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A Proposed High Efficient Current Control Technique for Home Based Upper Limb Rehabilitation and Health Monitoring System during Post Covid-19

M. Veeresh Babu[1], V. Ramya[2], V. Senthil Murugan[3]

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Abstract*:* The COVID-19 outbreak necessitates an urgent restructuring of the rehabilitation system to accommodate those overcoming a terrible COVID-19 who have post-intensive care syndromes, may result in cognitive decline and physical deconditioning, individuals who have comorbid conditions, and other individuals needing medical treatment during the crisis with limited or no admission to hospitals. These individuals can benefit from giving access to cheap and high-quality treatment through home-based recovery, recognizing the obstacles to good facilities and services that social distance and stay-at-home mandates generate. Hence, the proposed a current based buck converter to control stepper motor strategy for upper limb Rehabilitation robots with high accurate measurement of movement and muscular force. Various mechanical structures, current sensor and driving circuits, a database, and adynamic user interface are among the function modules that have been created. Secondly, the proposed system is a real-time remote monitoring system that utilizes the Internet of Things (IoT) to track essential dynamic indicators of patients, including heart rate, blood pressure, and blood oxygen saturation function (SPO2). A wearable device with a microprocessor, Wi-Fi hardware, and sensors serves as the system's brains. The health indicators of an individual are recorded by sensors, and the sensor data is transfer to a cloud database via a Wi-Fi module. Utilizing a Windows application and a SQL database, the doctor may keep track of the patient's progress in real time.

Keywords: *necessitates, deconditioning, obstacles, microprocessor, sensor*

1. Introduction

The medical field and its clients have been notably impacted by COVID-19. Stroke patients are not an exception in this regard; there are currently 4 million stroke survivors in the US alone, and up to half of them deal with persistent motor deficits [1]. A considerable residual handicap affects around one-third of stroke survivors, and older people often recover functionally more slowly [2]. Because of hurdles to excellent rehab facilities and services created by social exclusion and orders to stay home as a result of the COVID-19 outbreak, these individuals struggle to continue their physical treatment. In addition, 32% of COVID-19 patients who have recovered already have concomitant diseases, like stroke, and post-intensive care syndrome (PICS) as a result of lengthy ICU stays [3,4].An intensive care unit (ICU) hospitalization was necessary for 20% of infected patients, among the individuals included in the study, 33% had acute respiratory distress syndrome, while 13% showed immediate heart damage, based on an extensive review of 18 Chinese researches and one Australian research [5]. A large number of COVID-19 positive patients have been taken to hospital, while hospital staff, including doctors and nurses, appears to be highly understaffed in comparison. According to the WHO, there should be one doctor for every 1,000 people and three nurses for every 1,000 people. A survey was conducted taking into account the present-day population of India, and the results show that the doctor to patient ratio is 1:1493 and the nurse-to-patient ratio is 3:1777. Controlling the disease over the nation has become a difficult task due to the enormous demand for healthcare staff. The strain of routine patient monitoring can be lessened using the system provided. This concept uses sensors to collect various patient data that must be precise and simple to incorporate on a wearable device.

1.1. Rehabilitation Robots

The complex robotic equipment is made must be carried by the patient in order to ensure synchronized functioning of the human body. Both the mechanical design and the motor torque [6] must be light-weight. The most technical challenge in design is how to harmonize human-machine interaction. If the limbs and therapy equipment are not correctly controlled, the implications could put patients in danger. People who are elderly, recovering from surgery, or have special needs are all very concerned about their health [7,8]. Monitoring his progress during his recovery while he is living at home has become necessary due to rising healthcare expenses and an ageing global population [9, 10]. People are too busy pursuing their careers to find

[1] *Research Scholar, Department of Computer Science and Engineering, FEAT, Annamalai University, Tamil Nadu, India*
[2] *Associate Professor, Department of Computer Science and Engineering, FEAT, Annamalai University, Tamil Nadu, India*
[3] *Department of Networking and Communications, Faculty of Engineering and Technology, SRM Institute of Science and Technology, Kattankulathur, Tamil Nadu, India*

time for healthcare. Due to the single-family lifestyle, elderly persons who live separately must be constantly monitored. Therefore, remote health care services have increasingly become a part of daily life[11].

The Remotely Operated Rehabilitation System can enhance long-distance communication among patients and therapists and expand physical therapists' comprehension of patient healing during recovery. One should anticipate an efficient rehabilitation program since the goal of rehabilitation is to teach patients how to use their muscles and joints. Today, most rehabilitation is centered on the rehabilitation engineer helping patients, doing assessments, creating rehabilitation plans, and using the hospital's rehab tools to aid patients. Patients are assisted in recovering by using an upper limb rehab device [12].

The Taiwanese government emphasizes medical care and social services [13]. The rehabilitation system has to be improved so that patients can take the role of the existing doctors, and the software must be rendered lightweight, portable, and small with a SQL database to offer more efficient treatment. Doctors can utilize this tool for patient monitoring therapy planning and collection by the practitioner to obtain recovery data about each patient, such as personal status, and to visually depict the level of recovery. When managing several patients, treatment can be carried out anyplace while also saving medical resources. While the body is recovering, it is still essential to create a healthy, safe, comfortable, and successful workplace.

A Raspberry Pi-based embedded kernel with a micro controller is used to implement controller designs in this research [14]. To measure data like motor position, motor velocity, and motor voltage, the microcontroller PIC18F4331 may create a DC motor or encoder. Additionally, it accepts PWM signals as an output. A direct control method that measured motor current was utilized in limb rehabilitation to regulate the pressure of action to help the patient at the right time in accordance with the pressure threshold point specified by their therapist. Stepper motors rather than DC motors are employed in upper-limb therapy to increase efficiency. It features a short step angle, a high control speed range, and no speed holding torque. Stepper motors use a triple-loop control with position, force, and speed rules without a position sensor to produce the desired result with precision.

1.2. Patient Monitoring

The diagnosis, medication, and monitoring of patients of health issues both within and outside of hospitals are all significantly impacted by the Internet of Things. IoT significantly affects lowering medical costs and enhancing medical results. The medical industry uses sensors, which may be objects or parts of the body, for things like electroencephalograms (EEG), electrocardiograms (ECG), body temperatures (BT), heartbeat rates (HR), blood pressure (BP), blood oxygen saturations, and so on. Additionally, it may record data about the outside environment, including humidity, air quality, date, and time [15], [19-21]. Patients and doctors could only communicate with one another through visits, phone conversations, and texts prior to the Internet of Things. There was no mechanism for a physician to check on a patient’s health and offer suggestions. With the development of IoT-enabled devices, it is now able to remotely observe patients in the medical field, enabling doctors to deliver excellent care while maintaining patients safe and healthy. Since doctor-patient contacts are now quicker and easier, patient satisfaction has risen. The ability to remotely monitor a patient's vital signs reduces hospital stays and prevents re admissions[20], [22].

The patient is at home when the remote patient monitoring system collects and transmitsthe patient's health data to a database using sensors. In order to collect details of the external environment, the sensors could be positioned in a home or connected to the patient's apparel, bed, wearable watch, etc. The medical professional uses computers, PDAs, tablets, and smartphones for supervision. Real-time remote monitoring allows for fast action in medical situations and early identification of some patient health issues [21], [23], [24].

2. The Proposed System Structure of Rehabilitation Robot Arm

A unique rehab robot arm with a patient monitoring system is suggested for workouts of upper limb motor function. This wearable gadget helps occupational therapy patients regain physical function through workouts that simulate daily activities while simultaneously keeping tabs on their health in the COVID-19 setting. For the rehabilitation system structure shown in Fig. 1, a unique design model has been created; the structure is also sufficient to be safe, easy, and effective. The work planned using dspic30f4011 microcontroller for controlling stepper motor, control the motor torque using current sensor, monitor the patient SPO2, heartbeat rate, and blood pressure and which transmit the data through WIFI module. The device has access to a medical database, so physicians can effortlessly maintain track on patient conditions for upper-limb rehabilitation. the Visual Basic .Net with data base management using Microsoft SQL Server Improved clinical tasks on the internet allow clinicians to remotely control the exoskeleton device's range setting.

The suggested rehabilitation system for the upper limb is greater to the current rehabilitation system [25] since the portable device is with market values, has the benefits of being compact, light, inexpensive, user-friendly, and opposes the function of muscle action. The suggested system features triple loop control with the addition of force of muscle motion function, which enhances the efficiency of patient and doctor rehabilitation training. The current rehabilitation system operates under double loop control of position and speed.

The proposed architecture entails a control platform using a DSPIC30F4011 microcontroller together with a planetary geared unipolar stepper motor, a stepper motor driver, an ACS712 current sensor, a Buck converter, a MAX30102 heart rate sensor, a CK-101 Blood Pressure Sensor, and a WIFI module, as seen in Figure 3. The unipolar stepper motor is utilized to improve precise positioning via DSPIC30F4011 control. By precisely synchronizing with the pulse signal supplied by the controller to the driver, the motor runs. The ideal option for applications requiring quick placement across a short distance is a stepper motor since it can produce a lot of torque at low speeds with minimal vibration.

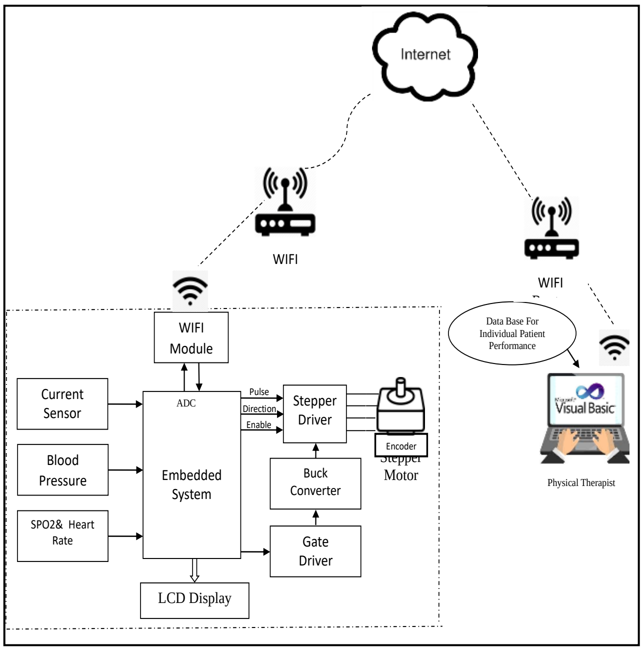

Fig.1. Proposed Rehabilitation System Architecture

A stepper motor, which rotates with a predefined step angle like a clock's second hand, increases the effectiveness of limb movement. The term "basic step angle" refers to this angle. Stepper motors from Oriental Motor are available with basic step angles of 0.36°, 0.72°, 0.9°, and 1.8°. Using pulse signals from the controller, the stepper motor's rotational angle and speed may be precisely regulated.

The pulse number (number of pulse signals) offered to the driver evaluate the rate at which the stepper motor rotates. The pulse signals, or pulse frequency, that are sent to the driver allow him to gauge the stepper motor's rotational speed. Stepper motors are compact and provide a significant amount of torque. These characteristics give them exceptional acceleration and responsiveness, making them ideal for applications demanding torque where the motor must often start and stop. To meet the need for increased torque at low speeds, Oriental Motor also provides geared motors that combine a compact size and high torque.

3. Hardware Specification

3.1 Current Sensor

To assess the pressure of muscle movements, the current sensor is interfaced with the analog pin of the DSPIC30f4011 controller. The current sensor value is taken according to the action switch action and output drive action which eliminates the ideal rest current and drive loaded current for patient action. The force threshold is then evaluated against the value of the picky current sensor to determine whether to aid or resist the patient's movements by operating the stepper motor. The motor is placed appropriately to stop the patient's limb movement when the measured force value is less than the specified force value. The motor travels to the next location at the appropriate set speed to support the patient's muscular movements when the measured force sensor value meets the specified value.The ACS712 device, which is seen in Figure 2, has a copper conduction channel that is close to the surface of the die and is exact, low-offset, and linear. Indicating the magnetic field produced by the applied current traveling down this copper conduction line, the combined Hall IC transforms it into a proportional voltage. The Hall transducer's accuracy is improved by the magnetic signals present nearby. The precision-configured, low-offset, chopper-stabilized BiCMOS Hall IC provides an accurate, proportional voltage after packing.

Fig 2. ASC712 Current Sensor

3.2 Node MCU Microcontroller

A board called NodeMCU is built on the ESP-12 module. It has an ESP8266 Wi-Fi module installed. It has nine digital I/O pins with built-in ADC, one analogue I/O pin, and works on a 3.3V power source. The device's specs include an on-chip Wi-Fi transceiver, 4MB of flash memory, and roughly 50k of useable RAM @ 80MHz [19]. The NodeMCU is shown in Fig. 1b.

Fig 3. ESP8266 Wi-Fi module

The VB.Net framework application (physical therapists) receives data from the DSPIC30F4011 control device (patient) through a Wi-Fi module. TCP/IP, also known as the Transmission Control Protocol and Internet Protocol, was developed to connect network devices on the Internet. TCP/IP's whole communication protocol outlines how information should be divided into packets, routed, transferred, and received at the destination. This describes the process through which data is transmitted via the internet. With a minimum amount of central management needs, TCP/IP is designed to render networks reliable and capable of automatically recovered from a failure of any device on the network. To monitor and store the data received from the DSPIC30F4011 control device (patient), a windows application is developed using VB.net framework using C sharp. The data is received from the web server and stored in the system using Microsoft SQL database and also application shows the current, force and angle respect to time plot is obtained with set points of speed and angle of limb motion, force threshold set value for assist or oppose motion.

3.3 The E2 Optical Encoder

An optical encoder is a transducer often used to measure rotational motion. A shaft that is connected to a disc that is round and has a track that alternately contains transparent and opaque areas that makes up the device. On the opposing sides of each track, a light source and an optical sensor are placed. The light sensor pulses when the shaft revolves because the design on the disc blocks the light source. This output signal could work well with digital circuits right away. The ratio of output pulses per second to the shaft's rotational speed may be computed since the number of output pulses produced by the disc each revolution is a known quantity. In applications that control motor speed, encoders are frequently employed. A straightforward, one-track E2 optical encoder wheel is shown in Figure 4. Two tracks that are 90 degrees out of phase with one another make up an incremental optical encoder that generates two outputs. The relative phase between the two channels may be used to identify whether the encoder is turning clockwise or counterclockwise. There is typically a third track that produces a single index pulse to serve as an absolute position reference. A relative location is all that an incremental encoder produces without this. A record of the exact location must be kept by the computer or interface circuitry.

Fig 4. E2 Optical Encoder

The E2 is a rotary encoder with a 5-pin locking or standard connector and a molded polycarbonate case. To provide digital feedback data, this optical incremental encoder is designed to easily connect to and remove from an existing motor shaft. The base, cover, hub/code wheel, and optical encoder module are the only four primary parts of the E2, making it simple to integrate into already-existing applications. Typically, applications with a length of 10 feet or less are suitable for the E2.

3.4 CK – 101 Blood Pressure Sensor

The CK-101 is an artificial wrist blood pressure monitor that can identify hypertensive patients' blood pressure and pulse rate. It is battery-powered, features an inflatable wristband, an integrated LCD display, and offers long-lasting performance and simple upkeep. Both the high pressure (SYS) and low pressure (DIA) are measured. The CK-101 Blood Pressure Sensor is depicted in Figure 1c.

Fig 5. CK – 101 Blood Pressure Sensor

3.5 MAX30102 Heart Rate Sensor

MAX30102 sensor that passes through the filtering and validation process. It monitors heart rate using the same methodology as PPG, but it also measures SPO2 using LEDs in a manner that is comparable to that of PPG. To obtain the ratio of the empirically deduced calibration curve, use IR/RED. The SpO2 and pulse testing system is suitable for use. Since recent developments have made it possible to place sensors outside of the body of the patient to monitor dynamic signs such oxygen level, temperature, pulse rate, etc., it follows that non-invasive sensors are likely to be accurate and produce trustworthy data. A sensor like MAX30102 uses the same minimally intrusive technique to assess the blood's oxygen content and heart rate.

Fig 6. Max30102 Sensor

When a blood vessel beats, this sensor reads the pulse and blood oxygen saturation utilizing various transmittances. The light source is a particular wavelength of a light-emitting diode that distinguishes between arterial blood's hemoglobin (Hb) and ox hemoglobin (HbO2). The change in the volume of the artery pulse causes the light transmittance to change, which is then turned into an electrical signal. Now the light reflected by the human tissue enters the photoelectric transducer, is converted to an electrical signal, amplified, and output.

3.6 Buck Converter and Driver

The buck converter revealed in Fig.8. is collected of the voltage of the DC-link as an input source (V_dc), buck inductor ($LBuck$), buck capacitor ($CBucll$), a diode (D), MOSFET (S) as a switch and the output voltage (V_Out) as an stepper motor voltage.

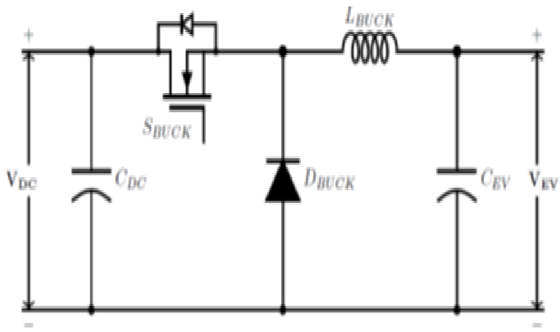

Fig.7. The Buck Converter diagram

The duty ratio is resolute from Eq. (1.12).

$$D_{Buck}=V_{Out}/V_{dc} \quad (1)$$

The buck converter's inductance for continuous current is estimated as follows:

$$L_{buck}=(V_{dc}-V_{Out})/(\Delta i_{LBuck}-f_s) \quad (2)$$

Δi_{Lbuck} (The ripple current) is intended as follows (taken as 13% of the charge current):

The output voltage ripple must not increase by 0.5%. The buck capacitor is considered using Eq. (1.14) .

$$C_{buck}=(1-D_{buck})/(8L\_buck((\Delta V_{Out})/V_{Out})) \quad (3)$$

4. Experiment and Results

The suggested upper-limb rehabilitation system enhances the training with current control stepper motor drive and implements the patient monitoring system with heart rate, oxygen level, blood pressure. Hardware controllers are used in this process to control and keep track of rehab patients. Data is transferred across long distances using VB-based Windows applications and the TCP/IP protocol.For data base storage and treatment outcome monitoring during rehabilitation, Net C sharp software has been established. The DSPIC30F4011 24-bit wide instructions used in the controller unit are designed by MPLAB Integrated Development Environment (IDE), which also created the 16-bit wide data path. NEMA17 planetary geared stepper motor of 60 kg/cm torque with Rhino Motion Controls (RMCS-1102) driver, ACS712 Current sensor is used to control the torque of the stepper motor using buck converter, MAX30102 and CK-101 sensor is used to monitor the patient condition like covid-19 pandemic. ESP8266-based Node MCU is an open-source platform that connects items. The calculated pressure is obtain full 100% of 3.3A stepper motor current at full load torque. From a Windows application, the medical professional can adjust variables such as speed, cycle duration, angle, and pressure to rehab patients.

The efficiency of the recommended upper-limb rehabilitation system is obtained in three types of special training as shown below.

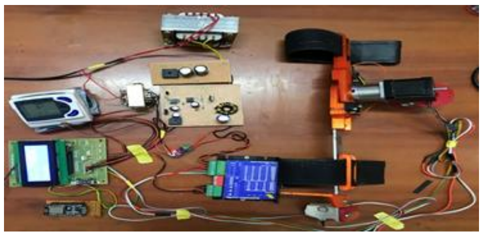

Fig 8. Experimental System Hardware Setup for Proposed Rehabilitation

4.1 Initial Training

This training is appropriate for patients in the initial stages of their recovery from surgery, an injury, a joint adhesion, etc. Patients struggle to do daily tasks at this stage, and joint range of motion is limited. In order to achieve joint extensibility, this technique must be aided by a rehab equipment in patients who are also receiving joint stretching, with the intention of switching later to the rehab of assist training. The loading, which will fluctuate in angle up to 30 degrees and pressure (less than 20%) during operational rehabilitation, will have an effect on the single loop position and velocity control system, where the current is 3.3*20%=00.66A, making it impossible to stabilize the patient while they truly operate and recover. Patients cannot accomplish the goal of recovery because altering loading angle affects the operation of the rehabilitation position response.

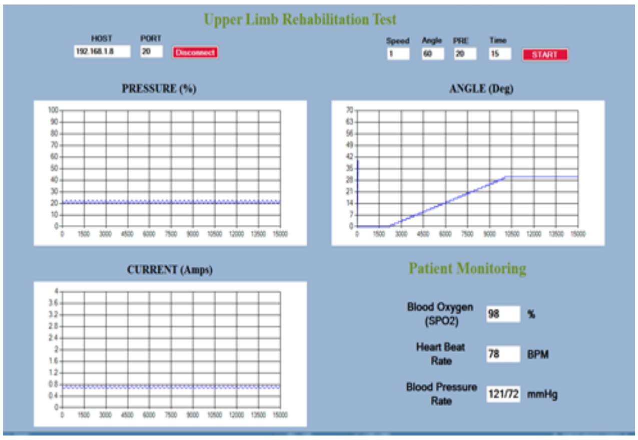

Fig .9. Experimental Result for Initial Training.

The experimental verification of proposed rehabilitation system for initial Training is obtained in two modes by changing the pressure and angle of upper limbs in single loop. After patient movement, the Motor current, pressure and angle is displayed to therapist as shown in Fig.10.

4.2 Assist Training

The Assist Training is appropriate for individuals who are in the middle of their rehabilitation process and who can extend their joints but are still unable to do so normally. Given technique, which is utilized to teach patients with joint activity, physicians can change the rehabilitation parameters by adjusting the patient's operation speed of 2.5 rpm, control angle limit of 45 deg and pressure (less than 30%) of movement which is controlled by the current control at 3.3A*30%=0.99Amps. Passive rehabilitation can result in the joints' reciprocating training. The motor flows to the next position at the required set speed when the patient's recorded pressure exceeds the set pressure value, assisting the patient's muscular movements.

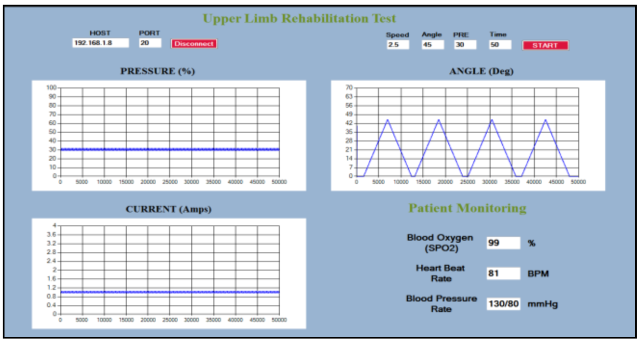

Fig.10. Experimental Result for Assist Training

The multi-loop position and pressure control system, illustrated in Fig. 11, makes it evident that regardless of whether it is loaded or not, changing the loading angle will not have any impact on the operating procedure.

4.3 Oppose Training

The Oppose Training is suitable for the patient's finalized rehabilitation because they can extend their bodies and have excellent mobility comparable to that of healthy individuals. The patient's rehab physicians may modify the rehab variables of operation speed 2.5 rpm, control angle limit of 45 deg, and pressure (less than 75%) of movement, which are controlled by the current control at 3.3A*75%=2.475Amps. In this period the patient wants to apply extra force to move the upper limb, this is done by opposed force applied by the motor. When the detected pressure value is less than the prescribed pressure value, the motor is configured to most effectively oppose the patient's limb movement.

If the measured pressure is lower than the predetermined pressure, the control system explicitly states that it will stop the patient from moving. The set pressure is 70%, and the multi-loop position angle is 45 degrees. Fig.12 illustrates the clinical validation of the suggested upper limb rehabilitation at opposing training.

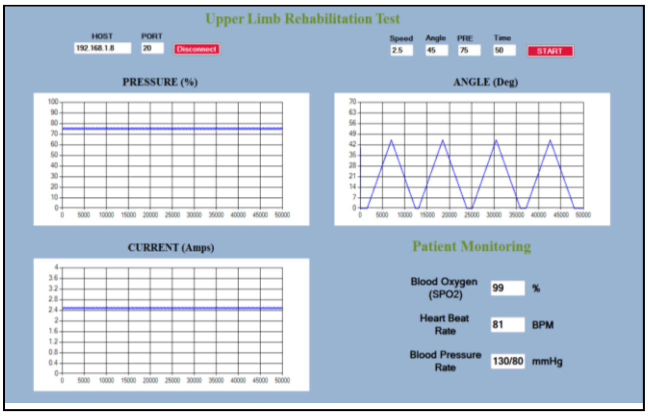

Fig.11. Experimental Result for Oppose Training

5. Patient Monitoring Data for Different age Groups

5.1. Oppose Training at Age 30

The Oppose Training is appropriate for the final rehabilitation of patient, the rehab patient is tested when they are 30 years old and has the same range of motion as healthy people. The figure given below shows the patient rehabilitation wave form with oxygen level blood pressure for the patient.

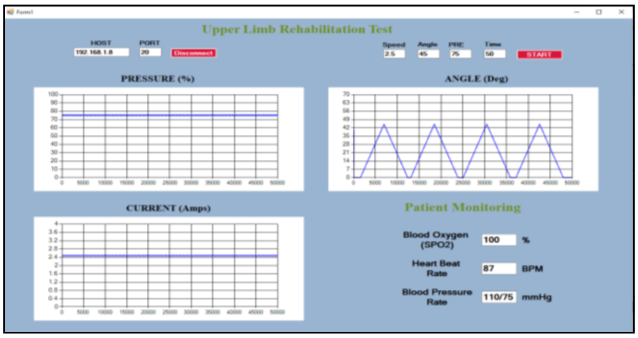

Fig.12. Experimental Result for Oppose Training at age 30

5.3 Oppose Training at Age 50

The Oppose Training is appropriate for the final rehabilitation of patient, the rehab patient is tested when they are 50 years old and has the same range of motion as healthy people. The figure given below shows the patient rehabilitation wave form with oxygen level blood pressure for the patient.

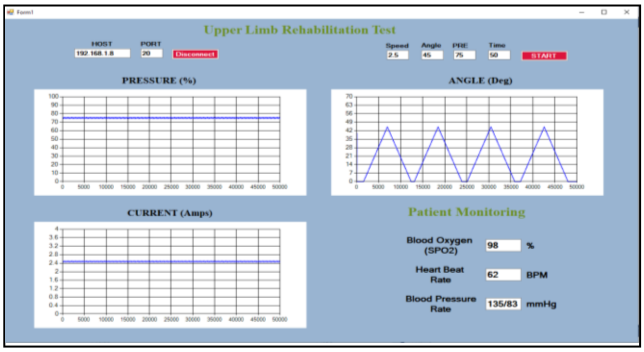

Fig.13. Experimental Result for Oppose Training at age 50

5.2. Oppose Training at Age 70

The Oppose Training is appropriate for the final rehabilitation of patient, the rehab patient is tested when they are 70 years old and has the same range of motion as healthy people. The figure given below shows the patient rehabilitation wave form with oxygen level blood pressure for the patient.

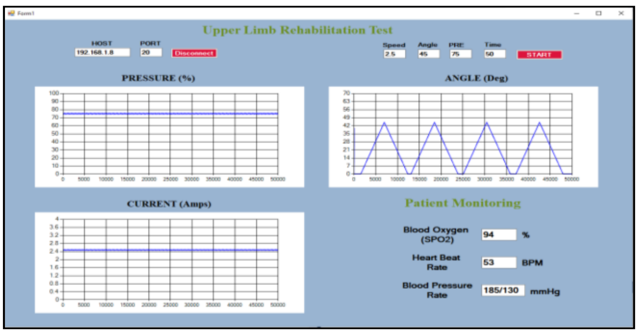

Fig.14. Experimental Result for Oppose Training At age 70

6. Conclusion and Future Scope

This paper presented a proposed upper limb rehabilitation system is designed and Internet of Things-based real-time remote patient monitoring device that can track the patient's basic health metrics, such as blood oxygen saturation function (SPO2), heartbeat rate, and blood pressure implemented using Embedded system and VB.net C-sharp. This proposed upper limb rehabilitation device current control stepper motor strategy for upper limb Rehabilitation robots with high accurate measurement of movement and muscular force with high efficiency and direct current control. To provide effective rehabilitation training for the patient Stepper motor work through the triple-loop control with position, motor current based force control and speed rule without position sensor. Additionally, depending on the patient's therapist-set pressure threshold point, it might support or oppose the patient at that time. The trial results show that the suggested rehabilitation gadget can support users in rehabilitation tasks in an efficient manner. Integrated web interface to view a record of a patient's rehab process, according to their real recovery, rehabilitation programme through remote set rehabilitation treatment planning. System integration testing aids in the provision of community-based and rehabilitative services to improve the standard of rehab health services and reduce the cost of medical staff and equipment. Additionally, IoT-based health monitoring devices can keep track of patients in real-time and alert them to any anomalies throughout upper training. In the sphere of medical science, the concept of a smart health monitoring system employing IoT designs is a fresh contribution that will help to prevent health problems and avoidable deaths. In Future, EMG, Temperature sensors can be added while making the rehabilitation.

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