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Design and Development of Foot Massage Assistive Device

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ABSTRACT

The operation of the Foot Massage Stick involves three essential elements: sequence, direction, and force. Among these, force is particularly difficult to describe and master. To provide users with a visual means of understanding the force being applied, however a product lacking such functionality on the market, this study decided to develop a pressure-sensing massage stick.

This study applied a systematic design approach to develop the foot massage stick. This approach included setting design goals, mechanical design, appearance design, and functional verification. Ultimately, this product was developed.

The key features of this design are as follows: 1) Performance meets the accuracy standards of commercially available instruments. 2) The applied force and duration are displayed in real time during the operation. 3) After the operation is completed, data such as the maximum applied force, average, standard deviation, and application time are displayed. 4) By visualizing the applied force, learning is facilitated, helping to ensure that the required operation is achieved. The results and procedures of this study can provide a reference for the development and design of assistive device products.

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Introduction

Foot massage involves applying targeted pressure to specific areas of the feet and can be administered either by a professional therapist or in a home setting. Generally, foot massage techniques fall into two categories: Manual Therapy (MT) and massage stick-assisted methods. Notably, hand injuries rank as the second most common type of work-related musculoskeletal disorders among Manual Therapy practitioners [1]. This high incidence is largely due to the repetitive motions and substantial forces that therapists must exert with their hands throughout the massage process [2]. Fung et al. investigated whether wrist posture, forceful exertion, and repetitive motion increase the risk of developing carpal tunnel syndrome (CTS). The study recruited 166 CTS patients and 111 non-CTS individuals from various hospitals in Hong Kong to complete a questionnaire. The results showed that individuals who frequently flexed their wrists had a 4.4 times higher risk of developing CTS. Those who frequently extended their wrists had a 2.7 times higher risk, while those who frequently performed forceful and sustained wrist movements (e.g., prolonged exertion) had a 2.6 times higher risk. In contrast, maintaining a neutral wrist position (neither flexed nor extended) or simply performing repetitive movements without significant flexion or force did not show a significant increase in CTS risk [3].

Cornwell et al., as reported by the American Physical Therapy Association, found that 38.5% of Physical Therapists (PTs) experienced Work-Related Musculoskeletal Disorders (WRMDs). Among the contributing factors, manual therapy (MT) was identified as the leading cause of these injuries [4].

Albert, Currie-Jackson, & Duncan conducted a survey of 502 Canadian Registered Massage Therapists (RMTs) and found that musculoskeletal pain and discomfort were most frequently reported in the wrist and thumb, followed by the lower back, neck, and shoulders [5]. Sadyapongse & Sithisarankul conducted an assessment of occupational health hazards and ergonomics among Thai massage and foot massage practitioners. The results indicated that during a 60-minute Thai massage session, practitioners applied force with their hands an average of 866 times. In a 50-minute foot massage session, the average number of hand force applications increased to 1,449 times. In both types of massage, the thumb was the most commonly used body part to apply force, followed by the base of the palm and the knuckles [6]. To effectively reduce the risk of musculoskeletal injuries, it is recommended to minimize the use of hands for performing massage or therapeutic procedures, and instead consider adopting alternative tools or equipment [7].

The massage stick serves as a substitute for manual therapy (MT) in performing actions that are difficult to execute by hand, such as rolling, pushing, lifting, and pressing. Additionally, it allows for more precise stimulation of acupressure points. As a result, most massage practitioners prefer the massage stick for its therapeutic effectiveness and operational convenience. Its use also contributes to a lower incidence of hand pain and related injuries [8].

The proper use of a massage stick involves three essential elements: sequence, direction, and force [9]. While sequence and direction can be easily visualized and recorded, force remains more difficult to articulate and to master. Since there is no product on the market that can display the applied force in real time and can also calculate the distribution of applied force during the application process, this study aimed to develop a foot pressure-sensing massage stick that provides visual feedback on applied force. This tool enables both learners and practitioners to reference measurable data during operation, thereby supporting skill acquisition and enhancing the quality of performance.

Methodology

The development of the foot pressure sensing massage stick in this study followed the product development procedure. At first, based on the analysis of market data, the study of existing technology principles and the investigation of usage requirements, the design objectives and specifications are formulated, and the mechanical design is carried out to achieve the design objectives. In this study, two technical applications such as piezoelectric elements and strain gauge elements are used as the basic components for the design. Secondly, the ergonomic design of the assistive device should be applied to the operation mode and human factors needs of the employees. Finally, by integrating the aforementioned functional design and ergonomic design, the development and pleasing appearance will meet the proposed design objectives and specifications.

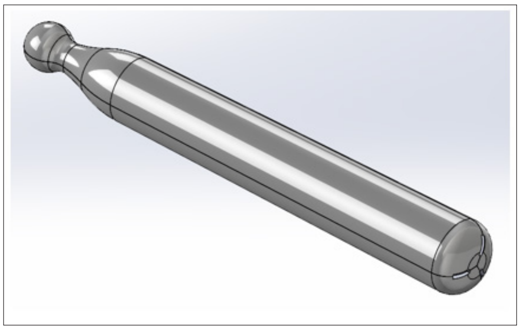
Based on a functional analysis of market products, the design specifications of the massage stick established for this study are as follows: 1) Display the applied force in real time to provide a reference for the user. 2) After the movement is completed, the force distribution of the movement can be calculated, including the maximum, average, standard deviation, and duration of the movement, to provide the user with feedback. 3) This information can be displayed to the user in real time using the massage stick and a visual display. 4) The force measurement accuracy must meet the standards of similar products currently available. 5) The dimensions of the massage stick must fit within the size of user's hand and allow for flexible operation. The dimensions are as follows: length within 150mm, diameter within 22mm, and massage head diameter within 12mm.

Design Results

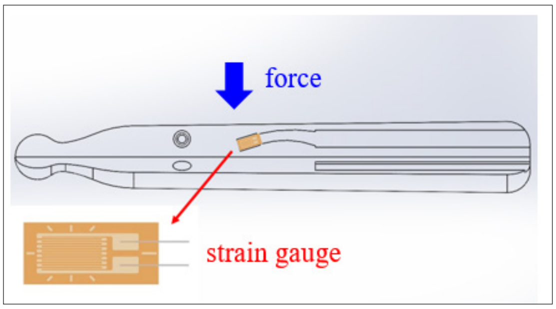
This research employed a systematic, cyclical product development process, progressing through the design and revision stages of Designs 1 through 4. Each version was tested, verified, and revised in various areas, including measurement sensitivity, structural design, material selection, and overall integration. Finally, Design 4 completed a single-point pressure sensing force transmission architecture that met functional and usability requirements. The following describes the issues, design revisions, and verification results of Designs 1 through 4, in order.

Foot Massage Stick Design 1

Design 1 uses metal foil strain gauges to measure massage force. The body of massager stick is divided into three thirds, each capable of attaching strain gauges. The design concept is that the three strain gauges can measure the change in resistance of the deformation of massager stick along the x, y, and z axes, and then convert this resistance change into applied force. The design is illustrated in Figures 1 and 2. The material used is PLA. The overall appearance is shown in Figure 3.



Figures 1: Foot Massage Stick Design 1 3D Appearance



Figures 2: Internal Structure and Strain Gauge Position

Figures 3: Overall Appearance Entity

Foot Massage Stick Design 2

Because Design 1 uses PLA material and the strain gauges located in the middle of the body, the strain gauges cannot measure deformation when force is applied, making it impossible to calculate the relative force applied. Design 2 places one strain gauge in the middle of the head to measure axial force, as shown in Figure 4. Two additional strain gauges are placed on either side of the front of the stick body to measure forces in the other two axes, as shown in Figure 5. The housing is now made of TPE elastic plastic, as shown in Figure 6.

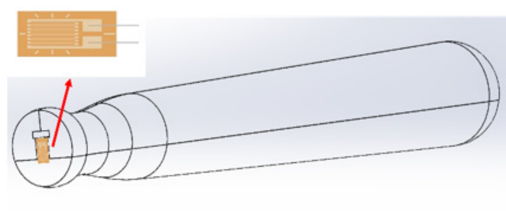


Figure 4: Position of the Strain Gauge at the Rod Head

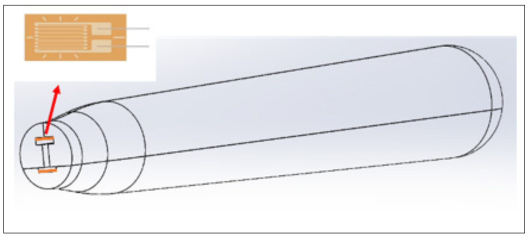


Figure 5: Two Additional Strain Gauges are Placed on Either Side

Figure 6: Overall Appearance Entity

Foot Massage Stick Design 3

The test results of Design 2 showed that the vertical force could not be measured, while the forces along the other two axes could be measured, the reliability was poor. Design 3 replaced the vertical force sensor with a ball-shaped pressure sensor module, as shown in Figure 7. The force sensors along the other two axes were identical to Design 2, but with modified structures, as shown in Figure 8. The overall design is shown in Figure 9.

Figure 7: Ball-Shaped Pressure Sensor Module

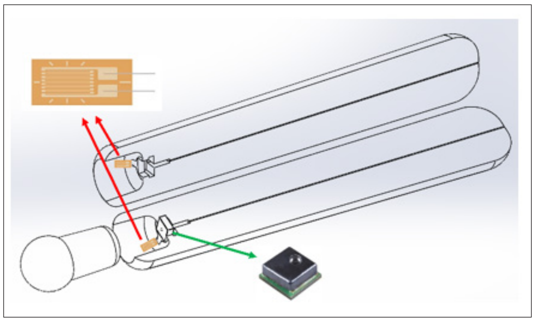


Figure 8: Strain Gauge Position and Ball-Shaped Pressure Sensor Module

Figure 9: Overall Appearance Entity

Foot Massage Stick Design 4

The test results for Design 3 showed that while forces along all three axes could be measured, the reliability of the vertical axis was high, while the reliability of the other two axes remained quite low. This review suggests that this may be due to the inherent precision limitations of the strain gauge itself. Therefore, this strain gauge was discarded for this study. Furthermore, massage sticks are primarily used in the vertical direction, and forces applied in other directions can be calculated using the vertical force component. Therefore, Design 4 was revised to retain only vertical force measurement. The structural design is shown in Figure 10. The finished design's appearance is shown in Figure 11.

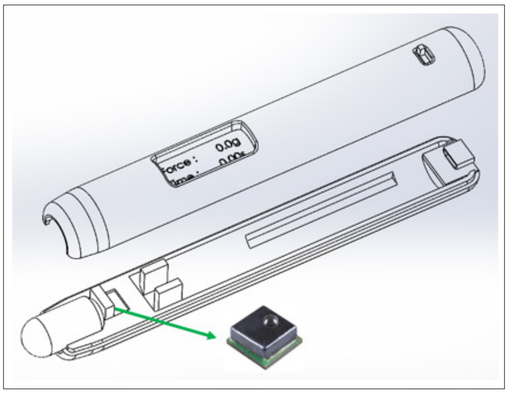


Figure 10: Internal Structure and Ball-Shaped Pressure Sensor Module

Figure 11: Completed Exterior Design of the Pressure-Sensing Massage Stick

Design Features and Specifications of Foot Massage Stick

The final version of the pressure-sensing massage stick is the result of iterative design revisions. This design meets the previously established specifications, as follows: 1) It utilizes a rechargeable power supply and charges via USB. 2) Measurement results are displayed directly on the screen of the massage stick, eliminating the need for an external monitor. 3) During operation, the device continuously displays applied force and time in real time. At the end of the operation, the screen displays applied force indicators, including maximum value, average value, standard deviation, and total applied force time (Figures 12 and 13). Figure 14 illustrates the device's internal electronic components. Figure 15 shows the charging module, and Figure 16 shows the dimensions of the pressure-sensing massage stick. Table 1 lists the overall specifications of this design.

Figure 12: Display of Pressure Measurement Data

Figure 13: Display of Pressure Measurement Data

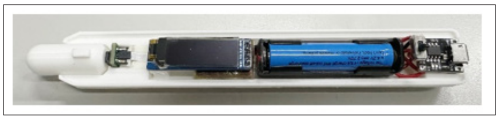


Figure 14: Internal Circuitry and Electronics of the Pressure-Sensing Massage Stick

Figure 15: Electrical Charging Apparatus Integrated with the Pressure-Sensing Massage Stick

Figure 16: Finalized form Factor of the Pressure-Sensing Massage Stick

Table 1: Specifications of the Final Design of the Foot Massage Stick

Categories	Items	Specifications
Construction	Dimensions	Length: 146.5mm, Diameter: 21.5mm, Head Diameter: 12mm
Sensor	Max load error	0-5 KG +- 0.05
Power supply	Batteries	18650 Li-ion Battery
	Charging pad	TP4056 Charging Board
	Dimensions	Length: 45 mm, Diameter:10 mm
Interface	Monitor	OLED screen module
	Dimensions	Length: 38 mm, Width: 12 mm, Thickness: 11 mm

Test and Verification

To evaluate the performance and accuracy of pressure-sensing massage stick, this study conducted pressure tests. We compared the measurement results of our massage stick with those of a pressure measurement device produced by G-CHEN Technology. The test method involved placing the head of the massage stick vertically on a G-CHEN pressure measurement pad and applying vertical forces of 0.5, 1, 1.5, 2, 2.5, and 3 kg respectively. The force values measured by the two devices were then recorded and compared.

The test results showed consistent outputs from both systems, validating the accuracy of the device developed in this study. Figure 17 illustrates a force of 1000 g (1 kg) applied to the massage stick. Figure 18 shows the corresponding pressure reading (1 kg) recorded by the G-CHEN device during the same test.

Figure 17: The Massage Stick was Tested Under an Applied Pressure of 1000 g

Figure 18: G-CHEN Pressure Sensor Test Results (1kg)

Discussion

Traditional massage devices rely on the massager's experience. Currently, there are few foot massage devices on the market that can instantly visualize and calculate force applied. The device developed in this study allows the user to observe the force and duration of their massage in real time. This transforms the previously relied-on feel into a visual numerical value, allowing the user to make immediate corrections. At the end of the massage, the system outputs the maximum value, average value, standard deviation, and total duration for the user to review and remember, enhancing learning and improving massage quality.

Furthermore, this design provides an objective tool for teaching and learning. It helps instructors and students monitor force application standards and manage force duration, avoiding excessive force and reducing the risk of muscle fatigue. Overall, this assistive device shifts foot massage practice from an experience-based approach to a data-driven one, significantly improving standardization, learning efficiency, and operator safety.

Conclusion

After four rounds of design and revision, this research resulted in the development of an assistive device that can display and record applied force in real time, achieving the intended design goals. The final design features are as follows: 1) The device's performance is comparable to the accuracy of commercially available instruments. 2) The applied force and duration are displayed in real time during the operation. 3) At the end of the operation, the system provides statistics of the operation, including the maximum applied force, mean, standard deviation, and total applied time. 4) This information can be displayed to the user in real time on the visual display of the massage stick. 5) The massage wand is designed to fit the user's hand and allow for flexible operation. Its dimensions are as follows: length no more than 145.5mm, diameter no more than 21.5mm, and massage head no more than 12mm. These features visualize applied force data, allowing learners to intuitively understand applied force results, ensuring that the applied force meets requirements and enhancing learning outcomes. The design process and results of this design can provide a reference for other assistive device designs.

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