Wearable Haptic Device For Proprioceptive Rehabilitation

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Abstract- *Proprioceptive rehabilitation is an important part of restoring motor coordination and proprioceptive awareness in people with neuromuscular disorders, after stroke, and with musculoskeletal injuries. Conventional rehabilitation techniques fail to provide feedback in real time, which restricts their benefits. This work introduces the Wearable Haptic Device for Proprioceptive Rehabilitation (WHD-PR), which improves therapy delivery incorporating force-sensitive sensors, vibrotactile feedback, and graphical representation. It includes five force sensors on the fingers where the force experienced is sensed and sent through voltage-controlled vibrations on the arm that is proportional to the force. Signal noise is reduced with transistors, LCDs showcase real-time values of forces, while integration with LabVIEW allows haptic responses to be graphically visualized, enabling better therapy analysis. Integrating these two modalities with body-worn sensors, this low-cost device weighs only 112 gm and is effective for use in clinic and home, while providing automated feedback-loop control to improve motor recovery and therapy delivery.*

Keywords- Wearable haptic device, proprioception, rehabilitation, force sensors,vibration feedback, LabVIEW Integration.

I. INTRODUCTION

Impairments due to neurological or musculoskeletal conditions can limit function in daily life and necessitate rehabilitation. Traditional approaches depend on the availability of physiotherapists to perform biomechanical assessments and physical rehabilitation, but whether they will be effective in practice can depend heavily on patient compliance and clinical access.

Our Wearable Haptic Device for Proprioceptive Rehabilitation is an innovative device that delivers real-time feedback through sensory stimulation. The device includes five point force sensors in each finger and changes vibration on the arm depending on the force exerted. This increases proprioception, and proprioception equals motor control and recovery.

It provides the feature of real-time force measurement using an LCD and its graphical representation in LabVIEW to be able to make precise therapy adjustments. Integrated switching units reduce noise interference for precise feedback.Our device provides a portable, interactive rehabilitation tool which increases patient participation, minimizes reliance on the clinic, and enables customized rehabilitation. Emerging technology will facilitate proprioceptive rehabilitation via wearable haptic devices in the future, ultimately improving recovery times and minimizing dependence on the rehabilitation process

II. LITERATURE REVIEW

Proprioceptive rehabilitation is an integral part of neuromuscular rehabilitation designed to help individuals with neurological injuries or musculoskeletal disorders. Traditional rehabilitation requires physical therapy exercises performed under the supervision of a therapist with compliance by the patient to achieve efficacy. In contrast to such previous approaches, inherent proprioceptive training has gained recent attention through the development of wearable devices that provide real-time feedback using haptic technology.

Research into wearable haptic devices targeted at motor control and rehabilitation has been abundant. Research reveals proprioceptive awareness could be enhanced with haptic feedback mechanisms provided as incentive enabling movement correction. In one study utilizing haptic-based rehabilitation for patients with stroke, vibratory feedback that targets certain muscle groups was reported to enhance sensory integration and motor coordination. [1] A study on force-sensitive wearable systems showed that real-time pressure information for body surface can improve grip strength and fine motor control in individuals with hand.[2]-

Recent efforts have also been devoted to combine haptic devices along with real-time monitoring and visualization of the data. Studies about rehabilitation implemented with various biofeedback have concluded that the basic visualization of sensory reactions by platforms such as LabVIEW allows for practitioners/therapists to inform patients via biofeedback by graphs more easily than not utilizing graphs. [3] The translational studies focussing+ on the fusion of electronics in rehabilitation devices not only highlight the need for noise elimination by optimized circuit designs (i.e. use of transistors to eliminate noise in signals). [4]

Wearable rehabilitation is moving towards personalized therapy more. Adaptive strategies for haptic feedback using AI-driven models have also been assessed, where the vibration level was adjusted to patient-centric demand, which increased engagement and efficiency of rehabilitation.[5] Additional research using force-sensitive rehabilitation gloves has established that varied sensory feedback aids in neural plasticity, thereby enhancing the recovery of post-injury patients with real-time changes in forces to support functional range of motion that develops and refines over time. [6]

Proprioceptive training via haptic feedback has been applied not only in medical rehabilitation but also in sports science and virtual reality. Haptic suits used on athletes to stimulate balance and coordination through focused vibratory stimulation. [7] Likewise, using virtual reality based proprioceptive training and haptic feedback has been shown to be effective for motor recovery in neurological disorders. [8]

Evidence from multi-sensory feedback systems have shown that when haptic feedback is paired with auditory and visual feedback, rehabilitation is improved. Research suggests that providing proprioceptive feedback related to synchronization of sensory cues enhances motor learning in patients recovering from neurological injury and increases movement accuracy (i.e., precision of responsiveness) [36]. Haptic feedback mechanisms in exoskeleton based rehabilitation have been integrated to provide help for patients with motor impairments [9]. Haptic sensors for real-time perception of forces integrated in exoskeleton designs helps with compensating movements towards restoring the impaired motor function. Such systems have been developed with a good level of efficacy for rehabilitation at the post-stroke stage using controlled vibratory feedback to promote neuromuscular adaptation. [10]

Wearable haptic devices have the potential to transform proprioceptive rehabilitation, when the need for a portable, cost-effective solution for rehabilitation becomes even stronger. The precise mechanism works along with a combination of force sensors to monitor real-time information along with noise reduction techniques. Ongoing advancements in AI and machine learning will continue to improve adaptive feedback systems, personalizing therapy and facilitating access to interventions.

III. EXISTING SYSTEM

Proprioceptive rehabilitation is central to the rehabilitation process of neuromuscular injuries, stroke or musculoskeletal disorders. Classical rehabilitation is mainly based on supervised exercises with a physical therapist. The exercises may include balance training, joint movement control, resistance exercises, and sensory re-education to regain proprioceptive awareness and motor coordination. Despite their effectiveness these conventional rehabilitation methods have serious limitations related to accessibility, efficiency, and compliance. The biggest drawback of the current system as it needs a therapist in the rehab center every time for a patient. This is especially difficult for people with mobility problems or those living in places far away from well-equipped clinics or medical facilities. Also, the conventional approach to rehabilitation invariably depends entirely on the observation of the therapist and lacks real time, measurable feedback on which progress of patients can be accurately quantified. Therapeutic efficiency reduces as due to absence of feedback, patients often fail to self-correct incorrect and improper movements. The other is the repetitive nature of rehabilitation exercises that can induce lower motivation and adherence, delaying recovery.

Biofeedback-based rehabilitation systems have been proposed to counter some of these issues. These systems use force-sensitive mats, electromyography (EMG), and motion capture to give immediate feedback about movement performance. In some rehabilitation set-ups, patients receive visual feedback about their movement on screen in graphical form and can correct their movements. For this reason, most of these systems require special cameras and equipment which ultimately adds to the cost and expense of home-based rehabilitation to be impractical.We believe recent advancements in the development of wearable rehabilitation technology have proven the value of incorporating haptic-based feedback devices to facilitate proprioceptive training. They deliver vibratory stimulation, electrical impulses, or mechanical resistance to direct movement correction. These tools encompass haptic gloves, force sensitive wearable devices to enhance grip strength and provide feedback to improve fine motor control, as well as systems focused on virtual reality for rehabilitation in which patients play interactive simulations with guidance of a therapist. A few systems even go as far as to pair with robotic exoskeletons that help with motor recovery by providing haptic feedback for accurate movement correction. Although these approaches are maturing, current wearable rehabilitation devices are still limited. Some are costly, need special training in order to use them or do not provide real-time force measurements, which are crucial when the aim is personal proprioceptive training. Furthermore, noise interference in the sensor-based systems leads to high accuracy, and many devices do not adapt to an individual patient.

Wearable rehabilitation devices can benefit from a more effective proprioception training by providing real-time force-sensitive feedback, reduced noise through optimized circuit designs, and user-friendly visualization tools. New future of rehabilitation with the systems that are accessible and affordable and patient-specific and therapy-oriented to enable recovery and better quality of life in your home environment.

IV. PROPOSED SYSTEM AND METHODOLOGY

The proposed system introduces a wearable haptic device designed for proprioceptive rehabilitation, offering an innovative solution to enhance motor coordination and sensory awareness in individuals recovering from neuromuscular impairments.It consists of five force sensors embedded in the fingers to quantify the pressure changes that occur during movement. These sensors communicate the data to a microcontroller that decodes force magnitude and adjusts the related haptic feedback. To enhance the perceptual-motor coupling, we align the Vibration motors on the arm where each touch applies specific force and provides a local vibration with respect to load force. It uses a noise immune optimized switching unit based on transistors for assured data transmission. The current force readings are displayed on an LCD in order for the user to be informed about the force being applied to the rehabilitation equipment while the collected data is visualized graphically through LabVIEW software allowing to monitor the rehabilitation progress accurately.

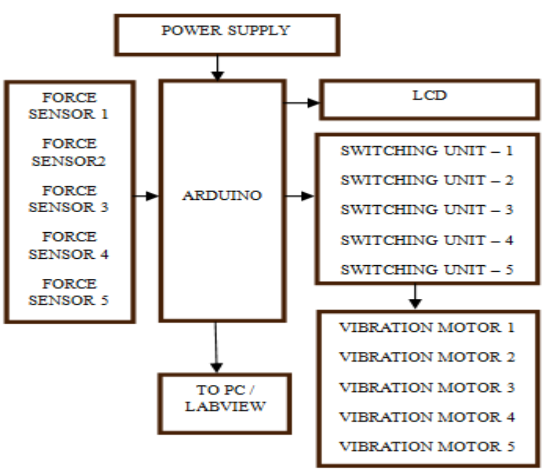

Fig 1. Block diagram

A. FORCE SENSOR

Force sensors are the import component of the system where it allows to record the amount of force that is being applied by each of the fingers while conducting rehabilitation exercises. The sensors as well sense the changes in the pressure applied and send real time data to the microcontroller. The system dynamically adjusts the strength of haptic feedback according to the force levels detected, to promote the correct motor patterns. Patients need to feel what they are putting in and be corrected immediately to understand exactly what they are receiving back, enhancing their proprioception. By using multiple force sensors, the condition of each finger can individually be checked to enable a detailed rehabilitation process that canbe adaptedindividually.

Fig 2. FORCE SENSOR

B. VIBRATION MOTOR

Vibration motors aligned on the arm will trigger when the sensors surface force is detected. They activate their respective vibration motor at an intensity directly proportional to the amount of pressure applied by the user. This feedback allows the patient to help them identify and modulate their force application in a way that promotes better motor control and sensory awareness. This means that the varying degree vibration levels act as motivation for the patient to keep the right level of force so that the rehabilitation process will be much more fun and effective. Multiple vibration motors ensure localized feedback to specific muscle groups for neuromuscular recovery.

Fig 3. VIBRATION MOTOR

C. ARDUINO UNO

The central control unit of the proposed wearable device for haptic feedback during proprioceptive rehabilitation is the Arduino Uno, which receives signals from force sensors in the fingers and controls vibration motors to perform real-time haptic feedback. It interfaces with ATmega328P microcontroller to digitize the analog values from the force sensors by appropriately deciding the vibration intensity, proportional to the applied force. The vibration strength is lowered using Pulse Width Modulation, which increases proprioceptive awareness through the enhancement of muscle memory. To minimize noise, a switching unit with transistors was added, which guarantees proper signal transmission. Communication between Arduino Uno and LabVIEW is established via USB interface, which allows electronic monitors to evaluate the efficiency of therapy sessions. This unit was chosen for the device due to its small dimensions, low weight, low power demand, and user-friendly programming interface, making it appropriate for autonomous rehabilitation while allowing users to minimize the need for a therapist's supervision.

Fig 4.ARDUINOUNO

D. OUTPUT DESIGN

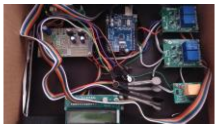

Fig 4. device for proprioceptive rehabilitation.

V. FUTURE ENHANCEMENT

Future improvements on the wearable haptic device use AI technology for feedback so that it can provide customized rehabilitation by looking at the user's movements. Adaptive feedback makes personalized rehabilitation easier. Improved Bluetooth or Wi-Fi capabilities make remote monitoring possible in real time. Enhanced precision will result from improved force sensors and vibration motors, while comfort and usability will be increased with the use of miniaturized flexible electronics. The use of VR and AR has the potential to make rehabilitation more engaging and faster. Integration of these technologies will increase the effectiveness, usability, and intelligence of the device so that it can be used with more patients suffering from different musculoskeletal and neurological disorders, subsequently improving their wellbeing.

VI. RESULT AND CONCLUSION

- The wearable haptic device designed for proprioceptive rehabilitation effectively promotes motor recovery by delivering real-time sensory feedback rooted in force detection. This innovative system features five force sensors strategically embedded in the fingers to gauge the pressure exerted, with this information relayed to a microcontroller responsible for modulating the vibration intensity felt on the arm via haptic feedback. An LCD monitor enables users and therapists to observe real-time force values, facilitating instant progress tracking.
- The integration of LabVIEW enhances the rehabilitation experience by providing graphical representations of force fluctuations and vibratory reactions, thus ensuring accurate movement adjustments.Furthermore, a transistor-based switching unit is incorporated to reduce noise interference, significantly enhancing the precision of force measurement. The device's portability supports home-based rehabilitation, effectively lessening reliance on therapists while ensuring sustained efficacy. More than just a cost-efficient solution, this system not only heightens proprioceptive responsiveness but also fortifies neuromuscular coordination. It proves particularly beneficial for individuals recovering from strokes, musculoskeletal disorders, or various motor impairments, empowering them to restore functional movement with improved accuracy and efficiency.

REFERENCES

[1] Rumshaa Yunus, Sara Ali and Yasar Ayaz (2020), ‘Development and Testing of a Wearable Vibrotactile Haptic Feedback System’, IEEE Access, Vol. 8, pp. 35172-35184.

[2] Martina Lapressa and Christian Tamantini (2020), ‘A Smart Solution for Proprioceptive Rehabilitation through M-IMU Sensors’, IEEE International Workshop on Metrology for Industry 4.0 & IOT, pp. 591-595.

[3] Matteo Rossi, Matteo Bianchi and Edoardo Battaglia (2019), ‘HapPro: A Wearable Haptic Device for Proprioceptive Feedback’, IEEE Transactions on Biomedical Engineering,Vol. 66, No. 1, pp. 138-149.

[4] Tim Bakker, David Abbink and Roel van Deventer (2017), ‘Development of a haptic device with tactile and proprioceptive feedback for spatial design tasks’, IEEE International Symposium on Mixed and Augmented Reality (ISMAR-Adjunct), pp. 223-228.

[5] Bulmaro A. Valdes and Mahta Khoshnam (2019), 'Robot-Aided Upper Limb ProprioceptiveTraining in Three-Dimensional Space', IEEE 16th International Conference on Rehabilitation Robotics (ICORR), pp. 121-126.
[6] Ahmad Hassan Kobeissi, Riccardo Berta and Hussein Chible (2017), 'Design and Implementation of an IOT System for enhancing proprioceptive training', 29th International Conference on Microelectronics (ICM).
[7] Shrey Pareek,Pramod Chembrammel and Thenkurussi Kesavadas (2018), 'Development and evaluation of Haptics-based Rehabilitation System', International Symposium on Medical Robotics (ISMR).
[8] Muhammad Raheel Afzal and Sanghun Pyo (2016), 'Haptic Based Gait Rehabilitation system for Stroke Patients', IEEE International Conference on Intelligent Robots and Systems (IROS), pp. 3198-3203.
[9] Lillian Chin, Michelle C Yuen, Jeffrey Lipton (2019), 'A Simple Electric Soft Robotic Gripper with High-Deformation Haptic Feedback', International Conference on Robotics and Automation (ICRA), pp. 2765-2771.
[10] Abdul Malik Mohd Ali and Sabilah abdul Halim (2017),'Biomechatronics Design of a Robotic Arm for Rehabilitation',InternationalConferenceonEngineering Technology and Technopreneurship(ICE2T).
[11] Haowei Ma (2020), 'Research on Control Method of Arm Rehabilitation Robot based on BP Neural Network', International Conference on Aviation Safety and Information Technology', pp. 710-713.
[12] Edmund F Hodkin and Yuming Lei (2018), 'Automated FES for Upper Limb Rehabilitation following Stroke and Spinal Cord Injury', IEEE Transactions on Neural Systems and Rehabilitation Engineering, pp. 10667-1074.
[13] Alexander R Dawson Elli and Peter G Adamczyk (2020), 'Design and Validation of a Lower Limb Haptic Rehabilitation Robot', IEEE Transactions on Neural systems and Rehabilitation Engineering, Vol. 28, No. 7, pp. 1584-1594.
[14] Evan Pezent and Ali Israr (2019), 'Tasbi: Multisensory Squeeze and Vibrotactile Wrist Haptics for Augmented and Virtual Reality', IEEE World Haptics Conference.
[15] Angelo Basteris, Tegan Plunkett and Sara Contu (2018), 'Robot Aided Bimanual Assessment of wrist proprioception in people with acute stroke',7th IEEE International Conference on Biomedical Robotics and Biomechatronics(Biorob), pp. 473-478