An innovative Rehabilitation based Gloves for curtailing pain in Arthritis Patients

Nazia Ejaz[1*], Mehwish Faiz[2], Ansharah Hasib[2], Inam Ul Ahad[3], Sohrab Khan[4], Jalal Shah[4], and Wazir Muhammad[1]

[1]Department of Biomedical Engineering, Balochistan University of Engineering and Technology, Khuzdar 89100, Pakistan nazia
[2]Ziauddin University (FESTM), Department of Biomedical Engineering, Karachi, 74200, Pakistan
[3]School of Mechanical and Manufacturing Engineering Dublin City University
[4]Computer System Engineering Department,Balochistan University of Engineering and Technology, Khuzdar 89100, Pakistan
ejaz94@yahoo.com

Abstract. Hand arthritis is a condition that affects the cartilage at the ends of the joints. The consequences of this condition include severe pain, stiffness, and often deformity of the hand. As the condition progresses, stiffness and deformity increase, impeding the ability to perform daily tasks. To address this issue, we have designed a cost-effective glove aimed at alleviating pain in patients by applying pressure to specific acupressure points. The glove features vibrators placed at areas affected by hand arthritis, particularly on LI4 (Hegu), PC8 (Laogong) and SI3 (Houxi) regions, to reduce pain and inflammation. Controlled by an Arduino UNO, the vibrators' operation timing is regulated. Tested on four arthritis patients, the glove has proven effective in pain reduction, offering a user-friendly solution for rapid pain relief and ease of use.

Keywords: Arthritis, pain, cost-effective, acupressure, Glove

1 Introduction

Hands are the complex anatomical structure comprising of multiple small bones and joints which aids in performing various movements including flexion, extension, abduction and adduction of fingers and thumbs. These movements are ceased due to a condition, Arthritis, characterized by joint inflammation and stiffness. Thus, affecting the quality of life by halting the daily life activities of individuals. The most prevalent types of arthritis are rheumatoid arthritis and osteoarthritis that decreases range of motion of the hand. However, Osteoarthritis (OA) is a prevailing health problem that has impacted more than 260 million individuals globally [1]. It leads to physical discomfort along with joint pain and stiffness thus more significant impairments in functionality [2,3, 14,15].

Regarding the management of OA, there is no specific medication to cure it. However, there are numerous therapy strategies available for the management of osteoarthritis, which can be broadly categorized as non-pharmacologic, surgical, complementary, or pharmacologic, and alternative methods. Moreover, alteration in

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lifestyle and physical therapy also has a positive impact on the arthritis patients to a certain extent [4,5].

The latest trend of merging new technologies with traditional treatment options led to the advent of some non-invasive therapeutic option. One such indispensable healing approach involves the assimilation of electronic devices with conventional techniques to mitigate the pain by applying pressure to distinct acupressure locations. The employment of pressure to meridian points or acupoints is a prevalent technique in conventional Chinese medicine and named as acupressure. It has been utilized for a multitude of objectives ranging from suppressing the pain to enhance the sleep quality or to reduce anxiety. This practice enhances the flow of energy to relieve the symptoms to a specific body part [6,7].

In hands, the most effective section where the pressure is applied to manage the pain caused by arthritis includes LI4, PC8 and SI3. Their particular location on hands is given as:

1. LI4 (Hegu) is situated on the dorsal side of the hand, within the interdigitalspace between the pollex and the index digit.
2. PC8, also known as Laogong, is located in the central region of the palm,situated between the heart and the pericardium meridian.
3. SI3 (Houxi) is located on the ulnar side of the hand, directly below thebase of the little finger. It is thought to alleviate stiffness and soreness in the hands and fingers [10].

The integration of acupressure with wearable technology, specifically hand gloves is a unique concept for arthritis therapy [8]. These gloves are design to apply targeted pressure on specific acupressure points in hands. It is done to alleviate arthritic symptoms and improve joint function. It could offer a way to apply even pressure consistently and in a more targeted fashion than can be achieved through extensive specialized training, provide pain relief without invasive procedures.However, the drawback of applying pressure to inflamed body part leads to further elevation in the temperature at that particular site, so a cooling mechanism is required [11,12].

2 LITERATURE REVIEW

The convergence of technology with conventional therapies has transformed the health and wellness industry. In current era, many developments signify to incorporate new devices with traditional methods; the recently designed glove for acupuncture points stimulation reflects this point. This review highlights the developments in this field especially describing how such technologies are helping to ensure a holistic well-being and health.

Several novel strategies to treat acupressure have been investigated recently, introducing gloves apparatus and finger cots that can target relevant acupoints by applying a therapeutic pressure. Yeh et al. also introduced a new approach for employing gloves or cots filled with one or multiple pellets, thus, they can be made of leather, cloth, rubber, neoprene, latex, and knitted wool. These pellets, which come in stainless steel, 24k gold plated stainless steel, titanium, silver, magnets or Vaccaria seeds

are fixed in positions on the palm surface of the gloves or the thumb and index finger cots. This design is advantageous in that it enables users to have acupressure anytime and anywhere making it an effective substitute for acupressure systems. The gloves and cots apply pressure on the acupressure points situated on the body or ear which will help to ease several pathological diseases through the continual use (Yeh, 2020). This makes it significant in illustrating continuity in the evolution of non-invasive treatment procedures in a bid to accord patients improved comfort and improved treatment outcomes [8].

Wearable technology in healthcare has proven to have the capacity to manage chronic diseases namely Rheumatoid Arthritis (RA). The study by Gozde and Topcuoglu (2017) proposed an e-textile based smart glove for the needs of the RA patients. The purpose of this glove is to apply electrotherapy for pain relief and to also avoid formation of hand deformities through the textile-based splint structures. This research further emphasizes the need to include the medical practitioners and RA patients to form a unified usable centered design team when designing the glove. Moreover, the study points the importance of characterization of comfort in wearable technology, for that defines that the user's comfort is crucial for effective performance of such devices. The smart glove is a clear demonstration of the effectiveness of wearable technologies in supplementing a wide range of rehabilitation services which in turns enhances the quality of life of persons with chronic ailments [9].

Siti, Hana, Nasir, and Troynikov (2019) highlighted the magnitude at which the gloves impact on the experience of pain relief and the functionality of the hand which is valuable in patients with arthritis. There are various models available in therapeutic gloves so it is easy to make adjustments according to the severity or the type of arthritis a patient has. The authors stressed the need to design a proper framework for these gloves that goes beyond the material properties to include aspects of ergonomics and feedback from patients in order to achieve the maximum therapeutic effect and wearable comfort. This design framework is instrumental to the improvement of the overall effectiveness and applicability of such gloves [10].

Aoun et al. (2018) designed an effective, portable and assistive soft robotic glove used in the improvement of hand rehabilitation of people with arthritis or other hand complications affecting the ability to use their hands. Their wearable glove design uses a combination of a soft glove material for the outer layer along with stainless-steel wires that are operated by the stepper motors that are mounted on the palmer side of the hand. Such an arrangement guarantees the glove's thin profile and ergonomics while offering the precise BTE, TTE as well as overall stretching arising from the finger forms. The mechanical programming of the system brings flexibility in the range of individual finger movements and offers the required amount of motion for every user. As opposed to other rehabilitation devices, the inventor's soft robotic glove gives users more freedom and autonomy because a waist battery pack and bi-mode 'Soft' and 'Hard' state compatibility [11].

In the most recent advancements in arthritis treatment, it was suggested that combination therapy to be incorporated in wearable technologies will facilitate self-

management and pain relief among patients. Amir-Ali and Golrokhian-Sani (2023) proposed a novel solution: gloves that offer cold, compression, and heat therapy to enable arthritis patients to manage pain at home. As for the gloves, being comfortable and functional themselves, they allow patients to control their pain at home and during various activities, which is vital for rehabilitation. For instance, they come with built-in features such as adjustable compression and heat functions, which shut off on their own after a certain period of time to guarantee the safety of the wearer. Furthermore, the compound involving the clinician's program enables the establishment of a daily cryotherapy schedule for patients with chronic conditions requiring consistent treatment. The authors stated that despite the great potential of this technology, there could be some constraints in the future concerning the cost and accessibility of this sophisticated technology. But they indicate that these problems may reduce with time as technology is enhanced [12].

In recent advancements in health and wellness technology, Huang, Zhou, and Hou (2013) introduced a novel device designed for stimulating acupuncture points on the hand: many people know the massage glove. This particular glove has been worn with elastane fabric materials and designed in an inner and outer layers with strategically located massage blocks corresponding with acupuncture points of the hands. Every block has vibrators which are linked by an electrical power line, accompanied with an easily operable switch and plug. The purpose of the massage glove is to give automatic massage to these acupuncture points which may be helpful in health care and health maintenance. The device may not provide adjustable pressure settings, which are crucial for effective acupoint stimulation [18].

The above literature highlights some major issues for the designing of hand gloves including complex hardware, proper selection of sensors that can deliver gentle pressure, appropriate size of the sensors to fit in the gloves, lack of analysis of glove material and non-appropriateness of open-fingertip design. Keeping these issues in view, we have proposed a cost-effective mini module sized sensor design of hand glove controlled by PID Controller to relive the pain in arthritis patients efficiently.

3 METHODOLOGY

A specialized glove has been designed to alleviate pain in individuals with hand arthritis. This glove incorporates integrated cooling and vibratory stimuli, which are expected to relieve the pain. The integration of multiple electronic components including the Vibrator, Peltier Chip and Temperature sensor with Arduino UNO in the design of glove lead to the reduction of pain. Figure 1. Shows the schematic diagram of the circuit.

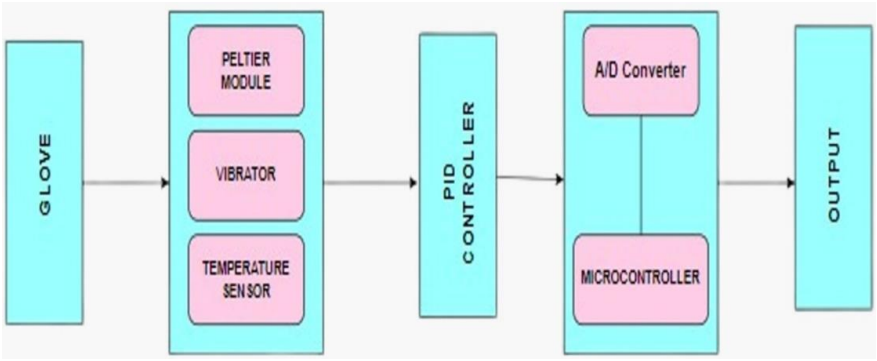

Fig.1. Block Diagram of the proposed glove.

The step-by-step process of designing and working mechanism is outlined below:

Specifications of Electronic Components: The two most elemental electronic components including Coin Vibration Motor – 3mm Type Model NFPC1234 and 00411-9J30-20CN Thermoelectric/Peltier Mini Module are placed in the hand Glove. The LM 35 sensor produces a varying output voltage in response to temperature changes within the range of -55 C to 150 C on the Celsius scale and is integrated in the circuit to monitor the temperature. These are connected with the microcontroller Arduino UNO. The microcontroller is equipped with an AD converter that transforms the analog data into digital format and presents it on an LCD. This close loop system is managed by PID Controller. Figure 2.
depicts the schematic diagram of the circuit.

Working Mechanism:

The gloves are worn by the participant, the hand that is afflicted with arthritic pain may have a slightly higher temperature than the rest of the body because of inflammation.

The temperature sensor within the glove detects the elevated temperature and send a signal to vibrator and Peltier Module to turn ON to induce the pressure and the cooling simultaneously at the acupressure points. It distributes appropriate amount of pressure to mitigate the pain.

Moreover, the incorporation of Peltier lessens the temperature of the arthritic sites as it already has increased temperature and vibrations will further increase it.

This pressure is delivered until the temperature of the hand restores the normal body temperature of around 37. As the temperature reaches 37 C, the Peltier chip and vibrators will be turned off. This mechanism is controlled by PID Controller.

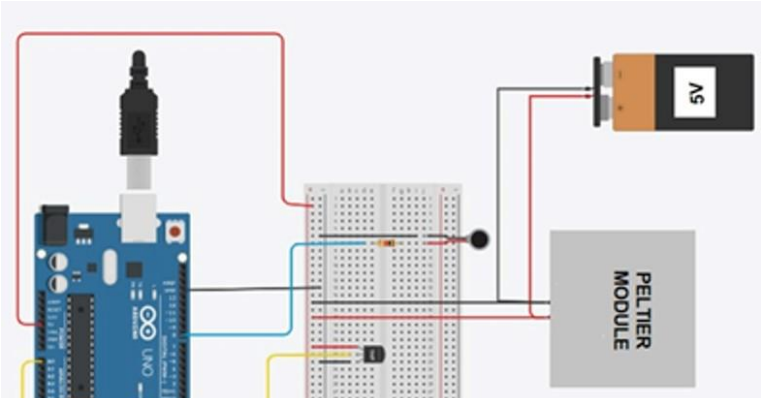

Fig.2. Schematic Diagram of the circuit of the glove.

In order to prevent excessive usage of the gadget, the system is only intended to operate for a maximum of 4 minutes per session.

Selection of material for Hand Gloves: One of the most significant aspects in designing this device is to select the appropriate material for the glove. For this purpose, various materials are analyzed and their characteristics are studied to choose the best material including woolen, Lycra and cotton. Among these, Lycra which is a copolymer of Polyether-polyurea is found to be more suitable as it has low heat retention ability with high stretchability and fabric breathability.

Glove Design and Implementation: The glove was conceived as a wearable solution to help combat hand arthritis through the real-time application of vibrations, coupled with central heating effect provided using Peltier chip in tip areas where inflammation due to Arthritis is prevalent. Positioned along the three distinct points on hands including LI4, PC8 and SI3, vibrators deliver targeted vibration therapy. Positioned along the finger tips, vibrators deliver targeted vibration therapy. This arrangement of sensors in the glove guarantees that the vibrators will directly target the inflamed joints of the fingers. Figure 3. shows the proposed device.

Cooling Mechanism: Vibrations delivered may elevate the temperature of the area where these sensations are given so a cooling mechanism is required to decrease the temperature. This is achieved by the incorporation of Peltier chip in the glove. The basic principle of these chip is the Peltier effect which is the application of the voltage across a conductor to produce the temperature differential between two electrical junctions. When current passes at the junction of different two conductors, one absorbs heat which lead to cooling and the other releases heat. This is done to help cool the inflamed area, which will reduce pain and swelling due from inflammation using a Peltier chip. To provide proper thermal management, the chip is placed at each fingertip inside the glove.

Fig.3. Prototype of hand glove for arthritis patients.

Temperature Regulator: A temperature sensor is incorporated into the glove in order to monitor the temperature of the affected areas continuously. The sensor sends real-time data to the control system. Cooling is activated at temperatures above 37 C (human body temperature) by activating the Peltier chip. At the same time, the vibrators are activated to produce a vibrating sensation. A continuous cooling and vibratory stimuli will be offered until the temperature is 37 C, then the Peltier chip as well as vibrators are switched off. The system is designed to work a maximum of 20 mins per session in order to avoid overuse of the device.

PID Controller for Temperature Control: The smart glove incorporates a Proportional-Integral-Derivative (PID) controller to automate acupressure therapy. This controller is specifically developed to regulate the temperature at acupressure efficiently points LI4, PC8, and S13 to alleviate arthritic pain. The system combines an LM35 temperature sensor and a Peltier module, with the PID parameters meticulously adjusted to optimize performance. The proportional gain (Kp = 0.00206812507453938) improves the transient response by minimizing rise and settling times, while the integral gain (Ki = 0.0339782106923304) reduces steady-state error by integrating the error over time. The derivative gain (Kd = 3.14697363162208e-05) refines the transient response by predicting future error trends and mitigating overshoot and oscillations. The controller continuously adjusts the Peltier module's power input based on real-time temperature measurements, ensuring precise thermal management. This configuration balances responsiveness and stability, which is crucial for effective and consistent pain relief in arthritis therapy. The given Figure 4. specifies the implementation of PID Controller in the device.

Control System: An Arduino microcontroller is responsible for managing the entire process, which includes monitoring the temperature, cooling the device, and stimulating the vibratory system. For the purpose of controlling the

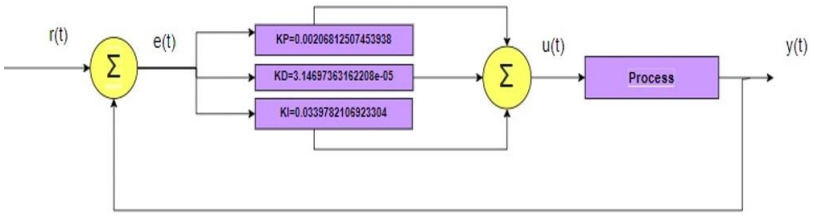

Fig.4. Specifications of the PID Controller in the proposed Gloves.

vibrators and establishing an interface with the temperature sensor and the Peltier chip, the Arduino has been meticulously programmed. The temperature data is processed, and it manages the activation and deactivation of the Peltier chip and vibrators based on the temperature thresholds that have been specified. Figure 2. Shows the proposed device.

PID Control for Vibrators: A Proportional-Integral-Derivative (PID) controller is used to adjust vibrator performance. A PID controller responds to temperature changes by adjusting the vibration frequency. The PID controller increases the speed of the vibrators to maximize effect when temperature exceeds 37 C. And vice versa, when the temperature returns to normal, so too does the speed of those vibrators. The therapeutic outcome is maximized as a result of this dynamic adjustment, which guarantees that the vibratory stimulation is in accordance to the variations in temperature.

Testing and Validation: The performance of the device is evaluated by taking four participants with hand arthritis issue and allowed to sit in still position by wearing the proposed device. The device is then turn ON by providing power to deliver the pain-relieving sensations to patients. Then, the feedback of the participant is gathered to figure out the working of the glove.

3.1 RESULTS

The performance of the device is evaluated by taking four participants with hand arthritis issue and allowed to sit in still position by wearing the proposed device. The device is then turn ON by providing power to deliver the pain-relieving sensations to patients. Then, the feedback of the participant is gathered to figure out the working of the glove. It is observed that the temperature sensor and Peltier chip turns ON simultaneously to distribute a pressure of 1.85 pounds to the acupressure points. All the four arthritic patients after wearing the device and receiving the vibrations gave the feedback of deterioration in the pain sensation. Table 1 displays the device's performance in a tabular format.

Table 1. Summary of Participants' Temperature and Device Status

No. of Participants	Temperature Sensed Initially (C)	Peltier	Vibrator	Temperature Sensed Finally (C)	Peltier	Relief in Pain
Participant 1	39.5	Turns ON	Turns ON	37.5	Turns OFF	YES
Participant 2	40.4	Turns ON	Turns ON	37.2	Turns OFF	YES
Participant 3	41.9	Turns ON	Turns ON	37.5	Turns OFF	YES
Participant 4	42.6	Turns ON	Turns ON	37.4	Turns OFF	YES

3.2 CONCLUSION

One of the most promising innovations for treating arthritis pain has to be glove developed specifically for those with hand arthritis. The ability of cooling to be integrated with vibratory stimulation using an inexpensive and portable device created by the combination Peltier chip, along with PID-controlled vibrators offers a versatile approach for arthritis symptoms. By analyzing physiological data collected by the sensor, the PID controller can accurately assess the user's likelihood of having a high body temperature and deliver immediate cooling. The PID controller will utilize the sensor data to dynamically regulate the temperature of the gadget based on the user's body temperature. This will aid in mitigating the transmission of excessive thermal energy by assisting the user in avoiding burns on their fingertips. The PID Controller is utilized to automatically regulate the temperature by activating the cooling mechanism through a Peltier chip when the user's body temperature surpasses the predefined threshold, based on feedback. This functionality, combined with the product being ergonomic and easy to use, increases its utility. Thus, while the early results appear to be encouraging there is a need for further studies on larger sample size and also research in long-term efficacy as well as safety.

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