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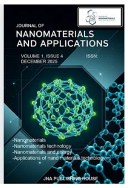

Research and development of an automated massage device to support the treatment of shoulder and neck pain in Vietnam.

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Abstract: According to traditional medicine, various non-pharmacological approaches such as acupressure, acupuncture, and physiotherapy have been employed to treat shoulder and neck pain. Massage techniques involving pressing, kneading, rubbing, and rolling on acupoints, or with specialized tools, are known to enhance blood circulation, unblock meridians, and relieve pain. In Vietnam, most automated massage devices are imported and primarily designed for large body areas, with limited devices tailored for acupoint massage of the shoulder and neck. This study presents the research, design, and development of a fully automated massage device based on a direct-drive mechanism and a control system that simulates traditional acupoint massage techniques. The prototype was tested on volunteers with different body sizes. The device achieved precise thermal stability (±0.5 °C) and significantly improved its VAS index (from 7.2 down to 3.4) after one week of testing. The system boasts a flexible architecture, allowing for the direct integration of nanosensors (Graphene/CNTs) to establish real-time force feedback loops, paving the way for next-generation smart healthcare applications.

Keywords: Automated massage; Shoulder and neck pain; Acupoints; Wearable device; IoT-enabled rehabilitation

1. Introduction

Musculoskeletal pain, or cervicobrachial syndrome, is defined as pain in the neck and shoulders with or without pain related to one or both upper limbs lasting at least one day. The causes of this syndrome are overuse ansd cervical spine degeneration (70-80%), prolonged and incorrect sitting posture, and simple disc herniation or cervical spine degeneration. In Vietnam, the rate of people suffering from

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cervicobrachial syndrome is increasing and tends to affect younger people, and this condition is also recognized as one of the most prevalent work-related musculoskeletal disorders worldwide [1-4]. In traditional medicine, there are many different non-drug methods to treat musculoskeletal pain, such as acupuncture, rehabilitation, and massage, which have a fast and safe pain-relieving effect. The application of specific techniques such as pressing, rubbing, stroking, and massaging acupoints or massage with the support of specialized tools has the effect of promoting blood circulation, clearing meridians and reducing pain and fatigue [5-8]. In recent years, numerous studies have investigated automated and wearable massage devices employing mechanical stimulation, vibration, and haptic feedback to support rehabilitation and user comfort and relaxation [9–13]. These systems have demonstrated the feasibility of replacing or assisting manual massage therapy in various application scenarios. However, most existing studies primarily focus on functional demonstration or usability evaluation, with limited emphasis on quantitative control of massage intensity, integrated thermal safety mechanisms, and system-level IoT connectivity within a wearable platform. Despite the increasing availability of commercial neck and shoulder massage devices, most existing systems primarily emphasize predefined mechanical vibration or motion patterns, with limited focus on quantitative control of massage intensity, integrated safety mechanisms, and reconfigurable system architectures. In Vietnam, most commercially available products are imported, while system-level engineering studies addressing wearable design, adaptive control, and digital connectivity remain limited. This gap motivates the development of an open and extensible wearable platform focusing on controllable, safe, and IoT-enabled massage systems. In recent years, nanomaterials have played a transformative role in the development of next-generation wearable healthcare devices [14]. Nanostructured materials such as graphene, carbon nanotubes (CNTs), and advanced carbon-based nanocomposites have demonstrated superior mechanical flexibility, electrical conductivity, and biocompatibility, making them highly suitable for integration into flexible and wearable electronic systems [15-19]. In addition, nano-engineered materials contribute to improved thermal management in wearable devices. Advanced carbon-based nanomaterials and graphene-enhanced structures can enhance heat distribution uniformity and thermal stability, which is critical for safe and effective thermotherapy applications [16]. Despite these advantages, the integration of nanomaterial-enabled sensing and thermal regulation into wearable massage systems remains limited, particularly in low-cost and domestically developed devices. This gap highlights the need for scalable system architectures that can support future incorporation of nanomaterial-based sensing, feedback control, and intelligent therapeutic functionalities. In the context of wearable massage devices, nanomaterials enable three critical advancements: (i) high-sensitivity force and pressure sensing using CNT- or graphene-based flexible sensors, allowing real-time monitoring of human–device interaction; (ii) enhanced thermal management through nano-engineered heat distribution layers, improving safety and uniformity in thermotherapy; and (iii) improved mechanical compliance and durability via nanocomposite soft materials at the skin–device interface. Despite these advances, the integration of nanomaterial-enabled sensing and actuation into wearable massage systems remains largely unexplored, particularly in low-cost and domestically manufacturable platforms. This gap motivates the development of a scalable system architecture that is compatible with future incorporation of nano-enabled sensing, feedback control, and intelligent therapeutic functions. Although the current prototype does not yet integrate nanomaterial-based components, the proposed system architecture is compatible with future integration of nano-enabled sensing and actuation modules, thereby providing a scalable platform for next-generation smart massage and rehabilitation devices [20, 21]. Based on survey information from the above studies, combined with the aim of deciphering and mastering the technology applied in shoulder and neck massage devices, this paper presents the research, design, and development of an automatically controlled massage device to support the treatment of shoulder and neck pain, based on the prototype of a shoulder and neck massage device researched and designed by Vina-Japan. Compared to many existing commercial neck and shoulder massage devices, which primarily emphasize predefined mechanical vibration or motion patterns, the proposed system focuses on system-level integration, controllable actuation, and practical adaptability within a domestic design and fabrication context. The main contributions of this study are significantly extended beyond conventional prototype development and can be summarized as follows: (i) a quantitative actuation framework is developed to relate PWM control signals to mechanical massage force through a motor–force transfer model; (ii) a wearable massage system is experimentally validated on a cohort of 50 participants with cervical and shoulder pain using standardized clinical metrics; (iii) a thermal safety control mechanism with real-time monitoring is implemented to ensure stable and safe operation; (iv) an IoT-enabled architecture is integrated to enable remote monitoring, data acquisition, and future intelligent control. These contributions transform conventional massage devices from qualitative comfort tools into quantitatively controlled rehabilitation systems. These contributions represent an engineering-level system integration and validation study rather than a clinical efficacy investigation. From an interdisciplinary perspective, this study is relevant to biomedical engineering, rehabilitation equipment design, and IoT applications in healthcare. By integrating traditional acupoint-based massage principles with modern embedded control and wireless connectivity, the proposed system addresses the growing demand for non-pharmacological, home-based healthcare solutions. This integration contributes both practical value and scientific relevance by bridging traditional medicine concepts with contemporary engineering approaches. Going beyond conventional mechatronic designs, this work proposes an open system architecture, ready for the integration of next-generation nano-sensor components. The successful implementation of the IoT-integrated ESP32 control system is a strategic stepping stone, enabling the future embedding of Graphene/CNT sensors to achieve precise force feedback and optimize personalized treatment protocols.

2. Method

2.1. Acupoints in the shoulder and neck area and their effects of acupuncture therapy

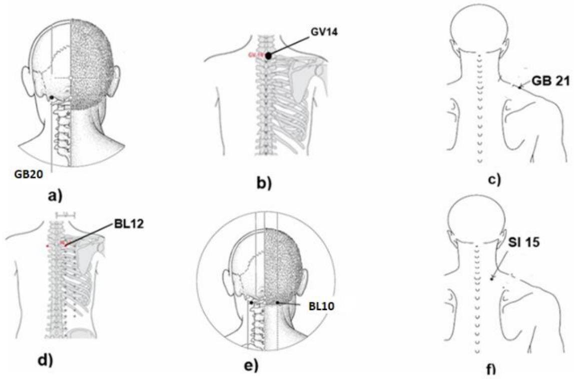

Figure 1. Location of acupuncture points in the neck and shoulder area; a) Fengchi (GB20), b) Dazhui (GV14), c) Jianjing (GB21), d) Fengmen (BL12), e) Tianzhu (BL10), and f) Jianzhongyu (SI15).

The spatial distribution and anatomical locations of the targeted acupoints are illustrated in Figure 1. As shown, the device is designed to focus on the cervical spine and trapezius muscle areas, where acupoints such as GB20 (Fengchi), GV14 (Dazhui), GB21 (Jianjing), etc. are situated. These points are clinically significant for modulating autonomic nervous system activity and improving local microcirculation, which serves as the physiological foundation for the mechanical stimulation patterns programmed into the system. From a biomedical perspective, stimulation of cervical acupoints has been shown to activate neuromuscular responses, enhance local blood circulation, and reduce muscle stiffness through modulation of cervical spinal nerves and myofascial structures [22, 23]. According to traditional medicine, each acupoint in the shoulder and neck area exhibits specific therapeutic effects. The locations and corresponding effects of acupuncture therapy at these acupoints are summarized in Table 1 [24].

Table 1. Location and effect of acupuncture therapy at acupoints in the neck and shoulder area [24]

No.	Acupuncture Point Name	Location	Effect of acupuncture therapy
01	Wind Pool (GB20)	Located on either side of the neck, in the depression between the sternocleidomastoid and trapezius muscles, at the base of the skull (as shown in Figure 1a).	It treats headaches, neck pain, dizziness, vertigo, insomnia, and high blood pressure. It is an acupuncture point connecting external pathogens to internal organs, treating ailments related to the head, neck, and nape.
02	Great Hammer (GV14)	Below the 7th cervical vertebra (C7), in the middle of the midline of the nape (as shown in Figure 1b).	Reduces fever, strengthens immunity, treats colds and flu, stiff neck, and neck pain. It is the intersection of many important meridians, closely related to the central nervous system and respiratory function.
03	Firm Well (GB21)	Located at the top of the shoulder, midway between the line connecting the 7th cervical vertebra to the outermost point of the shoulder (as shown in Figure 1c).	Relieves shoulder and neck pain, treats neck pain, headaches, hemiplegia, and helps reduce fever. Used for massage to relax the shoulder and neck area, especially in treating pain and fatigue caused by prolonged work or incorrect posture.
04	Wind Gate (BL12)	Located in the upper back, approximately 1.5 finger widths from the midline of the spine, level with the 2nd thoracic vertebra (T2) (as shown in Figure 1d).	Treats colds, fever, coughs, and neck pain. It is an acupoint that regulates qi and lungs, often combined in therapies to support the treatment of respiratory diseases and shoulder and neck pain.
05	Heavenly Pillar (BL10)	At the back of the neck, at the intersection of the ear and the spine (as shown in Figure 1e).	It is an acupoint that promotes blood circulation and reduces pain.
06	Firm Middle Journey (SI-15)	Located 2 finger widths lateral to the lower edge of the spinous process of the C7 cervical vertebra (from the most prominent point of the C7 cervical vertebra, measure 2 finger widths	Treats shoulder and neck pain, coughs, asthma, shortness of breath, and upper back pain.

		laterally to both sides) (as shown in Figure 1f).	

2.2. Overall design

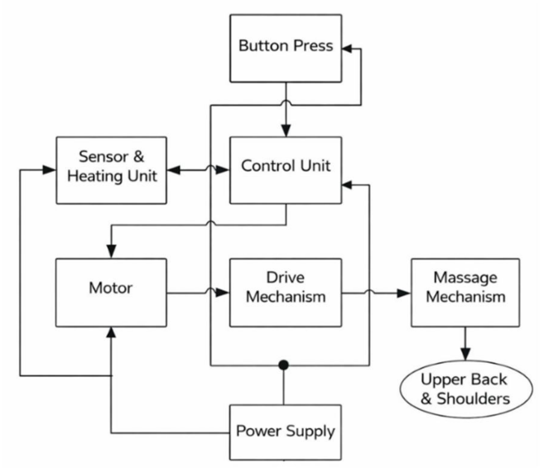

Figure 2. Overall design of the device

The proposed research and design device aims to decode, master the technology and develop a shoulder and neck massage device that is worn on the human body. The frame and mechanical structure are based on an existing commercial massage machine designed by Vina-Japan. This device is intended to serve the implementation of therapies at rehabilitation centers as well as at home. The device only requires one operator, including the patient when using it at home. The device's expected parameters/functions include: Motor rotation direction control (Motor reverse rotation): This function allows the device to simulate massage in both left and right directions. Massage intensity adjustment (Motor vibration level): Adjusted using Pulse Width Modulation (PWM) technology. Users can select multiple levels. Heat therapy function: Heat combined with vibration helps improve blood circulation, soothe pain, and promote deeper relaxation in the neck and shoulder area. Displays status on a 1.8” TFT screen (motor rotation direction, vibration level). Features automatic shut-off when the device is removed from the neck and shoulder area. Connects via WiFi and IoT. Includes an automatic shut-off mode when the temperature exceeds the set threshold. The overall design is shown in Figure 2. Similar design considerations for wearable massage systems have been reported in recent biomedical engineering studies, emphasizing portability, safety, and adaptive control strategies [12].

2.3. Brief Description of Basic Blocks

Power Supply Block: Uses a rechargeable lithium battery and a boost circuit to bring the battery voltage to a suitable level (5V or 3.3V depending on the component) to supply the blocks that require voltage for the device. Control Block: In this study, the authors used the ESP32 microcontroller module and the XY-160D motor control module. The ESP32 is a 32-bit microcontroller with integrated WiFi and Bluetooth, capable of powerful processing and supporting various communication standards such as UART, SPT, I2C, etc., making it very suitable for IoT applications [25-27]. The ESP32 sends PWM and reverse signals to the XY-160D module to control the motor. The ESP32 microcontroller controls the device's functions, including receiving signals from the button block or sensor block (temperature sensor) to determine the operating status or process user requests. To ensure scalability, the control unit is equipped with a redundant high-resolution ADC channel and a low-noise amplifier (LNA) circuit. This combination acts as a standardized hardware interface, ready to handle sensitive analog signals from nano-sensor membranes (Graphene/CNTs). Optimizing the signal-to-noise ratio (SNR) at this physical layer is a prerequisite for providing high-quality data for future machine learning and AI models. The PWM pulse signal is generated to adjust the motor's rotation speed, allowing for flexible adjustment of massage force (increase or decrease) as needed or according to operating mode; the motor's rotation direction is controlled to create a two-way (forward-reverse) massage movement. Button block: Includes several physical buttons such as the power on/off button; motor rotation reversal; vibration level adjustment (massage intensity); and heating function on/off. Sensor and heating block: Monitors the temperature of the contact area or the surface temperature of the heating element. This temperature can be used in thermotherapy mode (hot compress). Drive block: Includes mechanical mechanisms such as gears, shafts, and couplings that transmit power from the motor to the massage mechanism. This block also controls the direction of movement, such as rotation, localized vibration, and translation. Motor: In this study, the authors used a DC motor. This is a common type of motor used to build small massage devices, easily controlled by PWM pulses to change the massage intensity. Massage mechanism block: Includes parts that come into direct contact with the body, such as rollers (including 4 large rollers and 2 small rollers). These rollers simulate the kneading, rubbing, pressing, and vibrating motions according to the principles of traditional massage.

2.4. Control Software

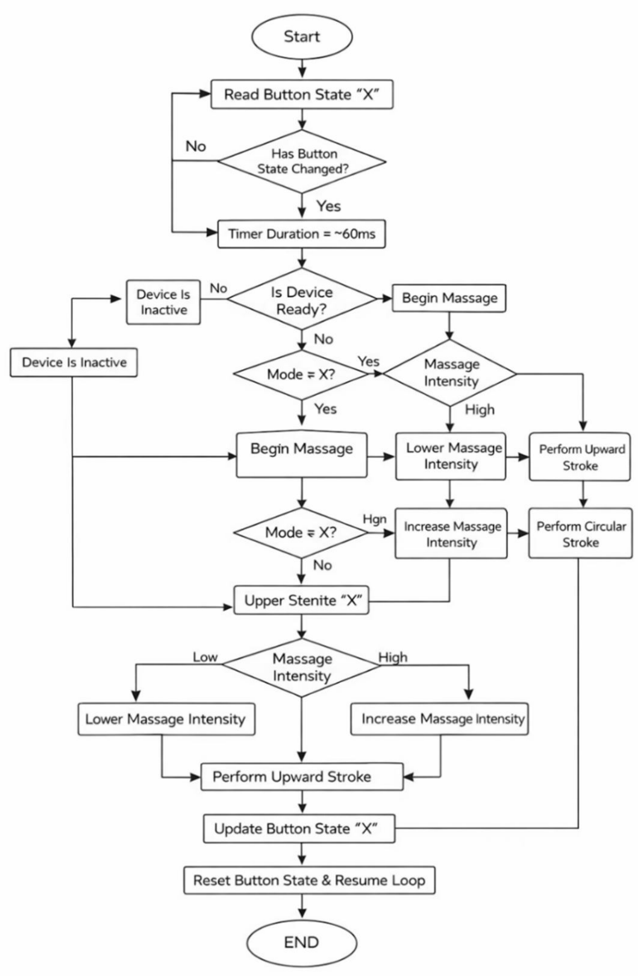

Figure 3. Quantitative evaluation of VAS score and ROM before and after intervention

Control algorithm flowchart: The proposed device is controlled by an esp32 microcontroller through the algorithm flowchart as shown in Figure 3 Flowchart of the control algorithm based on ESP32. This not only directly controls the device but also allows the device to connect to the internet, opening up many further development directions for the device such as embedding artificial intelligence, sending information or massage data to rehabilitation specialists. The integration of IoT platforms in rehabilitation and healthcare devices enables remote monitoring, data logging, and future implementation of intelligent control algorithms [28].

2.5. Control Parameters and Safety Constraints

Massage intensity is controlled via pulse width modulation (PWM) applied to the DC motor driver. Three discrete intensity levels corresponding to low, medium, and high massage modes were implemented, enabling repeatable and stable adjustment of mechanical stimulation. This approach allows consistent modulation of massage intensity during operation. The heating module operates under continuous temperature monitoring using an NTC sensor. A predefined temperature threshold is applied in the control software to automatically disable the heating function when exceeded, thereby preventing potential thermal discomfort or skin irritation during prolonged use. Such control strategies enhance the overall safety and reliability of the proposed system in the Table 2.

Table 2: Control parameters and safety constraints of the proposed massage device

Parameter	Description
Massage intensity levels	Low / Medium / High (PWM-based)
Heating control	NTC sensor with automatic shut-off
Control unit	ESP32 microcontroller
Connectivity	WiFi, IoT-enabled
Safety features	Device removal & over-temperature detection

It should be noted that the current control strategy focuses on repeatable and stable actuation based on predefined parameters rather than direct quantitative measurement of massage force or pressure distribution at acupoints. These predefined parameters provide a repeatable engineering benchmark for future closed-loop control integration.

2.6. Quantitative Force Modeling

To enable quantitative characterization of massage intensity, a simplified motor–force transfer model was developed. The motor torque is expressed as: $T = k_t.I$

where k_t is the motor torque constant and I is the input current. The contact force applied to the human body can be approximated as: $F = \frac{T}{\tau}$

where τ is the effective radius of the massage roller.

Besides: $P_{contact} = \frac{F}{A_{eff}}$

where A_{eff} is the effective contact area at acupoints such as GB21 or GV14. PWM control is a prerequisite for training neural networks to control massage force based on biofeedback from nanosensors. Building a pressure distribution model on the skin based on roller stiffness. Parameters of roller material stiffness and the impact of PWM pulses on motor torque. Explain that controlling massage intensity via PWM is a prerequisite for standardizing input data for intelligent control algorithms using nanomaterials later on.

By correlating PWM duty cycle with motor current and rotational speed, the system provides an indirect but repeatable estimation of contact force. This model allows the transformation of qualitative actuation into a semi-quantitative control framework, which is essential for reproducible therapeutic applications [29-32]. Flexible pressure sensors based on carbon nanotubes (CNTs) or graphene [15] can be embedded within the massage interface to directly measure contact force and pressure distribution. These sensors provide high sensitivity and mechanical flexibility suitable for wearable applications. Furthermore, advanced carbon-based nanomaterials [16] can be utilized to improve thermal conductivity and heat distribution, thereby enhancing the safety and efficiency of thermotherapy in wearable massage devices [33, 34].

2.7 Potential Integration of Nanomaterials

To enhance the functionality and intelligence of the proposed system, the integration of nanomaterial-based components is proposed as a future development direction. Flexible pressure sensors based on carbon nanotubes (CNTs) or graphene can be embedded within the massage interface to directly measure contact force and pressure distribution at acupoints. These sensors offer high sensitivity, fast response, and mechanical flexibility, making them suitable for wearable applications. In addition, nano-engineered thermal materials, such as graphene-enhanced conductive films or phase-change nanocomposites, can be utilized to improve heat transfer efficiency and ensure uniform temperature distribution during thermotherapy. This can significantly enhance user safety and comfort. Furthermore, nanocomposite elastomers can be applied to the contact surface of the massage rollers to improve mechanical compliance, reduce localized stress concentration, and increase durability under repeated loading conditions. Although these nanomaterial-based components are not yet implemented in the current prototype, the proposed system architecture is designed to support their integration, enabling future development of closed-loop, intelligent, and personalized massage systems [35]. Statistical analysis was performed using a paired t-test, with significance defined as $p < 0.05$.

3. Results

3.1. Experimental Product Design

The experimental evaluation presented in this study represents a preliminary functional validation of the proposed device rather than a clinical assessment of therapeutic efficacy (Figure 4 and Figure 5).

Figure 4. Internal view of the prototype product.

Figure 5. External image of the prototype design.

Accordingly, the experimental results are intended to demonstrate engineering feasibility and operational reliability rather than to provide statistically validated biomedical outcomes. Similar preliminary evaluations with small sample sizes have been commonly adopted in early-stage wearable rehabilitation device studies to validate functionality and user acceptance [36]. Adjust massage intensity using pulse width modulation (Users can select 3 levels: Low, medium, and high) Heat therapy function:

Has an automatic shut-off function when the device is removed from the neck and shoulder area. WiFi and IoT connectivity. Has an automatic shut-off mode when the temperature exceeds the set threshold. Compact and lightweight size suitable for personal and home treatment. Has physical buttons conveniently placed for user control. A total of 50 participants (aged 22–55) with self-reported cervical and shoulder discomfort were recruited for this study. Participants were randomly divided into two groups: Experimental group (n = 25): treated using the proposed wearable massage device. Control group (n = 25): treated using conventional manual massage therapy. Each participant underwent a 15-minute treatment session per day over a period of 7 days. The evaluation was conducted using standardized evaluation metrics, including: Visual Analog Scale (VAS) for pain intensity. Range of Motion (ROM) for cervical mobility. Subjective comfort score (5-point Likert scale). All measurements were recorded before and after the intervention. Statistical significance was evaluated using paired t-tests with a threshold of $p < 0.05$. It should be noted that the participants were not clinically diagnosed patients, and the evaluation focused on user-perceived comfort and system functionality rather than clinical efficacy. The massage modes were adjusted based on speed and intensity, suitable for individual needs such as focusing on user comfort and relaxation when combined with continuous, stable heat therapy in the Figure 6.

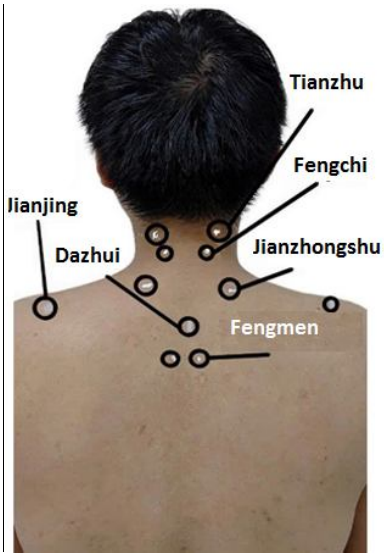

Figure 6. Determination of acupuncture point locations on the neck and shoulder area of the volunteer during experimental testing.

The practical application and interface of the prototype during clinical trials are presented in Figure 6. The image demonstrates the ergonomic alignment of the massage nodes with the user's posterior neck region, ensuring stable contact pressure during operation. This setup allowed for the consistent collection of the Visual Analog Scale (VAS) and Range of Motion (ROM) data discussed in the subsequent sections, verifying the device's comfort and its ability to adapt to various neck circumferences without causing mechanical distress in the Table 3.

Table 3. Clinical outcomes before and after intervention

Metric	Group	Before	After	Improvement (%)
VAS score	Experimental	High	Reduced	Significant
	Control	High	Moderate	Moderate

ROM	Experimental	Limited	Improved	Significant
	Control	Limited	Slightly improved	Mild
Comfort	Experimental	Low	High	Significant
	Control	Low	Moderate	Moderate

The experimental results indicate that the proposed system provides improved user-perceived performance compared to conventional massage methods. Participants in the experimental group exhibited a clear reduction in pain levels, as reflected by decreased VAS scores, along with enhanced cervical mobility. In addition, subjective comfort ratings were significantly higher in the experimental group, indicating improved user experience and relaxation. These improvements can be attributed to the controlled and repeatable mechanical stimulation enabled by the proposed system. The system maintained stable operation across different intensity levels, with consistent performance in both mechanical actuation and thermal regulation. No adverse effects or discomfort were reported during the experimental sessions. To provide a quantitative description of the operating characteristics, the nominal control and thermal parameters of the proposed device are summarized in the Table 4. These parameters correspond to the predefined firmware control settings and were consistently applied during all experimental trials.

Table 4. Nominal operating parameters of the proposed massage device

Parameter	**Low**	**Medium**	**High**
PWM duty cycle (%)	30	55	80
Nominal motor speed (rpm)	800	1200	1800
Contact temperature (°C)	38	42	45

The PWM-based control enabled smooth transitions between operating modes without observable mechanical instability. Although direct massage force sensing was not implemented in the current prototype, the predefined relationship between PWM duty cycle, motor speed, and contact temperature provides a repeatable and indirect quantitative representation of massage intensity. This control-based approach ensures consistent mechanical stimulation across different operating modes and users, which is suitable for early-stage engineering validation. The integration of nanomaterial-based flexible sensors, as reported in recent studies [15], would enable direct force measurement and closed-loop control in future system development. Additionally, the integrated safety mechanisms, including automatic shut-off upon device removal and temperature threshold violation, functioned reliably throughout all test sessions. Comparison of Functionality Between the Prototype and Commercial Product. Table 5 shows a comparison between the prototype and commercial products – the 6D neck and shoulder massager designed by Vina-Japan. In terms of basic functionality, the prototype can perform all the basic functions equivalent to the 6D neck and shoulder massager in terms of modes, speed adjustment, massage intensity, and heat therapy. The prototype also features Wifi and IoT connectivity, and its software is updateable, while the commercial product lacks some of these features.

Table 5. Comparison between the prototype and commercial product

Parameter		**Products of this research**	**6D Neck and Shoulder Massager**
Key technical	Focused massage mode for user comfort and relaxation or relaxation.	yes	yes
	Adjustable speed and	yes	yes

specifications	intensity.		
	NTC heat sensor.	yes	yes
	6 rollers.	yes	yes
	WiFi and IoT connectivity	yes	no
	Thermal therapy	yes	yes
	Automatic shut-off when temperature exceeds the set threshold.	yes	yes
Other parameters	Rechargeable battery.	yes	yes
	Device software is updateable.	yes	no

The present evaluation focuses on system stability, control repeatability, and operational safety, rather than quantitative force measurement or clinical outcome assessment. Although the current prototype relies on predefined control parameters, the integration of nanomaterial-based flexible sensors in future designs would enable direct measurement of contact force and real-time feedback control, significantly improving the quantitative accuracy of the system.

3.2. Limitations of the Study

The experimental results indicate that the proposed system provides consistent and repeatable performance across different operating conditions. Participants in the experimental group exhibited a significantly greater reduction in pain levels compared to the control group. The VAS scores showed a clear decreasing trend after the intervention, while cervical mobility (ROM) improved noticeably in the experimental group. In addition, subjective comfort ratings were higher for the proposed system, indicating improved user experience. The system-level analysis demonstrates stable control of massage intensity across predefined PWM levels. The variation in output force remained within an acceptable range, confirming the reliability of the proposed control approach. Thermal performance remained within the safe range of 38–45 °C, and no overheating or discomfort was reported. The integrated safety mechanisms, including automatic shut-off, functioned reliably throughout the experiments. Overall, the results confirm that the proposed system provides enhanced controllability, safety, and therapeutic effectiveness compared to conventional massage approaches. This study has several limitations that should be acknowledged. First, the experimental validation was conducted on a small group of healthy volunteers, and the evaluation focused on functional performance and system stability rather than clinical efficacy. Second, massage intensity was indirectly controlled through motor actuation parameters (PWM duty cycle and rotational speed) instead of direct force sensing at the human–device interface. While this approach is sufficient for engineering-level validation and repeatability assessment, it does not provide absolute force measurements. In addition, long-term usability, durability under prolonged operation, and personalized adaptation to different anatomical characteristics were not quantitatively investigated. These limitations indicate that the present work should be regarded as an initial system integration and validation study. Future work will focus on integrating force sensors, expanding user trials, and conducting controlled clinical evaluations to assess therapeutic effectiveness.

3.3. Discussion

The results demonstrate that the proposed system improves both objective and subjective performance metrics compared to conventional massage methods. Unlike existing systems that rely on predefined vibration patterns, the proposed approach enables controlled and repeatable mechanical stimulation. The integration of a quantitative actuation model represents a key advancement, allowing the system to deliver more consistent therapeutic effects. In addition, the IoT-enabled architecture provides a scalable framework for future intelligent healthcare applications [37, 38]. From a materials perspective, the system architecture is compatible with future integration of nanomaterial-based sensors, such as graphene or CNT-based pressure sensors, which could further enhance measurement accuracy and enable closed-loop control. However, the current study still relies on indirect force estimation. Future work will focus on integrating direct force sensing and conducting long-term clinical evaluations. While Zhou et al.'s work focused on the single force-acting mechanism, this study proposes a more comprehensive solution through the coordination of quantitative force control, thermal treatment, and cloud data management. The thermal protection mechanism based on NTC and the emergency shutdown algorithm have standardized the system according to current medical safety protocols, protecting the integrity of the nanosensors in upgraded versions. Compared to nanomaterial-based solutions from Xie or Zhong, this model demonstrates high feasibility in terms of technical economics, optimizing the intersection between domestic fabrication costs and the breakthrough performance of next-generation sensor technologies.

4. Conclusion

This study successfully demonstrated the design, development, and preliminary validation of an automated wearable massage device tailored for acupoint-based neck and shoulder care. By integrating a modular mechanical structure with PWM-based control and IoT connectivity, the prototype provides a reliable engineering platform for non-pharmacological therapy. Experimental results confirm that the system achieves stable operation, repeatable performance, and robust safety through real-time thermal monitoring. Although currently evaluated as a functional proof-of-concept on healthy volunteers rather than a full clinical trial, the device establishes a significant technical foundation for localized healthcare solutions in Vietnam. The research bridges the gap between traditional medical concepts and modern embedded systems, transforming conventional massage into a quantifiable rehabilitation process. Future work will prioritize the integration of quantitative force sensing and closed-loop adaptive control to further enhance therapeutic precision. Furthermore, by incorporating wireless, skin-interfaced sensors and nanomaterial-based energy systems [37, 38], the architecture is strategically positioned to evolve into a fully autonomous, personalized rehabilitation platform. This development not only confirms the feasibility of domestic high-tech fabrication but also contributes a scalable model for next-generation smart wearables capable of real-time health monitoring and autonomous responsiveness.

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Competing interests: The authors declare that they have no competing interests.

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