stimulation system simulation.

B. Simulation of Electrical stimulation circuit

The electrical stimulation design consists of a power unit, an electrical stimulation unit, and a logic unit as shown in Figure 2. The power unit is a DC/DC step-up converter that converts a 12 V battery into a 60 V which supplies the stimulation unit shown in Figure 5. The stimulation unit includes three stages: voltage-current converter, complementary current source, and H-bridge. The original design was made by Wang et al. [17]. An additional modification was made to adjust the parameters and achieve the desired effect for the kyphotic patients by relaxing and training the affected muscles. Moreover, the unit will be controlled through a smartphone application. The design simulation was done using *NI Multisim* software.

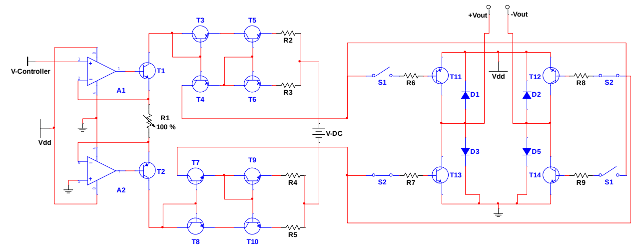

Fig. 5 Electrical stimulation unit design.

The first stage is the voltage-current converter, it consists of two operational transconductance amplifier (OTA) that converts the voltage input coming from the controller into a current. Next, the complementary current stage involves two improved Wilson current mirror circuits to overcome the circuit load by duplicating the input current and producing it as an output with a constant value in an opposite direction. The output then is sent to the H-bridge stage to convert the monophasic currents pulses coming from the previous stage into a biphasic current signal that represents the output signal to the muscles.

After generating the pulse signal, the logic unit delivers the signal to the desired channels. The unit is designed using two parallel demultiplexers controlled by the ESP32 (Espressif Systems, China).

III. Results and Discussion

A. System simulation

The system was simulated using *LabView* with an allowed cervical bending range of 10°, and an allowed thoracic bending range of 10°. The allowed bending range is changeable, either the patient or the physician can specify the value needed. As shown in Figure 6, the system's front panel consists of posture monitoring continuous readings, patient's cervical and thoracic references, muscles stimulation settings, and muscles stimulation waveform graphs.

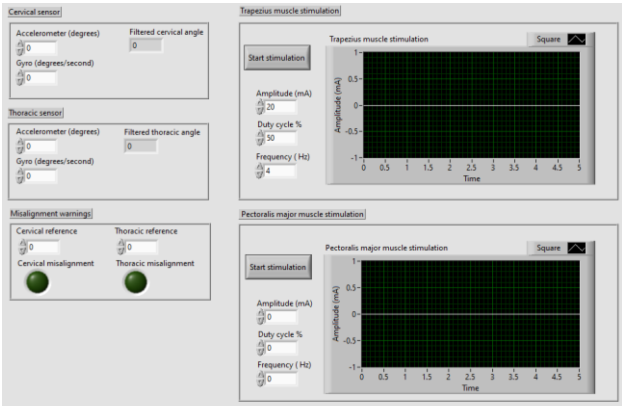

Fig. 6 front panel of the system simulation.

Presumptive accelerometer readings, gyroscope readings, cervical reference, and thoracic reference were used for testing as shown in Figure 7. The MPU6500 (TDK InvenSense, US) measurements can range from 0° to 360°. In the application of posture monitoring the angles used are restricted by the maximum neck and trunk ranges of motion. In Figure 7, the measured filtered cervical angle has exceeded the allowed cervical bending range above the reference reading which turns on the cervical LED that represents the notification that would be sent to the patient's smartphone through a programmed application to adjust his/her posture. Another set of presumptive accelerometer and gyroscope readings were fed to the system to test the thoracic monitoring system using the same method.

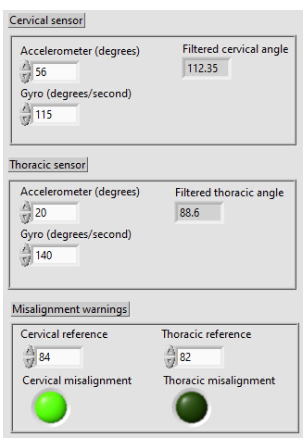

Fig. 7 Cervical monitoring alarm testing.

The user-controlled electrical stimulation sessions were simulated and tested using different input amplitude, duty cycle, and frequency as shown in Figure 8. The generated electrical signals are square biphasic current pulses with the settings specified by the user. These settings are decided based on the patient's case, the targeted muscle, and the needed effect.

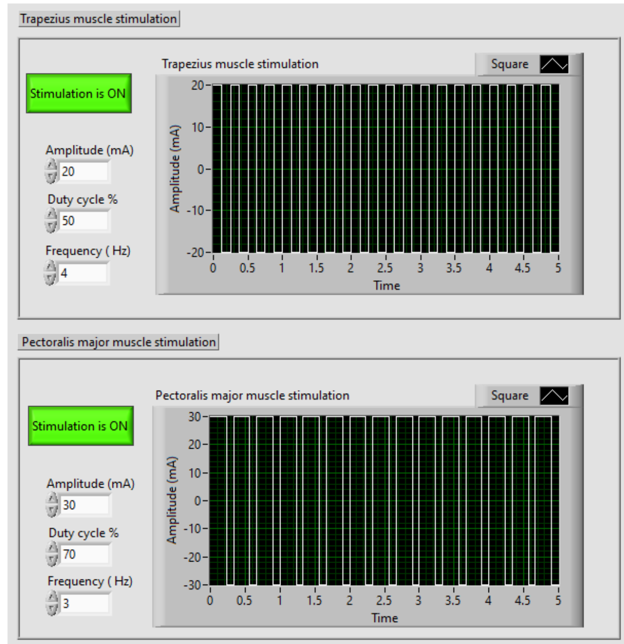

Fig. 8 User-controlled electrical stimulation testing.

B. Electrical stimulation circuit simulation

A symmetric biphasic square wave with an amplitude reaching 120 mA, frequency of 35-70 Hz, and pulse duration of 50-500 µs comprises the main requirement for efficient muscle strengthening and rehabilitation [16], [18], [19], [20]. Accordingly, a simulated circuit was designed using *NI Multisim* software.

An input of a square signal of frequency 50Hz, 50% duty cycle and an amplitude of 0.5 V supplied the first stage of the circuit which is the voltage-current converter.

After the voltage-current converter stage, the complementary current stage duplicated the input current and produced a constant monophasic signal with an amplitude equal to 9.312 mA.

Next, the H-bridge converted the monophasic signal to a biphasic signal, by switching S1 and S2 between 'on' and 'off' states, controlled by the ESP32 controller. An output of 1.9 mA was measured from peak to peak as a result of turning S1 switch off and S2 switch on. This output is relatively low due to the low input voltage from the controller. To get a higher output current, the input voltage needs to be increased.

IV. Conclusion

Although postural kyphosis is a mild thoracic defect, it causes serious impacts that affect several life aspects. Non-surgical treatments like physical therapy and bracing can improve the kyphosis curvature but they have unpleasant effects. The proposed design overcomes the limitations of the existing techniques to provide a more effective and practical solution. The whole device system was simulated successfully using *LabView* software, and the electrical stimulation circuit was designed using *NI Multisim* software. The simulation results provide a good base for future hardware implementation. The project is underdevelopment to innovate a wearable, conductive, non-invasive device that reduces pain with minimum side effects. The device stimulates and strengthens the affected muscle, provides mechanical support for improved spine stability, and enhances the patient's posture habits to reduce all kyphosis complications. Future considerations include orthosis fabrication, hardware implementation, smartphone application development, verification, validation, and clinical trials.

V. References

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