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Design of a Pneumatically Actuated Wearable Glove for Stroke and Injury Rehabilitation

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***Abstract*— Hand rehabilitation is used to assist people who are recovering from a stroke or injuries to the hand. Repeated exercises will facilitate recovery of movements. This paper describes a low-cost pneumatic glove without sensors and designed for use in passive hand therapy. The system is comprised of soft, air-filled bellows along the fingers that cyclically inflate and deflate with the use of a small air pump. The Arduino Uno drives solenoid valves to control the flow of air and produces repeated opening and closing hand motions,i.e. simple therapy exercises. Unlike other rehabilitation devices which require expensive sensors and feedback control, the glove is low-cost while still having a simple design and able to allow proper joint movement and provide activation of muscles. Results from the tests that have been carried out show that the glove provides smooth and repeatable motion. Hence the glove is suitable for use in early-stage therapy. The lightweight, modular parts and portable structure of the glove make it comfortable to wear and easy to use in both clinics and therapy at home. The glove provides an affordable and scalable solution, especially in resource poor settings.**

***Key words*— Hand Rehabilitation, Pneumatic Glove, Soft Robotics, Passive Therapy, Wearable Assistive Device.**

I. Introduction

Recently, actuator soft pneumatic has been able to be used for hand rehabilitation. It helps fingers open and close smoothly, so that they have good control, comfortable and flexibility to use [1], [2], [3]. Most glove systems use light and flexible materials as can be worn by the user for a long period of time without getting tired or uncomfortable when wearing [3], [5]. Various system open and close fingers are both a lot more effective and helpful in rehabilitation [6], [9].Soft inflatable actuators help to provide fine gripping control and better controlled motion which helps the patients to improve their fine motor skills during rehabilitation [5]. The addition of sensors in the glove allows the feedback from the system, rehabilitation to be safer and more effective [7], [11]. Pneumatic rehabilitation gloves have been very promising for clinical and home rehabilitation.

Their simple design, non-invasive, affordable and easy to use makes it suitable for people that require long-term therapy, without getting tired or uncomfortable when wearing [4], [8], [10], [12]. These gloves allow the user to make repeated hand movements that help to activate the muscles, rehabilitation to rebuild strength and regain their mobility, helping the user to become more independent in their daily activities.

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This paper describes the design and testing of a smart pneumatic glove designed to improve hand motion. This glove helps easy and natural to use for rehabilitation by enabling fingers to move in a smooth way by controlling the air pressure inside the glove. This design focuses on low cost, adaptable and easy to use for rehabilitation both in hospital and at home.We have done a hospital survey to develop our project, to gather information about rehabilitation for stroke patients and people who had an accident that affected their hands. Rehabilitation through automated assistive devices used either in hospital or at home reduces the need for manual therapy, hence making rehabilitation more consistent, effortless and achievement oriented.

The glove helps to provide gentle assistance to help rehabilitate the hand in a safe and comfortable way. With repeated hand movements, users can gradually re-activate their muscles in a slow way and can have more mobility in the long run. Finally, it helps them to become more independent in their daily activities. This smart glove is a new advancement in rehabilitation technology. It is a very practical, low-cost and empowering way for recovery and functional improvement one at a time. Pneumatic powered gloves are an affordable, convenient and easy access way to hand therapy. It’s simple and easy-to-use design is suitable for clinic-based therapy as well as rehabilitation at home by the user itself to regain its hand mobility. To have better understanding of rehabilitation needs for stroked patients and people who had an accident that affected their hands, we also conducted a hospital survey in the development of this system Practice, repetition of movements and feedback are the keys to re-establishing skills and enhancing neuroplasticity in therapy. Virtual reality is the name we give to artificial environments created with headsets, motion sensors and more through which the patient sent to participate in an exercise and activity in real time. It is well known that VR is very useful for patients with different physical, neurological or psychological disorders due to the stimulation, control and easy modification of the therapy environment. the most recent advances in tele monitoring, supervision of therapy and analysis of data in real time have provided a stimulus for physiotherapy to access more people.

Fig: 1.Availability of physiotherapy in rural areas

II. Standard Methods

A. Virtual Reality

While in rehabilitation, VR can lower the patient’s pain and anxiety level by transporting them to interesting and distracting virtual worlds. VR can also be designed with social features that allow the patients to see others exercising or even interacting with people in virtual spaces to inspire them and guide their own exercises. VR physical therapy aligns with the motor learning concept of practice and repetition required to learn new skills. With VR, patients can exercise and practice movements they would not be able to perform in real life due to physical restrictions and/or safety concerns.

Fig:2 Virtual Reality

B. Wearable Technology

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Fig:3 Wearable Technology

C. Tele- Rehabilitation

The increasing availability of technology and remote healthcare systems has made telecommunication and digital technologies delivering rehabilitation services more feasible. Below is a summary of tele-rehabilitation physiotherapy. Tele- rehabilitation removes geographic barriers for patients living in rural and underserved areas, allowing access to physiotherapy without the need to travel long distances to see a specialist. This is particularly beneficial for patients with mobility challenges, recovering after surgical procedures, or those residing in healthcare-desert regions. Several patients may have difficulty learning how to use tele- rehabilitation and may not be comfortable with digital technologies. Tele-rehabilitation gives autonomy to patients to select times for their sessions, making it easier to fit rehab into their daily routines, which helps improve adherence to the Rehabilitation work.

Fig: 4 Tele –Rehabilitation

D. Robotic-Assisted Therapy

Robots offer precise help in physical therapies, minimizing human mistakes and providing therapies in a highly controlled way. Patients can regain mastery of essential daily activities through robotic systems which enable selection of task-specific exercises. This pertains to the skill of the brain to reorganize itself and create new neural connections. Through repetitive task training, robotic-assist therapy physiotherapy fosters neuroplastic changes, motivating the brain to adapt and recover from injuries. This type of rehabilitative physiotherapy uses robotic systems to assist recovery for individuals with neurological or musculoskeletal disorders. In rehabilitation robotic-assisted therapies, sensors, and AI are implemented to automate tasks as well as to facilitate repetitive exercises which assist in restoring a patient's function, strength, and mobility. Robotic systems can also be employed in stroke recovery, spinal cord injury rehabilitation, and in post- operative rehabilitation. The progressive data in assessing the patient's movement over time helps therapists brainstorm strategies for better practices. The robotic device can assist with passive range of motion exercises allowing limb movement.

III. LITERATURE SURVEY

Han et al. [1] designed a rehabilitation glove with wearable fiber- reinforced soft pneumatic actuators (SPBAs) for hemiplegia and stroke patients. The glove could bend up to 260° and deliver5.1 N fingertip force at 0.25 MPa, enabling stable grasping and rehabilitation movement. A sliding mode impedance control offered adaptive and safe performance. While adequate for everyday activity support, problems occur with motion freedom and precision force feedback, which could encourage actuators and sensor improvements.

Xie et al. [2] developed a smart soft composite structure actuated wearable glove (Glove-SSCS) consisting of SMA springs, steel sheets, and bending sensors. The 120 g glove enabled five-finger flexion (90–110°) and extension (30–40°) with higher comfort levels than for rigid exoskeletons, even though SMA durability and thermal safety remain concerns, and suggesting optimization in actuation and control in the future.

Ge et al. [3] developed wearable glove-based fabric-based pneumatic actuators (SFPAs) to provide assist with thumb abduction and finger flexion/extension. The fabric structure reduced weight while optimizing assistive force, enabling grasp restoration to be highly effective. Scaling torque is still difficult despite being promising, and sensing must be integrated for adaptive control. Sehun Park [4] developed wearable arm and hand rehabilitation devices by utilizing flat inflatable actuators. Compared to rigid exoskeletons, soft devices are safe, cost- effective, and light but provide strong support for forearm rotation and finger extension.

Experiments confirmed feasibility in mildly paralyzed patients but continue to have problems with slippage of the device and application to more severely paralyzed individuals. Refining anchoring strategies and clinical trials may be the way forwardable et al. [5] also made a light- weight rehabilitation glove with thermoplastic polyurethane (TPU) inflatable actuators that delivered 3 N fingertip force and sufficient motion for pinch grasp tasks. While effective to give personalized rehabilitation, external actuation pack usage limits portability and suggests future integration of small-sized rechargeable systems. Lai et al. [6] proposed a bidirectional soft rehabilitation glove with pneumatic flexion actuators and SMA spring- based extension actuators to support finger extension and flexion. The system improved response speed using a water- cooling system and showed great improvement in stroke patients' finger movement and grip force. Weight constraints and response time constraints, however, suggest future work on optimizing the actuator design and control for increased portability.

Zhang et al. [7] developed a soft robotic glove with an integrated fabric- based sensor for virtual reality– based hand rehabilitation. The system allows task-oriented training with real- time tracking of motion, and a light and dexterous design is provided. Durability and sensor calibration remain problems, indicating future need for adaptive control and wireless integration.

Chotisathiantham et al. [14] developed a wearable robot glove using additive manufacturing (AM) to provide light, adjustable, and biocompatible assistive support for hand rehabilitation. The glove performed normal types of grasps and object manipulation effectively, but fingertip geometry limited the grip force and spherical object handling, suggesting potential future modifications in geometry and cable tensioning.

IV. PROPOSED METHOD

The system under consideration is a wearable glove that aids hand rehabilitation through pneumatic actuation for patients recovering from a stroke or injury. It is fitted with flexible bellows along the fingers that expand and contract, causing the fingers to move and mimicking the natural opening and closing of a hand. Air from an air compressor is directed into the bellows through a set of solenoid valves controlled by an Arduino UNO microcontroller.

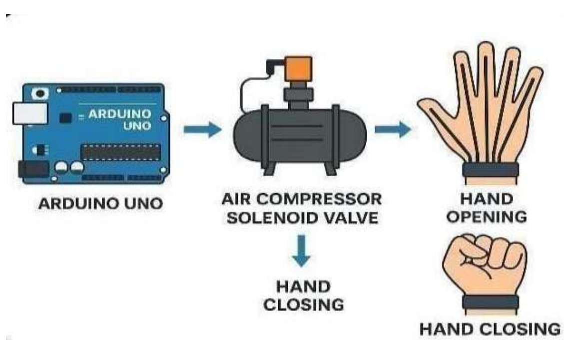

Fig. 5 Procedure to opening and closing of the hand

The solenoid valves are activated in turns based on a basic timed sequence written into the Arduino, allowing the glove to repetitively perform flexion and extension movements of the fingers. The system operates in passive rehabilitation mode, which means the glove carries out movements without any voluntary effort from the user [4]. This feature greatly aids patients in the very early recovery phases where active muscle movement is very limited. As with all passive rehabilitation devices, the glove is intended to be low- cost, user- friendly, and suitable for both home and clinic therapy sessions.

A. Arduino Uno

The Arduino Uno is a easy to use microcontroller board based on an Atmega328p [5] which is quite suitable for most of the embedded projects due to its simplicity and versatility. In our current project it works as the main controller due to its read input and send signals to the actuators [7]. It will turn on and off each of the solenoid valves at instance of time so that it can control the timing of the finger movements. It is quite natural that it will be good for real time rehabilitation system with actuators and sensors connected to its digital and analog input/output pins.
Technical specifications:

- Microcontroller: ATmega328
- Operating Voltage: 5V
- Input Voltage (recommended): 7-12V
- Input Voltage (limits): 6-20V
- Digital I/O Pins 14 (6PWM output)
- DC Current per I/O Pin 40Ma
- DC Current for 3.3V Pin 50Ma

Fig: 6 Arduino Uno

B. Air compressor

The compressor is the main air power supply for the system. The pressurized air that comes out of the compressor is used to inflate the pneumatic bellows (assistors for finger motion) [4]. The air that is supplied from the compressor should be safe and prescribed pressure (typical range: 0.2 – 0.4 MPa), so that the glove can only assist the motion and not cause any injury or pain to the user. Small and almost-silent compressors are used so that the system is portable and comfortable for the user.

C. Solenoid Valves.

A solenoid valve is an electrical device that controls the flow of air from the compressor to each of the pneumatic actuators of the fingers. Each valve connects to one finger below and is controlled by the Arduino Uno. When on, the valve is on and allows air to pass through; when off, the valve is off, and it stops the flow of air or releases it to the atmosphere. This “open-close” function allows us to program which fingers move, how often they move, and for how long, which enables personalized therapy for each user.

D. Pneumatic Bellows

Pneumatic bellows are soft (typically silicone or some other stretchy material) air chambers. They line the fingers of this glove and inflate when air pressure is introduced; they deflate as the air is released [6]. This motion mimics the natural movement of the joints and gives passive assistance in opening and closing the joints [4]. Since the actuators are pneumatic, they cannot hurt or inconvenience the user in any way while still providing a useful amount of force for therapy exercises.

V. RESULT

The glove managed to perform simple grasping and releasing activities. The movement was smooth and consistent. The air-powered system produced safe and soft motion and therefore was good for passive hand therapy. The initial testing results indicated that the glove can be used to support hand motion in a useful way and in a controlled manner.

Fig:7 Glove at ON position

Fig:8 Holding of bottle

VI. CONCLUSION

This project was made for a wearable smart glove for hand rehabilitation with Arduino Uno, bellows, air pump and solenoid valves. The motivation of the development is to provide gentle and passive finger movements with soft air- powered bending to rehabilitate persons who had stroke or hand injury. The inflation and deflation of the glove inflate and deflate the bellows attached to each finger, which cause controlled bending and straightening. On and Off from these actions are done by the solenoid valves controlled by the Arduino. This project provides repeated exercises of hand movement, which are very important in the early stages of rehabilitation, to avoid stiff joints and for better fundamental hand movement.I n t h i s p r o j e c t no sensors involved and not even smart control, I think this is one of the advantages; it shows that very helpful rehab devices can be made with only a few pieces.

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