SSURJET

Sir Syed University Research Journal of Engineering & Technology
2021, Vol. 11, No. 2,
https://doi.org/10.33317/ssurj.248

Assistive Device for Rehabilitation of Acute-Stroke Upper Extremity

Naveed Shahzad[1]

[1]*Department of Electrical Engineering, COMSATS Institute of Information Technology, Abbottabad, Pakistan*

Correspondence Author: Naveed Shahzad (nshahzad@cuiatd.edu.pk)

Received November 02, 2020; Revised October 07, 2021; Accepted November 02, 2021

Abstract

Stroke is one of the principal reasons for illness and death in elders in the industrialized world and the foremost source of disability all around the globe. Those who survive from stroke suffer from many neurological insufficiencies or impairments, such as hemiparesis, aphasia, cognitive deficits, or disorders in Visio-spatial perception. 70 % to 80 % of stroke survivors achieve the ability to walk on plane surfaces, 50 % of individuals gain limited communal ambulation and less than twenty percent get an unrestricted social gathering. Regular physiotherapy can be interrupted by other commitments of the patient or by the doctor's unavailability. This may lead to a delay in the recovery process. Therefore, efforts are needed to tackle the problem. The proposed device can be used to monitor and carry out selected exercises advised by the doctor. Here the upper right limb is our focus because it is the most common area to be affected. Furthermore, the android application is also designed which have different consoles for doctors and patients. The patient's app., shows the history and progress of the patient while the doctor sets the time and can also see the progress. Firstly, the unit tracks finger and wrist movements and the signal strength of the muscles being exercised and then performs assisted flexion/extension manipulation of the limb. The results are shown in the app., using graphs so that the patient and the doctor can both monitor the progress. Thus, this design gives ease to the patient as well as the doctor. With the world shifting towards smart devices and remote monitoring and control, there is a need to apply modern technology in the health department using the platform of Internet of Things (IoT), certain medical treatments can be made easier for the doctors and effective for the patients. By using different sensors, a microcontroller, Arduino software, mobile application, the patient's physiotherapy exercises can be monitored, recorded, and assisted.

Index Terms: *Stroke, Rehabilitation, Electromyography, Myoware, Blynk.*

I. INTRODUCTION

Stroke is a medical illness that has many causes i.e., high BP, obesity, smoking, etc. After ischemic heart disease, stroke is the second biggest cause of death worldwide, accounting for 10.2 % of all fatalities in 2016. Strokes were responsible for 67.3 % of all neurological-related deaths. In 2016, 5.2 % of worldwide Disability-Adjusted Life Years (DALYs) were lost due to stroke. Every year, around 15 million new people are diagnosed with a stroke around the world. Stroke prevalence has risen over the last three decades, with an annual increase of 14.3 % documented in low-income nations. Stroke prevalence, morbidity, and mortality have been reported to vary significantly between geographic locations and regions, particularly in nations with varying socioeconomic levels [1].

The stroke treatment is continuous physiotherapy. The doctor advises exercises to the patient which directly and indirectly work on strengthening the affected muscles. On a deeper level, this procedure speeds up the process of other neurons taking up the work of the injured neuron to supply signals to the attached muscle. The improvement rate due to physiotherapy is affected by age, regularity, and cooperation [2].

The improvement rate of a stroke patient can be increased if the patient maintains regular sessions. These sessions can be affected by the patient's commitments, the doctor's unavailability, and the patient's cooperation with the doctor. The proposed device can solve these issues by being available all the time and can be used at the patient's convenience. The doctor will only need to set time durations for different exercises and will monitor the progress remotely.

The described work in this paper involved the use of several sensors and the development of a handy data logging method. It is also cost-efficient [3].

Previously applied techniques had invasive Electromyography (EMG) as their core method. Invasive EMG is when a needle is inserted into the muscles under observation. Although the results are more accurate, they can be performed by trained individuals only.

The suggested device uses a non-invasive technique so that it can be performed by everyone. This proposed system is simple, lightweight, and allows for free movement when in operation. It is a low-cost device and can be used at home by stroke patients with little or no help from doctors or healthcare providers.

II. MATERIAL AND METHODS

Our proposed device has two modes i.e., monitoring and exercise. In monitoring mode, different sensors are used on the affected areas. Arduino has been used in this device to process and control signals generated from flex and Myoware sensors. The performed exercises activate the sensors and send data to the Arduino through ‘NodeMCU’, which displays it on the mobile application which has been developed in ‘Blynk’. The exercise data then become visible for doctor and patient, and they can observe the progress through the mobile application as shown in Figure 1.

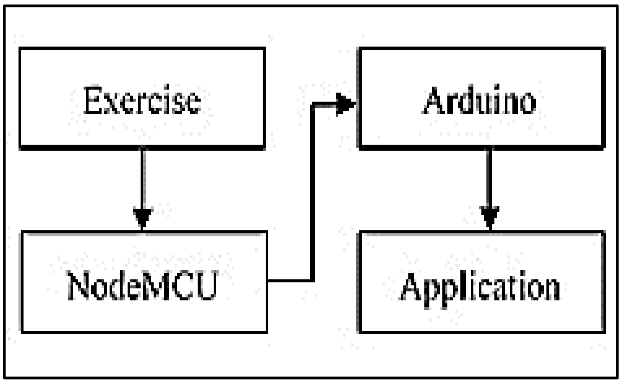

Figure 1: Monitoring Mode

The second is exercise mode. This assistive device is activated by the instructions given through the application from the first mode. The assistive device is designed for arm rehabilitation. This device can work in assisted movement and passive mode. Real-time instruction from the first mode is not needed for passive mode, only the time duration is set for this mode of operation [4]. For assisted movement, the threshold value for a set of exercises and the speed of the motor are set from the mobile application. In this mode, the doctor can control the device remotely, as shown in Figure 2.

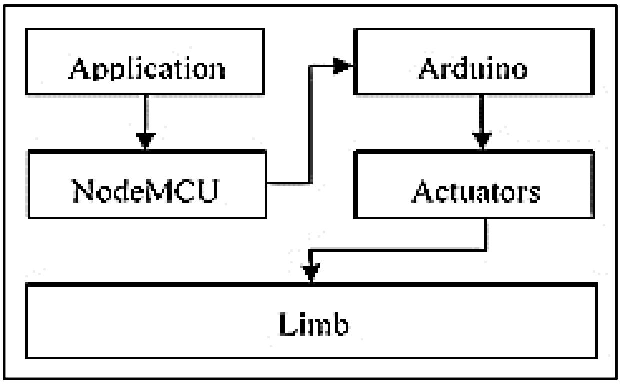

Figure 2: Exercise Mode

A. Flex Sensor

Total six flex sensors are used in flex gloves which are connected in a voltage divider network. Normal readings of the healthy persons performing the selected exercises were taken and their average is set as a standard. The standard and the patient’s readings both are displayed on the app., Through comparison with standard readings, the patient progress is monitored [5]. The flex sensor is shown in Figure 3.

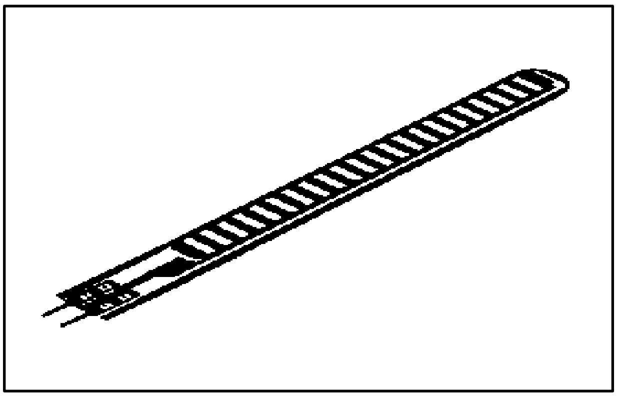

Figure 3: Flex Sensor

B. Muscle Sensor

Myoware sensor using the EMG signal is used to monitor the muscle strength of the patient while performing selected exercises.

The values are contrasted with the standard to track the patient’s progress, and the standard values were set by having the average values of the healthy person. Myoware sensor is shown in Figure 4.

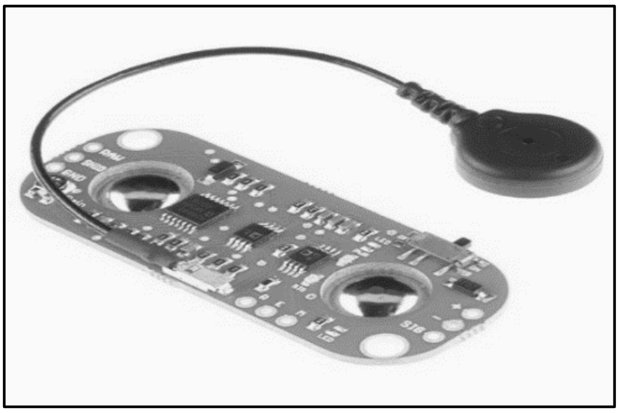

Figure 4: Myoware Muscle Sensor

C. Muscle Sensor and Assistive Device

An Assistive device is constructed to carry out passive and assisted movements. The passive movement of the limb can be carried out by activating the device and setting the time duration on the app. The “assistive” movement can be carried out by setting a threshold of muscle strength. As soon as the patient meets that threshold, the Assistive device will complete the motion. The threshold can also be set from the app., [6].

The best approach is to take readings according to healthy subjects and then score the patient accordingly [7].

There are three parts to the hardware of the project. The first is the flex glove, the second is the Myoware sensor and the third is the Assistive device. A certain set of exercises is allotted to each part and readings are taken and analyzed [8].

D. Flex Glove

A total of five exercises can be performed through the flex glove which can be monitored and uploaded to the patient and doctor’s applications. A set of readings are taken from healthy subjects to be kept as a standard for the patient. [9]. The flex glove is shown in Figure 5.

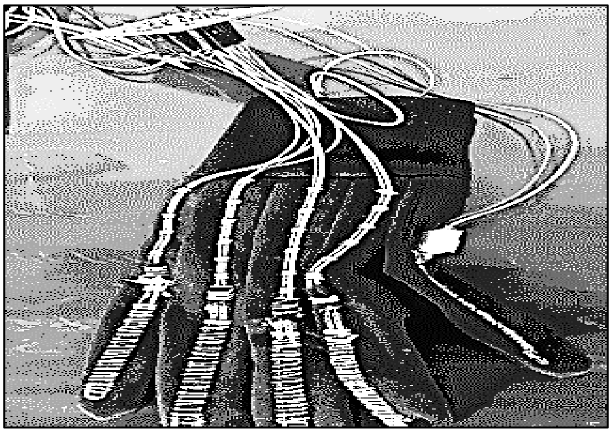

Figure 5: Flex Glove

We designed a questionnaire split into two categories such as socio-economic information and psychometric scale.
Exercises to be performed are:

- Thumb extension and flexion
- Wrist extension
- Power grip
- Full grips
- Clenched fists

a) Thumb Extension and Flexion:
Thumb Extension and Flexion are demonstrated in Figure 6.

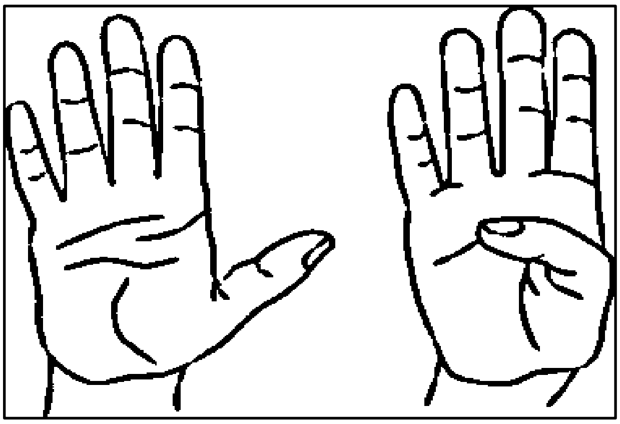

Figure 6: Thumb Extension and Flexion

b) Wrist Flexion:
Wrist Flexion is shown in Figure 7.

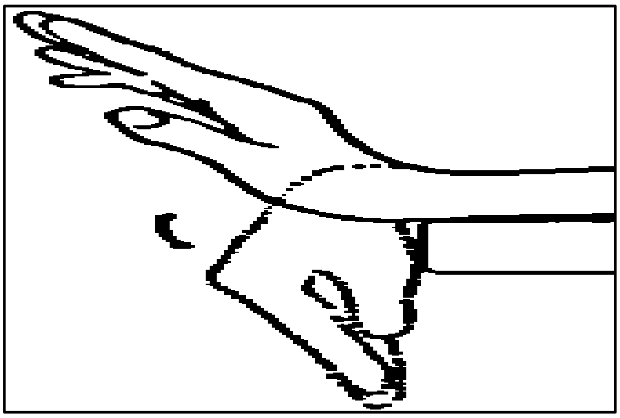

Figure 7: Wrist Flexion

c) Power Grip:
In this exercise, a softball is held in the hand and all the fingers are pressed into the ball, so that all the flex sensors are considered when taking the readings, except the one located at the wrist. Power Grip is shown in Figure 8.

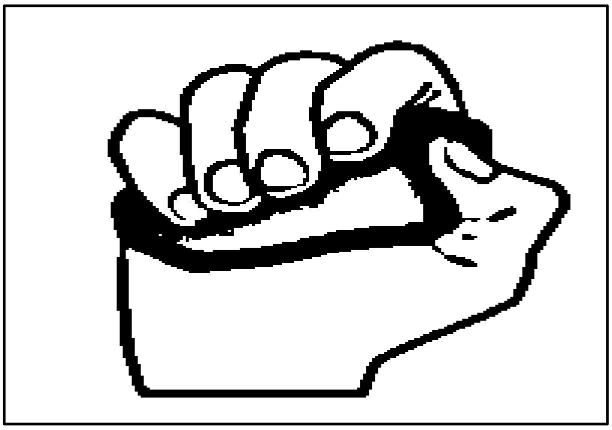

Figure 8: Power Grip

d) Full Grip:
All fingers except the thumb are forced into the ball in this exercise so that only certain fingers can be noticed when taking the readings [10]. The full Grip is shown in Figure 9.

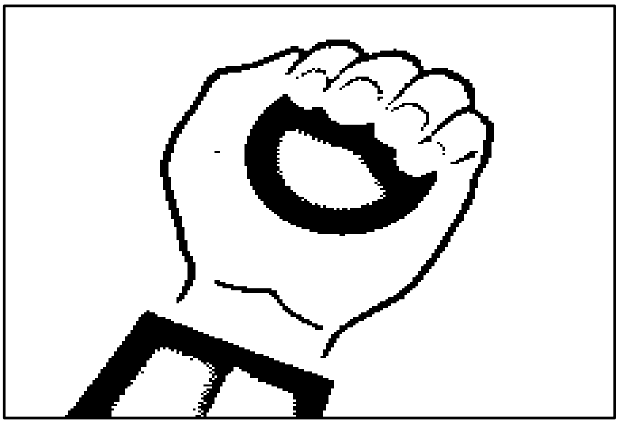

Figure 9: Full Grip

e) Clenched Fist:
The clenched Fist is shown in Figure 10.

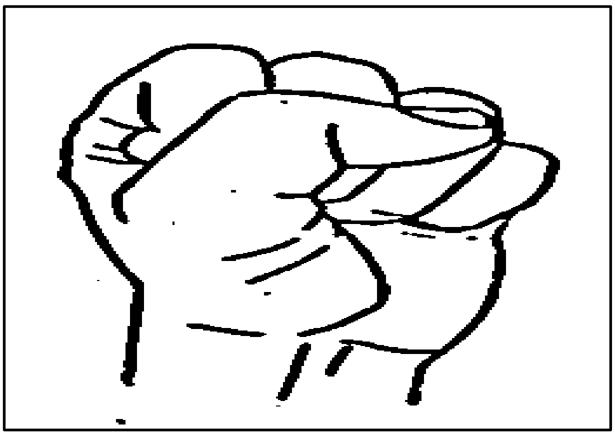

Figure 10: Clenched Fist

E. Myoware Sensor

Myoware sensor is used to study the signal strength of a patient. During the exercises, the peak and mean values of the graphs are taken.

Different grades of muscle power can be defined as:

Grade 0: No movement at all.

Grade 1: Flickering when attempting to perform instructed movement.

Grade 2: No movement against gravity, no external resistance applied.

Grade 3: Movement against gravity, 25 % bodyweight resistance.

Grade 4: Movement against gravity, 50 % bodyweight resistance.

Grade 5: Movement against gravity, 75 % bodyweight resistance.

III. ASSISTIVE DEVICE

An 'Assistive System' is designed to move the upper limb flexion/extension. Specifically designed to make it lightweight and portable The Assistive System consists of a wearable arm rehabilitation monitoring system based on flex and Myoware. We suggested using an elbow guard. A flex sensor is attached to the elbow guard to detect arm bending activities, and a Myoware sensor is used to detect muscle strength. [11].

A. The Range for Assistive Device

Inner, mid and outer limits are ranges for the movement of limbs. The proposed assistive system is to ensure that the patient completes mid-range everyday life tasks or Activities of Daily Living (ADL's). These activities include dining, bathing, dressing up, etc. [12]. The range for Assistive Device is shown in Figure 11**.**

Figure 11: Range for Assistive Device

B. Modes for Assistive Device

There are two modes of operation for the Assistive Device. The first is for passive movement, while the second is for assisted movement. The Myoware sensor and devices are mounted to the arm in both cases, and the device is then adjusted to one of two modes. Both approaches are discussed in the subsequent paragraphs.

C. Passive Movement

The first step of physiotherapy of a completely paralyzed patient is to perform the passive movement on the patient. When passive movement is performed, a stimulus is sent to the brain from the muscle that is being helped to move. This stimulus activates the portion of the brain neurons that are connected to the limb affected. The brain is helped to recognize the damaged limb as a part of the body with the help of this passive movement.
For this mode, the Myoware sensor threshold is set to zero from the application of the doctor. In this mode, only a time setting is needed for exercise [13].

D. Assisted Movement

Physiotherapy's second stage is to do assisted movement. The patient is advised to apply some force of his/her own during this stage and the rest of the movement is done by the physiotherapist. Over time as the patient's condition improves, the patient is forced to apply more and more force before the limb recovers to the degree that vigorous activity is practiced within the chosen range [14].
So, for this mode, the threshold of the Myoware sensor is set to zero and a simple check is applied. If the patient applies the specified amount of power, the machine is activated, and the movement is performed by it. If the patient fails to apply the specified power the machine does not perform the movement. From the value of the threshold, it is a numerical indication of how much the patient has improved [15]**.**

IV. MOBILE APPLICATION

The application involves a separate doctor and patient consoles. Blynk is one of the most popular Internet of Things (IoT) platforms that can connect different types of hardware to the Blynk server and can be used to design applications to control them. The applications can be designed by dragging and dropping different widgets. After designing the apps, these apps., are linked to the hardware through the Arduino software and controller [16]. Blynk is shown in Figure 12.

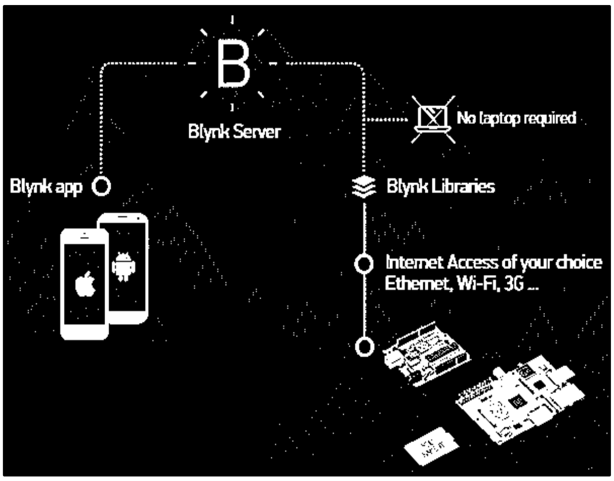

Figure 12: Blynk

The mobile application was specifically configured for doctors and patients. The various widgets used for the two apps., are as follows:

A. Numeric Input Setting

This widget is used to set the threshold value for the assistive movements. A value may be set in a range between minimum and maximum.

B. Slider

The speed of the motor is controlled with the aid of the slider which is used for assisted arm movement. The value can also be set between a minimum and maximum range. The slider is shown in Figure 13.

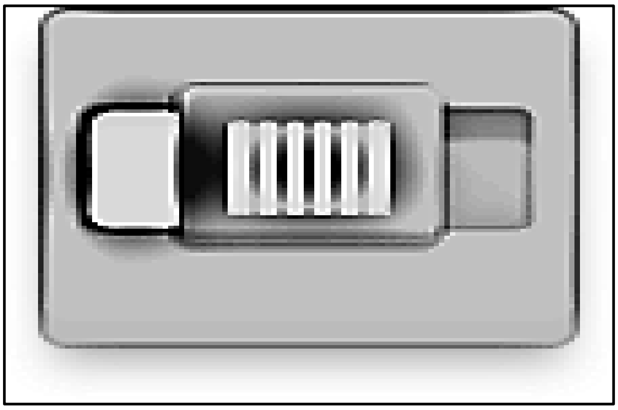

Figure 13: Slider

C. Vertical Level

This widget is used to show the progress to the patient and doctor. Value is also shown at the side.

D. Button

This text input is used for the doctor to send a message to the patient which will be displayed on the Organic Light-Emitting Diodes (OLED).

E. Super Chart

The Super Chart is used to see live and previous data. Super Chart is shown in Figure 14.

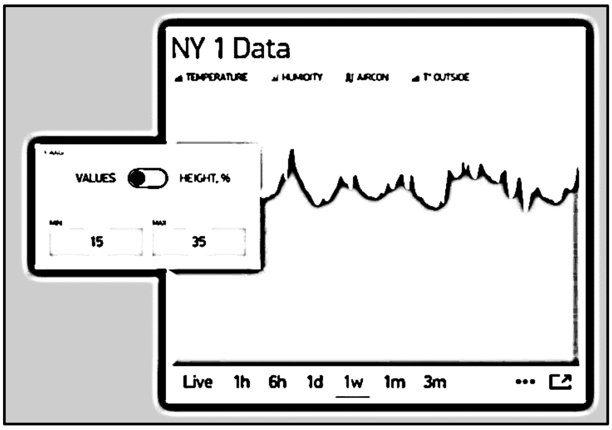

Figure 14: Super Chart

F. Timer

The timer is used to set schedules so that exercises can be performed accordingly [17]. The timer is shown in Figure 15.

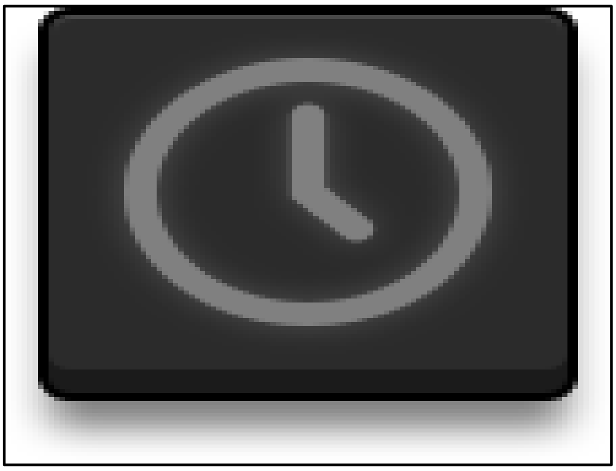

Figure 15: Timer

Mobile application which is developed for a doctor in which the exercises performed by the patient is observed and the instructions can be sent to the assistive device is shown in Figure 16.

Figure 16: App., for Doctor

The flow of the patient app., is shown in Figure 17

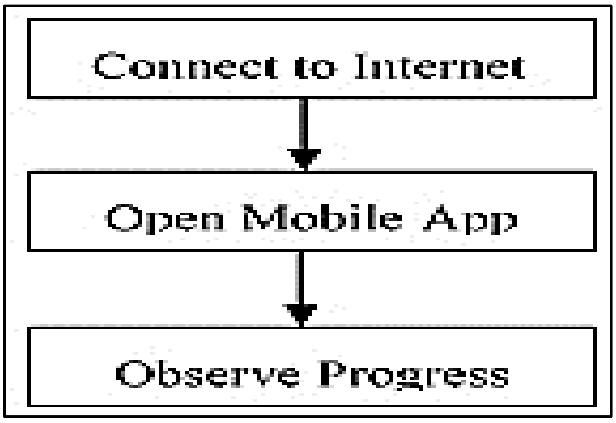

Figure 17: Patient's App., Flow

V. RESULTS AND DISCUSSION

Generalizations of data from patients with stroke cannot be achieved because there are several factors on which patient recovery is dependent, the main factors of which are:

A. Age

Neuroplasticity in the body decreases with age. Neuroplasticity is the ability of the body to repair neurons concerning the changes in the body. If a neuron is damaged, it is observed that it is repaired much quicker during youth rather than older age [18-21].

B. Left or Right-Sided Stroke

The recovery of a stroke also depends on whether the patient is left or right-handed and whether the stroke has occurred on the same side of the other. If a person is right-handed, the left side of the body is usually neglected as most of the work is done by the right hand so if this person has suffered a stroke in which the upper left limb has been affected, the recovery is slower.

C. Type of Stroke

The type of stroke which has occurred also has an impact on the rate of recovery. Ischemic stroke is shown to recover faster than hemorrhagic stroke.

D. Cognitive Status

Cognitive status refers to the state of mind of the patient and how much the patient is receptive to treatment. For example, if the patient is also suffering from Alzheimer's disease, then the patient keeps forgetting to exercise and stick to the schedule set by the doctor, thus delaying the recovery process.

E. Depression

For a depressed patient, it is difficult to find the willpower to work on the affected limb because of the extra effort. Proper support of family members and friends is needed to stay on track towards recovery.
After consulting various physiotherapists, a table was developed which links the grade of muscle power to the voltages produced in a healthy subject's arm.
The voltages obtained for a healthy subject for the different grades are shown in Table 1. This data is based on the muscle Flexor Digitorum Longus. i.e., the muscle used in flexing the wrist.

Table 1: Myoware Grading

GRADE NUMBER	VOLTAGES
Grade No 2	380 – 400 mV
Grade No 3	500 – 550 mV
Grade No 4	600 – 800 mV
Grade No 5	750 – 950 mV

The voltages obtained from the healthy subject for the muscle Extensor Digitorum Longus are shown in Table 2

Table 2: Myoware Grading (2)

GRADE NUMBER	VOLTAGES
Grade 2	400 – 450 mV
Grade 3	450 – 500 mV
Grade 4	550 – 600 mV
Grade 5	600 – 650 mV

The graph in Figure 18 is for Myoware when connected to the bicep muscle. When the muscle contracts the Myoware detects the contraction and makes the received signals readable for Arduino, then the graph is presented in the form of voltage.

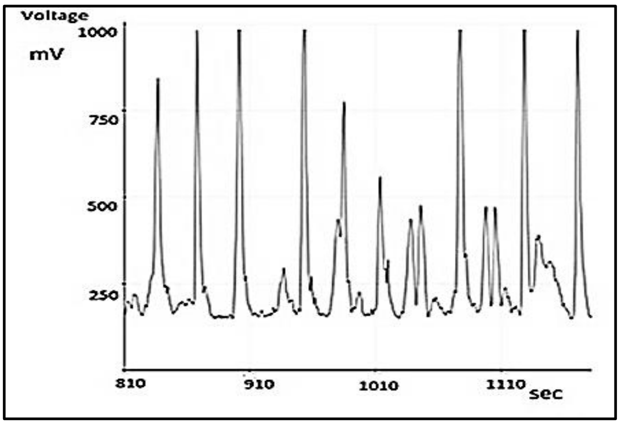

Figure 18: Bicep Graph

Figure 19 is the graph of the Myoware sensor when connected to the triceps, when the muscle contract the Myoware detects the contraction.

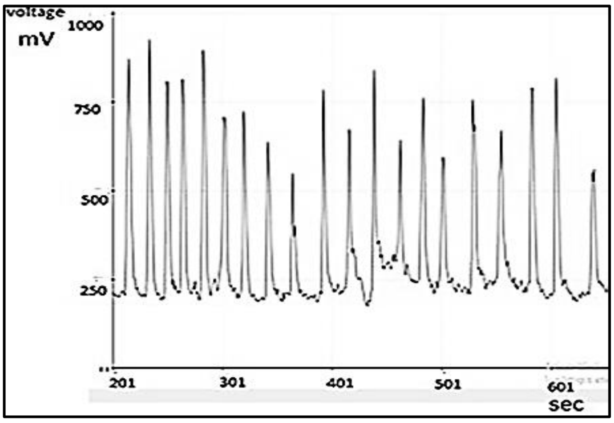

Figure 19: Triceps Graph

Figure 20 is the graph of wrist extension when Myoware is connected to the wrist. It detects the contraction of wrist muscles. Then the signals are made readable for Arduino and the graph is displayed in the form of voltage.

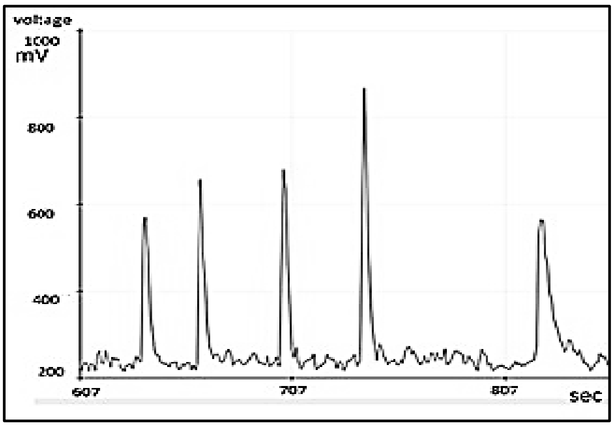

Figure 20: Wrist Extension

Figure 21 is the graph of the Myoware sensor when connected to the wrist flexors muscles, similarly, it detects the muscle power and makes it readable for Arduino. The reading received this time is greater than that of extensors. It means more power is required to train the flexor muscle group.

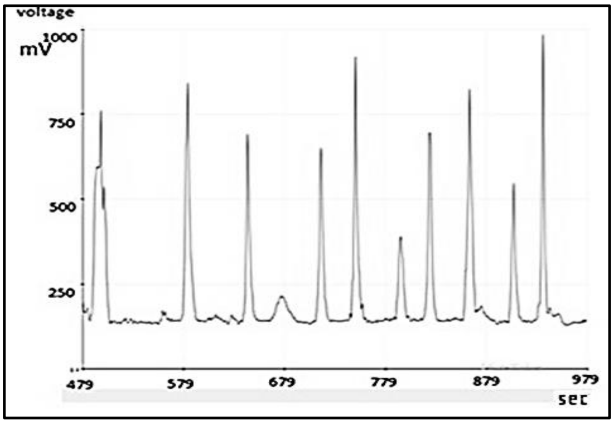

Figure 21: Wrist Flexion

One conclusion that can be drawn from these readings is that the voltages of the extensor muscle are less than the flexor muscle which supports the fact that more force is required to move the flexor muscle as compared to extensor muscle. Physiotherapists also agree with this fact because in their experience more work needs to be done on the flexor muscle as compared to the extensor to rehabilitate the patient.

Grade 0 and Grade 1 cannot be accounted for because a healthy subject will perform Grade 5 movements when instructed by the physiotherapist.

VI. CONCLUSION

A wearable arm rehabilitation device with a monitoring system was designed and proposed for post-stroke rehabilitation. The Arduino-based microcontroller system described here includes a flex, Myoware sensors, and an Android mobile application. This translates to many benefits like;

The proposed system is compact, lightweight, and does not restrict movement while in use.

Stroke patients can use this low-cost device at home with little or no assistance from doctors or healthcare providers.

The proposed system is simple to fasten to the arm with very little external help.

VII. FUTURE WORK

In future work, the same procedure can be applied to the lower limb. The assistive device that is to be designed should be able to be used for both the left and right limbs as designed for the upper limb.

Similarly, an application can be designed to keep the patient and doctor aware of the progress and to keep in sight of the future.

Acknowledgment

The author is very thankful to the Chairperson of the Department of Electrical Engineering, COMSATS Institute of Information Technology, Abbottabad, Pakistan and the management of the organization, for their support and their assistance throughout this study.

Authors Contributions

The author, Naveed Shahzad, confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

Conflict of Interest

The author declares no conflict of interest and confirms that this work is original and has not been plagiarized from any other source. The information obtained so far from all of the sources is properly recognized and cited.

Data Availability Statement

The testing data is available in this paper.

Funding

This research received no external funding.

References

[1] Sherin, A., Ul-Haq, Z., Fazid, S., Shah, B. H., Khattak, M. I., & Nabi, F. (2020). Prevalence of stroke in Pakistan: Findings from Khyber Pakhtunkhwa integrated population health survey (KP-IPHS) 2016-17. *Pakistan Journal of Medical Sciences, 36*(7), 1435.

[2] Ambar, R., Ahmad, M. S., Ali, A. M., & Jamil, M. A. (2011). Arduino based arm rehabilitation assistive device. *Journal of Engineering Technology, 7(*2011), 5-13.

[3] Talbot, K. (2014). Using Arduino to design a myoelectric prosthetic. Honors Theses, 1963-2015.55.

[4] Gamba, M. T., Nicola, M., & Motella, B. (2020, June). Galileo OSNMA: An implementation for ARM-based embedded platforms. In *2020 International Conference on Localization and GNSS (ICL-GNSS)* (pp. 1-6). IEEE.

[5] Marchal-Crespo, L., & Reinkensmeyer, D. J. (2009). Review of control strategies for robotic movement training after neurologic injury. *Journal of neuroengineering and rehabilitation*, *6*(1), 1-15.

[6] Konrad, P. (2005). The abc of emg. A practical introduction to kinesiological electromyography, *1*(2005), 30-5.

[7] Maceira-Elvira, P., Popa, T., Schmid, A. C., & Hummel, F. C. (2019). Wearable technology in stroke rehabilitation: towards improved diagnosis and treatment of upper-limb motor impairment. *Journal of neuroengineering and rehabilitation,* 16(1), 1-18.

[8] Takahashi, C. D., Der-Yeghiaian, L., Le, V., Motiwala, R. R., & Cramer, S. C. (2008). Robot-based hand motor therapy after stroke. *Brain,* 131(2), 425-437.

[9] Wu, J., Huang, J., Wang, Y., & Xing, K. (2010, November). A wearable rehabilitation robotic hand driven by PM-TS actuators. In *International Conference on Intelligent Robotics and Applications* (pp. 440-450). Springer, Berlin, Heidelberg.

[10] Fukuda, H., Morishita, T., Ogata, T., Saita, K., Hyakutake, K., Watanabe, J., ... & Inoue, T. (2016). Tailor-made rehabilitation approach using multiple types of hybrid assistive limb robots for acute stroke patients: a pilot study. *Assistive Technology,* 28(1), 53-56.

[11] Lucas, L., DiCicco, M., & Matsuoka, Y. (2004). An EMG-controlled hand exoskeleton for natural pinching. *Journal of Robotics and Mechatronics,* 16, 482-488.

[12] Reinkensmeyer, D. J., Emken, J. L., & Cramer, S. C. (2004). Robotics, motor learning, and neurologic recovery. *Annu. Rev. Biomed. Eng.*, 6, 497-525.

[13] Vanoglio, F., Luisa, A., Garofali, F., & Mora, C. (2013, April). Evaluation of the effectiveness of Gloreha (Hand Rehabilitation Glove) on hemiplegic patients. Pilot study. In *XIII congress of Italian Society of Neurorehabilitation* (pp. 18-20).

[14] Iwamoto, Y., Imura, T., Suzukawa, T., Fukuyama, H., Ishii, T., Taki, S., ... & Araki, O. (2019). Combination of exoskeletal upper limb robot and occupational therapy improve activities of daily living function in acute stroke patients. *Journal of Stroke and Cerebrovascular Diseases*, 28(7), 2018-2025.

[15] Iqbal, J., Tsagarakis, N. G., Fiorilla, A. E., & Caldwell, D. G. (2010, September). A portable rehabilitation device for the hand. In *2010 Annual International Conference of the IEEE Engineering in Medicine and Biology* (pp. 3694-3697). IEEE.

[16] Maciejasz, P., Eschweiler, J., Gerlach-Hahn, K., Jansen-Troy, A., & Leonhardt, S. (2014). A survey on robotic devices for upper limb rehabilitation. *Journal of neuroengineering and rehabilitation*, 11(1), 1-29.

[17] Mulas, M., Folgheraiter, M., & Gini, G. (2005, June). An EMG-controlled exoskeleton for hand rehabilitation. In *9th International Conference on Rehabilitation Robotics*, 2005. ICORR 2005. (pp. 371-374). IEEE.

[18] Kahn, L. E., Zygman, M. L., Rymer, W. Z., & Reinkensmeyer, D. J. (2006). Robot-assisted reaching exercise promotes arm movement recovery in chronic hemiparetic stroke: a randomized controlled pilot study. *Journal of neuroengineering and rehabilitation*, *3*(1), 1-13.

[19] Saeed, S. (2019). A Conceptual System on Ubiquitous Cardiovascular Health-Care System (UCHS). *Sir Syed University Research Journal of Engineering & Technology*, 9(1).

[20] Elderneedslaw.com. (2021). Activities of Daily Living and Medicaid Eligibility. Retrieved from: https://www.elderneedslaw.com/blog/activities-of-daily-living-and-medicaid-eligibility.

[21] Javed, S., Javed, H., Saddique, A., & Rafiq, B. (2018). Human Heart Disease Prediction System Using Data Mining Techniques. *Sir Syed University Research Journal of Engineering & Technology*, 8(II).