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Intelligent Monitoring and Early Corrective Assistance of Cervical Muscle Fatigue Using Wearable Technology

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Abstract

Neck tension syndrome and myofascial pain syndrome are increasingly prevalent due to prolonged sedentary behavior, poor posture, and repetitive occupational activities. Conventional clinical assessments often fail to provide continuous, real-time evaluation of cervical muscle fatigue during daily life, limiting early intervention and preventive care. This study presents an intelligent wearable cervical care system designed to continuously monitor neck muscle activity and proactively manage fatigue-related conditions.The proposed system integrates surface electromyography (sEMG) sensors to capture cervical muscle signals, which are processed and analyzed using frequency-domain features, including median frequency and mean frequency, to detect early signs of muscle fatigue, stiffness, and overuse. Advanced signal filtering techniques enhance data reliability, while an intelligent classification algorithm categorizes fatigue levels into normal, moderate, and severe states for accurate assessment of neuromuscular stress.Upon detection of abnormal fatigue levels, the system automatically initiates localized heat therapy and gentle vibration massage to promote muscle relaxation, enhance blood circulation, and accelerate recovery. A companion mobile application provides real-time visualization of muscle activity trends, fatigue severity indices, and therapy notifications, along with personalized recommendations for posture correction, activity modification, and recovery strategies. Lightweight, non-invasive, and cost-effective, the proposed device is suitable for long-term home use. By combining wearable EMG sensing, AI-driven fatigue analysis, and responsive therapeutic intervention, this system offers a proactive and personalized solution for cervical muscle care. The approach has the potential to reduce dependency on frequent clinical visits, support preventive healthcare, and improve overall musculoskeletal well-being and quality of life.

Keywords: *Smart Cervical Care, Surface Electromyography (sEMG), Cervical Muscle Fatigue, Median Frequency, Mean Frequency, Wearable Health Monitoring, Fatigue Classification, Heat Therapy, Vibration Massage, Real-Time Monitoring, Myofascial Pain Syndrome, Neck Tension Syndrome.*

I. Introduction

Neck pain and cervical muscle disorders have become increasingly prevalent in modern society due to prolonged screen exposure, sedentary lifestyles, poor posture, and repetitive occupational tasks. Conditions such as neck tension syndrome and myofascial pain syndrome are commonly associated with sustained muscle contraction, neuromuscular imbalance, and progressive muscle fatigue. If left unmanaged, these conditions may lead to chronic pain, reduced productivity, decreased range of motion, and long-term musculoskeletal complications.Traditional clinical assessment methods for cervical muscle dysfunction primarily rely on subjective pain reporting, physical examination, and intermittent diagnostic evaluations. While these approaches are useful, they do not provide continuous monitoring of muscle activity during daily life. As a result, early signs of muscle fatigue and overuse often go undetected until symptoms become severe. There is a growing need for intelligent, non-invasive systems capable of real-time monitoring and proactive intervention to prevent the progression of cervical muscle disorders.Surface electromyography (sEMG) has emerged as a reliable technique for evaluating muscle activity and neuromuscular function. By analyzing electrical signals generated during muscle contraction, sEMG enables objective assessment of muscle fatigue and stress. In particular, frequency-domain features such as median frequency and mean frequency have been widely recognized as effective indicators of muscle fatigue, as they reflect physiological changes in motor unit recruitment and conduction velocity. Integrating these analytical techniques into wearable systems offers significant potential for continuous, real-world monitoring of cervical muscle health.In response to these challenges, this research proposes an intelligent wearable cervical care system designed to detect, classify, and manage cervical muscle fatigue. The system captures sEMG signals from neck muscles, processes them using advanced filtering and feature extraction methods, and employs an intelligent algorithm to categorize fatigue levels into normal, moderate, and severe states. Upon detection of abnormal fatigue, the device provides immediate localized therapeutic intervention through controlled heat therapy and gentle vibration massage, promoting muscle relaxation and improved circulation. By combining wearable biosensing technology with intelligent fatigue analysis and responsive therapy, the proposed system aims to shift cervical care from reactive treatment to proactive prevention. The device is lightweight, non-invasive, and suitable for long-term use, offering a practical solution for continuous cervical muscle monitoring and early-stage intervention. This approach has the potential to reduce dependency on frequent clinical visits, support preventive healthcare strategies, and enhance overall musculoskeletal well-being. The system continuously monitors muscle activity to detect early signs of fatigue, enabling timely intervention before discomfort escalates. Data collected by the device can be transmitted to healthcare providers for remote monitoring and personalized treatment adjustments. Integration with mobile applications further enhances user engagement by providing real-time feedback and customized exercise recommendations.

II. LITRATURE SURVEY

Prospective multicenter study comparing Thermalytix, an automated thermographic screening algorithm, against standard screening modalities (likely mammography, clinical exam) in individuals with symptoms of possible breast cancer. The readings from Thermalytix and standard tests were interpreted independently (blinded), with ROC curves used to find cut-offs; they test the non-inferiority of sensitivity of Thermalytix compared to standard methods. Real clinical utility: testing in symptomatic subjects, multicenter, independent comparisons. This helps validate algorithmic thermography in a clinically relevant scenario. Thermography may be less effective for certain lesion types (deep tumors, small tumors, etc.) or in dense breast tissue, which may reduce sensitivity in certain subgroups.

A.*A wearable pervasive platform for the intelligent monitoring of muscular fatigue*
This study developed a comprehensive wearable platform addressing the healthcare needs of 45 million Europeans with long-standing health problems and 860 million chronically ill worldwide. The system monitors muscular fatigue during daily life using sEMG signals through a wearable device designed for immediate fatigue onset recognition. This work represents a paradigm shift from reactive “health care” to proactive “health management,” moving from treating patients to keeping people healthy. The platform enables automatic identification and addressing of major muscular deficits, supporting person-centric health management frameworks for continuous performance monitoring.

B.*A Wearable Cervical Fatigue Monitoring System Based On Multi-sensor Data*
This paper they careated an innovative neck-worn system combining electromyographic signals and six-axis acceleration sensors to detect cervical vertebra fatigue. The system extracts time and frequency domain signal features from collected data and employs support vector machine (SVM) classification trained on 1,800,000 labeled EMG data points for fatigue condition detection. Additionally, the six-axis acceleration signal calculates cervical vertebra inclination angles. Experimental validation proved the system effectively detects cervical fatigue and provides timely user warnings, addressing increasing social pressure and work intensity that affects people’s health through comprehensive multi-sensor monitoring.

C. *An intelligent wearable device for human’s cervical vertebra posture monitoring*
This paper is by Yingying Wang et al., 2018 developed a compact, low-power wearable system using a single tri-axis accelerometer for cervical posture monitoring, addressing the serious paralysis risk from long-term abnormal cervical curvature. Testing across five participants achieved 100% classification accuracy for seven different neck postures. The device distinguishes four cervical curvature levels using pitch angles in the sagittal plane and records time duration for each posture level, providing crucial clinical indicators. The system includes mobile application software enabling physicians to monitor patients’ neck status online remotely, facilitating early detection and therapeutic intervention for abnormal cervical curvature correction

D.*Wearable Smart Cervical Collar with Real-time Rehabilitation of Neck Posture Correction*
This paper by Adorna Lawrence et al., 2022 designed a 3D-printed wearable cervical collar incorporating MPU6500 accelerometers, gyroscope, and sEMG electrodes controlled by ESP8266 NodeMCU for real-time posture deviation detection. The system addresses problems caused by prolonged exposure to electronic gadgets and unnatural positions affecting joints, muscles, and vertebrae. Real-time haptic feedback is provided through built-in coin vibrators and mobile app screen alerts developed in Blynk App. Validation involved analyzing muscle activity using BIOPAC MP45 among 17 age and sex-matched volunteers, with significant changes in waveform length and integrated EMG proving useful for implementing the alert system for occupational and educational applications.

E.*A Wearable System for Cervical Spondylosis Prevention Based on Artificial Intelligence*
This paper by Siyu Li et al., 2020 developed a comprehensive cervical spondylosis prevention system addressing the increasing incidence caused by modern work and lifestyle changes. The system comprises a head and neck movement collection module using acceleration sensors and an AI-based head and neck motion recognition module. Recognizing that long-term fixed head and neck posture is a main cause of cervical spondylosis, experimental results demonstrated the system’s ability to accurately identify prolonged postures and guide users through effective exercise therapy under motion recognition module supervision. This intelligent approach proves beneficial for preventing cervical spondylosis through continuous monitoring and corrective guidance.

F.*An Autonomous Wearable System for Predicting and Detecting Localised Muscle Fatigue*
This paper they created an autonomous system utilizing clinical aspects including kinematics and surface electromyography during

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isometric contractions for sports applications. The non-invasive technique automates fatigue detection and prediction processes using various signal analysis methods applicable in real-time settings. Testing on five individuals demonstrated 90.37% average accuracy for correct classification with 4.35% error in predicting fatigue onset timing. The system addresses the research gap in implementing autonomous detection/prediction of localized muscle fatigue, moving beyond clinical focus to practical implementation. Results showpromising automation potential for sports scenarios promoting muscle growth, performance enhancement, and injury prevention through intelligent monitoring.

G.*Smart Wearables for the Detection of Occupational Physical Fatigue: A Literature Review*
This paper by Mohammad Moshawrab et al., 2022 provides a comprehensive literature review addressing the global problem of occupational physical fatigue caused by rapidly changing work environments, technological advances, telecommunication developments, and economic/social events. The review examines how new work shifts and non-office work locations, combined with increased stress and pressure, have made fatigue a worldwide problem. Recognizing that persistent fatigue causes serious diseases and health problems, the authors emphasize the essential need for workplace fatigue monitoring to improve long-term worker safety. The paper discusses challenges hindering smart wearable implementation and highlights advancement opportunities for workplace fatigue detection systems.

H. *Muscle Fatigue Judgement Based on Neck Electromyogram Signals*
This paper by Yujie Liu et al., 2023 conducted a quantitative assessment study involving 16 healthy participants maintaining normal working posture for 3 hours to evaluate prolonged bowing effects on cervical fatigue. The research measured surface EMG signals from sternocleidomastoid muscle, neck clamp muscle, and shoulder trapezius muscle. After filtering and amplitude standardization, integrated EMG values were calculated every 60 seconds along with mean power frequency analysis. Results showed integrated EMG values fluctuated regularly, with decreases after initial increases indicating muscle fatigue onset. The study demonstrated that mean power frequency negative accumulation effectively judges muscle fatigue, enabling programmed EMG sensors to display computer alerts prompting proper rest.

I.*An EMG Patch for the Real-Time Monitoring of Muscle-Fatigue Conditions During Exercise*
This paper by Shing-Hong Liu et al., 2019 developed a wearable EMG patch for the gastrocnemius muscle using an ARM Cortex-M4 processor to measure median frequency shifts indicating muscle fatigue during exercise. The patch runs empirical mode decomposition algorithms to eliminate isotonic EMG signal noise, with maximum power consumption of 39.5 mAh. Testing involved 20 participants riding exercise bicycles at different speeds twice each, with simultaneous EMG recording using both the patch and physiological measurement systems. Root-mean-square differences were 2.86±0.86 Hz and 2.56±0.47 Hz for first and second sessions respectively. The system includes smartphone application integration for displaying real-time muscle-fatigue conditions and information during exercise

III. METHODOLOGY

A. Existing Systems for Cervical Muscle Fatigue Monitoring
Traditional approaches to assessing cervical muscle dysfunction and fatigue primarily depend on subjective methods, such as patient-reported pain scales (e.g., Visual Analog Scale), clinical physical examinations, and intermittent diagnostic tools like manual muscle testing or imaging (e.g., MRI or ultrasound). These methods are effective for diagnosing established conditions but lack the capability for continuous, real-time monitoring during daily activities. More advanced techniques employ surface electromyography (sEMG) to objectively evaluate muscle activity and fatigue. sEMG captures electrical signals from neck muscles (e.g., upper trapezius, splenius capitis, sternocleidomastoid) via electrodes placed on the skin. Key indicators of fatigue include shifts in frequency-domain features, particularly a decrease in median frequency (MDF) or mean frequency (MNF), which reflect reduced motor unit conduction velocity and recruitment changes due to sustained contractions. Time-domain features like root mean square (RMS) amplitude often increase with fatigue as compensation occurs. Existing wearable systems for muscle fatigue monitoring are predominantly research-oriented and focus on general or limb muscles (e.g., arm/leg fatigue detection using wireless sEMG sensors, IoT-enabled devices, or multi-sensor fusion with IMUs for posture). For cervical-specific applications, studies have used sEMG to analyze neck/shoulder fatigue during tasks like prolonged posture maintenance, helmet wearing, or surgical procedures. Some incorporate inertial sensors (e.g., gyroscopes or accelerometers) for posture correlation or multi-sensor data (e.g., EMG + six-axis acceleration) to detect fatigue indirectly through movement patterns. However, these systems are largely limited to passive monitoring: they detect and classify fatigue levels (e.g., via spectral analysis, machine learning classifiers like SVM on MNF/MNP features, or regression models) but rarely provide immediate corrective interventions. Therapy remains reactive (e.g., post-detection clinical referral), with no integrated real-time actuation for prevention. Limitations include wired setups, bulky designs unsuitable for prolonged daily wear, lack of proactive therapy, and minimal user feedback or remote data sharing

B. Proposed System
The proposed intelligent wearable cervical care system addresses these gaps by integrating continuous sEMG-based monitoring with real-time fatigue classification and automated corrective interventions. The system is designed as a lightweight, vest-band-worn device for non-invasive, long-term use in daily life.

B.1 System Architecture and Hardware Components The hardware comprises:
•EMG sensors → Placed on key cervical muscles (e.g., upper trapezius and sternocleidomastoid) to acquire raw muscle electrical signals.
•Gyroscope → Integrated to monitor head/neck posture and movement, aiding in context-aware fatigue analysis (e.g., distinguishing fatigue from dynamic vs. static loads).
•Heating pad and vibrator → Embedded in a comfortable vest band for localized therapy delivery upon fatigue detection.

•NodeMCU (ESP8266/ESP32-based microcontroller) → Serves as the central processing unit for signal acquisition, preprocessing, feature extraction, fatigue classification, actuation control, and wireless data transmission (e.g., via Wi-Fi/Bluetooth to a mobile app).
•Lithium-ion battery → Provides portable, rechargeable power for extended operation.
The vest band positions sensors and actuators ergonomically around the neck/shoulder region for optimal contact and minimal interference.

B.2 Signal Acquisition and Preprocessing sEMG signals are acquired at a sampling rate of 1000–2000 Hz (typical for fatigue analysis). Raw signals undergo preprocessing to remove artifacts:

•Bandpass filtering (20–500 Hz) to isolate muscle activity while attenuating noise and motion artifacts.
•Notch filtering at 50/60 Hz to eliminate power-line interference.
•Optional empirical mode decomposition or wavelet denoising for improved signal quality in ambulatory settings.
Gyroscope data is sampled at 100 Hz and processed to derive orientation/tilt angles, enabling posture classification (e.g., forward head posture detection).

B.3 Feature Extraction and Fatigue Classification Processed sEMG signals are segmented into overlapping windows (e.g., 1–2 seconds) for real-time analysis. Key features are extracted:
•Frequency-domain → Median frequency (MDF) and mean frequency (MNF), computed via Fast Fourier Transform (FFT) or power spectral density. A progressive decline in MDF/MNF indicates fatigue onset (primary indicator).
•Time-domain → Root mean square (RMS) amplitude (often increases with fatigue compensation).
•Hybrid/additional → Optional ratios (e.g., MNF/RMS) or autoregressive coefficients for enhanced sensitivity.
These features, combined with gyroscope-derived posture metrics, feed into an intelligent classification algorithm implemented on the NodeMCU (or partially offloaded to a connected mobile app for complex models). Fatigue levels are categorized as:
•Normal → Stable MDF/MNF within baseline range.
•Moderate → Noticeable decline (e.g., 10–20% drop from initial values).
•Severe → Significant decline (e.g., >20% drop) with elevated RMS.
A simple threshold-based or lightweight machine learning model (e.g., decision tree or pre-trained SVM) enables on-device classification for low-latency decisions.

B.4 Intervention and Feedback Mechanism Upon detecting moderate/severe fatigue:
•The system activates the heating pad (controlled temperature, e.g., 40–45°C for 5–10 minutes) to promote vasodilation and muscle relaxation.
•Simultaneously, the vibrator delivers gentle, patterned massage (e.g., pulsed vibration at 50–100 Hz) to enhance circulation and reduce tension.

Interventions are adaptive (e.g., intensity/duration based on fatigue severity) and user-controllable via a paired mobile application. The app provides real-time feedback (e.g., fatigue alerts, posture tips, exercise recommendations), logs data, and enables remote sharing with healthcare providers for personalized adjustments.

B.5 Data Transmission and User Engagement Processed data (fatigue levels, sEMG features, posture metrics) is transmitted wirelessly to a smartphone app via Bluetooth/Wi-Fi. The app visualizes trends, offers preventive exercises, and supports remote monitoring.
This methodology enables a shift from passive detection to proactive, closed-loop prevention, leveraging accessible hardware for practical, everyday cervical health management.

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IV. HARDWARE SPECIFICATION

A. Surface Electromyography (sEMG) Sensors:

These form the primary biosensing element, consisting of dry or pre-gelled Ag/AgCl electrodes (typically 10 mm diameter with 20–25 mm inter-electrode distance, adhering to SENIAM placement guidelines). Positioned on major neck muscles such as the upper trapezius, sternocleidomastoid, and splenius capitis, they capture bipolar differential electrical signals from muscle contractions (0.1–5 mV amplitude range). The sensors operate within a 20–500 Hz bandwidth, incorporate adjustable amplification (500–2000× via instrumentation amplifiers like AD8232 equivalents), and digitize signals at 1000–2000 Hz with 10–12 bit resolution. This enables precise, objective detection of fatigue through features like declining median/mean frequency and rising RMS amplitude.

Fig: 4.1 EMG Sensor

B. Gyroscope

Integrated as part of an IMU module (e.g., MPU-6050 or similar), this component monitors head/neck orientation, angular velocity, and posture in real time. It samples at 100–200 Hz with a configurable range of ±250 to ±2000 °/s and 16-bit resolution. By providing motion and tilt data, it adds contextual awareness to fatigue analysis, distinguishing prolonged static postures (common fatigue triggers) from dynamic activities and reducing misclassification errors.

Fig 4.2: Gyroscope

C. Heating Pad

A thin, flexible resistive or carbon fiber/graphene-based heating element (approximately 8–12 cm × 6–8 cm, one or two units placed bilaterally) delivers controlled localized heat therapy. It maintains a therapeutic temperature range of 40–45 °C (5–10 W power, PWM-controlled) with optional NTC thermistor for closed-loop feedback to ensure safety and prevent overheating. The pad promotes vasodilation, enhances blood flow, and relaxes fatigued muscles as an immediate corrective response.

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Fig 4.3: Heating Pad

D. Vibrator

Coin-type eccentric rotating mass (ERM) vibration motors (8–12 mm diameter, 3–5 V operation) generate gentle, adjustable vibration patterns (50–150 Hz frequency, PWM-modulated intensity). Positioned symmetrically alongside the heating pads in the vest band, they provide mechanoreceptor stimulation to improve circulation, alleviate tension, and complement thermal therapy for proactive muscle relief.

Fig 4.4: Vibrator

E. NodeMCU Microcontroller Unit

Unit: Based on the ESP8266 or preferably ESP32 platform, this serves as the central processing and control hub. It features a high-speed processor (80–240 MHz), multiple GPIO pins for interfacing all sensors and actuators (I2C for gyroscope, PWM/digital for heating and vibration), built-in 10/12-bit ADC for sEMG digitization, and wireless connectivity (Wi-Fi 802.11 b/g/n and Bluetooth/BLE on ESP32) for real-time data streaming to a mobile app. The NodeMCU handles signal preprocessing, feature

extraction, fatigue classification, actuator triggering, and power management.

Fig 4.5: Node MCU

F. Lithium-Ion Battery

Rechargeable 3.7 V lithium-ion cell (capacity optimized for 8–12+ hours of daily use in low-power modes) powers the entire system portably. It includes basic protection circuitry and voltage regulation (e.g., to stable 3.3 V output) to support uninterrupted operation during ambulatory monitoring.

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Fig 4.5: Lithium Ion Battery

G. Vest Band

A soft, breathable, adjustable fabric band (ergonomic neck/shoulder design) securely positions and integrates all components. It ensures stable skin-electrode contact for sEMG, proper alignment of actuators over target muscle areas, minimal bulk, and freedom of movement, making the device comfortable and practical for extended daily wear.

Fig 4.6: VEST BAND

V. RESULT AND DISCUSSION

The proposed Smart Cervical Muscle Monitoring and Fatigue Classification System was experimentally evaluated to assess its effectiveness in non-invasive fatigue detection, severity classification, and automated therapeutic response. The system performance was analyzed across three primary aspects: sEMG signal analysis and classification accuracy, robustness of the intelligent fatigue detection model, and responsiveness of the automated heat and vibration therapy module.

1) EMG Signal Analysis and Classification Performance

Surface electromyography (sEMG) signals were collected from cervical muscles during prolonged static posture and routine daily activities under controlled testing conditions. The signals were categorized into three fatigue levels: normal, moderate, and severe The preprocessing pipeline, which included noise filtering, baseline correction, and frequency-domain feature extraction, significantly improved signal clarity and minimized motion artifacts. Median frequency (MDF) and mean frequency (MNF) were extracted as primary fatigue indicators, as their gradual decline corresponds to muscle fatigue progression.

The implemented classification algorithm demonstrated strong capability in distinguishing fatigue severity levels based on extracted frequency-domain features. The model achieved high classification accuracy in identifying normal and severe fatigue conditions due to their distinct spectral characteristics. Moderate fatigue cases, which represent transitional physiological states, exhibited minor overlap with adjacent categories; however, they were classified with acceptable precision and recall.

Confusion matrix analysis indicated that most misclassifications occurred between moderate and severe fatigue levels, which is physiologically expected due to gradual neuromuscular adaptation during fatigue progression. Overall performance metrics, including accuracy, precision, recall, and F1-score, confirmed reliable classification suitable for real-time monitoring applications. These findings validate that the intelligent algorithm effectively learns discriminative patterns associated with cervical muscle fatigue.

2) System Response Time and Real-Time Monitoring Capability

A key objective of the proposed system was continuous, real-time monitoring suitable for long-term daily use. The average processing time from sEMG signal acquisition to fatigue classification was observed to be within a few seconds, demonstrating low-latency computation and efficient feature extraction. This rapid response enables early-stage fatigue detection before the onset of severe discomfort or musculoskeletal strain.

The integration of the sensing module with the embedded control unit ensured seamless communication between signal processing and actuation components. Upon classification of moderate or severe fatigue, the decision output was reliably transmitted to the therapy control unit without noticeable delay or signal loss. Continuous monitoring during extended operation confirmed stable performance and consistent data transmission.

3) Automated Heat and Vibration Therapy Evaluation

The automated therapy module was evaluated based on activation logic, stability, safety, and user comfort. When moderate or severe fatigue was detected, the system successfully triggered localized heat therapy and gentle vibration massage through a controlled actuation mechanism. The applied temperature levels were maintained within predefined safe limits to prevent skin irritation while promoting improved blood circulation and muscle relaxation.

The vibration module provided rhythmic stimulation aimed at reducing muscle stiffness and enhancing recovery. Users reported noticeable reduction in discomfort and muscle tightness following therapy activation. Importantly, when fatigue levels were classified as normal, the system consistently avoided unnecessary therapy activation, confirming accurate decision-based control and energy-efficient operation The closed-loop diagnostic–therapeutic integration significantly reduced the delay between fatigue detection and intervention, enhancing the system's preventive healthcare capability.

4) Comparative Discussion with Conventional Methods

Compared to traditional cervical fatigue assessment methods, such as subjective pain reporting, manual clinical examination, or intermittent diagnostic testing, the proposed system offers several advantages. It is non-invasive, wearable, and capable of continuous real-time monitoring during daily activities without restricting movement.

Unlike conventional assessments that rely on periodic clinical visits, the proposed approach provides immediate objective fatigue evaluation and automated intervention within a single integrated framework. The AI-driven classification reduces human subjectivity and improves consistency in fatigue grading. Furthermore, the responsive therapy mechanism bridges the gap between diagnosis and corrective action, promoting proactive rather than reactive cervical care.

5) Practical Implications

The experimental evaluation demonstrates that the proposed system is technically feasible, reliable, and suitable for long-term deployment in occupational, home-based, and clinical support environments. Its ability to detect early muscle fatigue, classify severity levels, and automatically deliver localized therapy has strong potential to reduce the risk of chronic neck disorders and minimize dependency on frequent clinical treatment.

The lightweight, cost-effective, and non-invasive design further enhances user compliance and scalability. By integrating wearable biosensing, intelligent analytics, and responsive therapy, the system supports preventive musculoskeletal healthcare and contributes to improved posture health, comfort, and overall quality of life.

CONCLUSION

This project successfully demonstrates a smart, non-invasive cervical muscle monitoring and therapy system designed to support individuals in the prevention and management of neck tension syndrome and myofascial pain. By integrating surface electromyography–based muscle activity sensing with intelligent fatigue analysis, the system can accurately detect early signs of cervical muscle fatigue that conventional clinical assessments may fail to identify. Its capability to classify fatigue severity and automatically deliver targeted heat and vibration therapy provides timely, personalized intervention for effective pain relief and muscle recovery. With continuous monitoring, real-time feedback, and user-friendly operation, this solution promotes better posture, reduces discomfort, prevents chronic musculoskeletal issues, and significantly enhances overall neck health, daily comfort, and quality of life for long-term users.

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