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Development of portable elbow joint device for stroke patient rehabilitation

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Abstract

Stroke is a brain disease occurs when blood stops flowing to any part of the brain, damaging brain cells and causes joint stiffness. By doing continuous passive motion (CPM) exercise, the joint stiffness can be reduced and it helps maintaining the range of motion (ROM) of the joint. Portable Elbow Joint Device (PEJD) will provide CPM exercise to patients with Neurological problems such as stroke and traumatic brain injuries that affected the arm. Existing devices of the elbow rehabilitation therapy are large, complex and difficult to be carried anywhere. The upgrading of PEJD focuses on reducing cost, ensuring comfort, and making it portable and light in weight. Besides, PEJD will assist stroke patients in involuntary progressive muscles weakness. A Gear Motor w/Encoder, model No. GB37Y3530-12V-83R is used to move the arm/elbow joint and its angle in controllable speed, timer by using Arduino Nano (microcontroller). The Arduino Nano is a small, complete, and breadboard-friendly board based on the ATmega328 (Arduino Nano 3.0. A rechargeable battery is added on the device to enable the device to operate using DC power supply. The innovation of PEJD will benefit the stroke and elbow injury patients during rehabilitation process as the angle is adjustable, count and speed buttons are also available for such therapy treatment.

Keywords: Stroke, joint stiffness, continuous passive motion (CPM), elbow joint rehabilitation device, Arduino Nano

Introduction

The elbow is the joint connecting the proper arm to the forearm. The elbow joint structure is shown in **Figure 1**. It is marked on the upper limb by the medial and lateral epicondyles and the olecranon process. Structurally, the joint is classed as a synovial joint and functions as a hinge joint. The elbow joint is a compound synovial joint, which means that it is a large working structure that is made up of several smaller moving parts or separate articulations. A synovial joint, otherwise known as a diarthrosis, is the most flexible type of joint [5], seeing as it achieves its range of movement at the point of contact between the articulating bones. This mechanical area forms the meeting point between the radius and ulna of the forearm with the humerus of the brachial region [5]. It is deemed a compound joint because the joint cavity is continuous with the radioulnar joint, as well as the contact points between these bones and the humerus respectively.

Every joint in the human body has its own range of motion. The orientation of the bones forming the elbow joint produces a hinge type synovial joint, which allows for extended 180° (straighten out lower arm) and flexion 150° (bring lower arm to the biceps) of the forearm [1].

Continuous passive motion

Portable Elbow Joint Device (PEJD) provides continuous passive motion (CPM) exercises to the patients with neurological problems such as stroke and traumatic brain injuries which affected the arm [2]. Besides, it is used during the first phase of rehabilitation process following an elbow injury or elbow that has undergone surgical procedure. Rehabilitation program supports the findings of Gates et al (1992) that post-use of CPM improves total range of motion and therefore function. Thus,

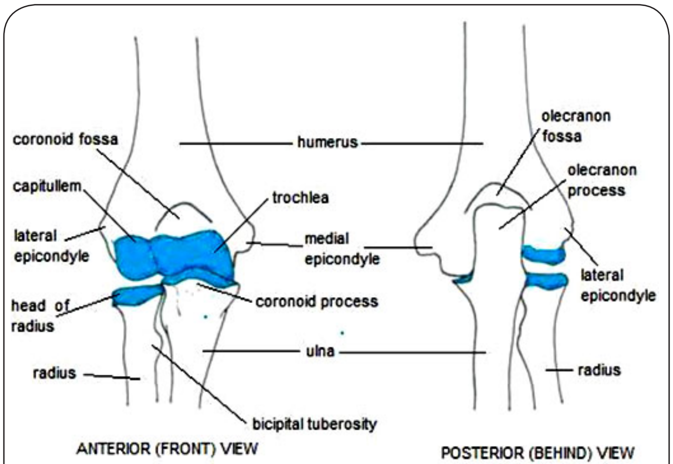

Figure 1. The structure of the elbow joint.

continuous passive motion exercises are important to the patient's elbow recovery from stroke, traumatic brain injuries and also from elbow injury.

A CPM machine or elbow joint rehabilitation device is an electrical, motor-driven device that helps support the injured limbs. It is used to move a joint at variable rates through a progressively increasing range of motion (ROM) [4]; no muscular exertion is required of the patient. CPM acts to reduce blood and fluid accumulation in and around traumatized joints or that have undergone surgery. In this way, CPM is useful in avoiding the development of subsequent joint stiffness in the first few hours or days.

CPM Elbow (Model 3142), a Micro-Computer controlled unit, represents the latest breakthrough in CPM technology. Solid state circuitry control panel with highly visual LED Digital readouts allows Flexion and Extension of Elbow joint through a prefixed Range of Motion and Time.

The existing devices of the elbow rehabilitation device are large, expensive and too heavy, complex and difficult to be carried anywhere due to the size attached to the chair. Patients should be hospitalized for the elbow rehabilitation therapy frequently. The current device which comes together with a wheel stand is not stable and it causes trouble to patients while undergoing treatment. It is also hard for patients to move around because they must stay at one place during the elbow rehabilitation therapy. As the device may move, patients need to sit down during rehabilitation process to ensure the treatment runs smoothly. Furthermore, current devices need to operate on AC power supply.

The therapy process takes place in a comfortable state anywhere. PEJD also facilitates the movement of patient's elbow during treatment. It can reduce the patients' burden when they bend their arm. Furthermore, it can also provide continuous passive motion exercises to help the patient's recovering from stroke, ulnar nerve and elbow injury. The device can be controlled as the count, speed and angle are adjustable during the treatment process.

Methodology

Technical Design

The feature of basic mechanical design is conglutinated wilfully and supported with high strength of the aluminium alloy holder as shown in **Figure 2**. It provides immobilization by fixing the elbow in every 10-15° with padded shoulder strap to release the pressure around the shoulder. PEJD can simply press and rotate hinge with lock. In addition, it can extend limitation from 0° ~ 90° and flexion limitation from 0° ~ 120°. From this mechanical, additional design of brace for support the movement of motor.

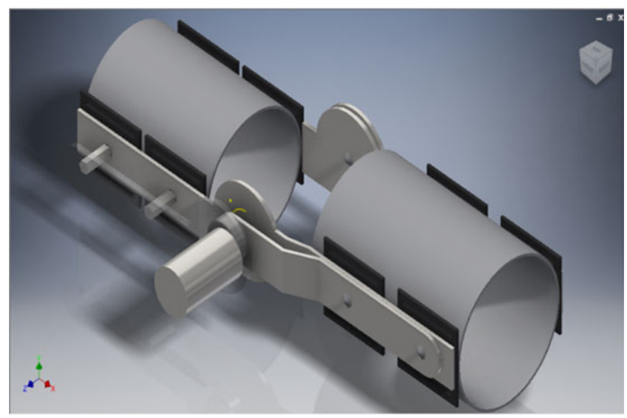
Figure 2. The basic mechanical design of PEJD.

This model is designed by inventors using 3D CAD software. The DC motor is providing the elbow movement. The material used includes adjustable strap which is lightweight, and it is made from breathable fabric and easy to wear. In addition, the design is suitable for both men and women. The casing is designed for extra protection to the hardware. This mechanical design provides fully adjustable tightened impact and better compression to the elbow.

Electronic Hardware and Software Interface Design

The electronic hardware is shown in **Figure 3**, consists of Arduino Nano (ATmega328), Arduino Software, DC Motor with encoder, Encoder, Nokia 5110 LCD and Motor Driver L298N. Arduino is a computer hardware and software company, project and user community that designs and manufactures microcontroller kits for building digital devices and interactive objects that can sense and control objects in the physical world [8]. The project's products are distributed as open-source hardware and software. The controller of PEJD, Arduino Nano, is a small, complete, and breadboard-friendly board based on the ATmega328 (Arduino Nano 3.0) or ATmega168 (Arduino Nano 2.x) as shown in **Figure 4**.

Figure 5 shows the gear motor with encoder, model No

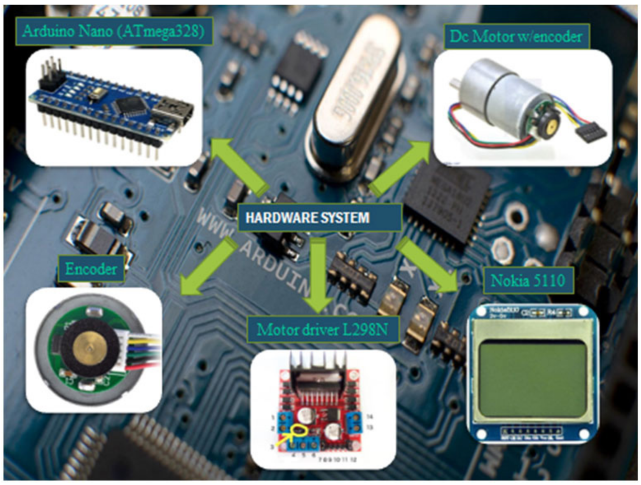

Figure 3. Electronic hardware.

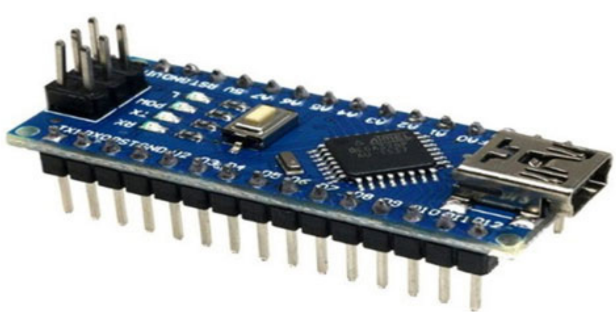

Figure 4. Arduino Nano (ATmega328).

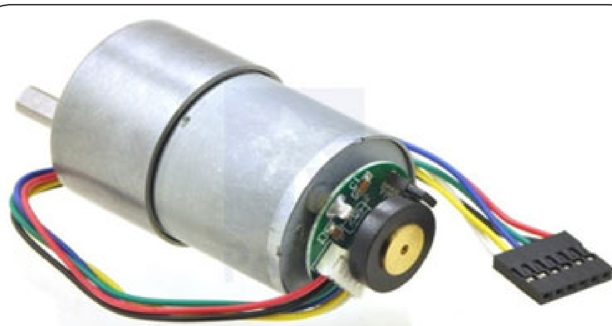

Figure 5. DC Motor with encoder.

GB37Y3530-12V-83R. It is a powerful 12V motor with a 131:1 metal gearbox and an integrated quadrature encoder that provides a resolution of 16 counts per revolution of the motor shaft, which corresponds to 2096 counts per revolution of the gearbox's output shaft. These units have a 0.61" long, 6 mm-diameter D- shaped output shaft. This motor is intended for use at 12V, though the motor can begin rotating at voltages as low as 1V.

The function of PEJD is summarized in **Figure 6**. From power

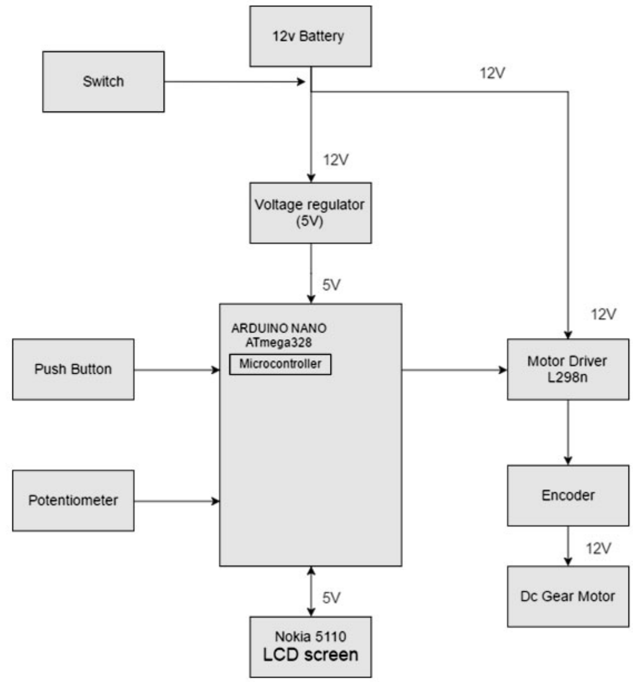

Figure 6. Block Diagram of Design.

supply 12V battery, this device uses voltage regulator (5V) and motor driver L298n. From voltage regulator (5V), power will be enter the microcontroller (Arduino Nano ATmega328) [8]. The microcontroller (Arduino Nano ATmega328) controls the entire system. The mode can be selected from the potentiometer for speed, angle and count setting. The signal from potentiometer goes into microcontroller (Arduino Nano ATmega328). The motor driver L298N will receive a signal from the microcontroller (Arduino Nano ATmega328) to submit to the DC gear motor. The push button is used to run the operation of the device. Nokia 5110 LCD screen will display the speed, angle and count while the device is running. PEJD runs using rechargeable battery. A rechargeable battery can be charged, discharged into a load, and recharged many times, while a non-rechargeable or primary battery is supplied fully charged and discarded once discharged. It is composed of one or more electrochemical cells.

User's satisfaction survey

Thirty stroke patients volunteered to participate in the survey for user's satisfaction survey. The survey involves interview and observation after the trial test of the device. The respondents are from various levels of age, jobs, qualification and family background. Age ranges from 20 to 50 years and average height and body mass are 1.50±0.2 m and 50±5 kg, respectively. The inclusion criterion is that the patient should only use the device after surgical procedure or consultation by physiotherapist so it couldn't interfere with the user's study performance. The PEJD device is categorized as first phase of rehabilitation following a soft tissue surgical or trauma. The exclusion criterion is the morbidity of any direct use before any consultation. The trial was carried out with cooperation of patients, doctors and physiotherapists.

Procedures

Each patient completed trials within a single day. Subjects operate the device following the steps indicated. The simple procedure starts with ON button. After that, a few settings will be adjusted depending on the patients' condition and comfort. Settings include motor speed, angle and counting times. The trials were performed in range of high and low for speed, angle of 15°, 30°, 45°, 60° and 90° and counting times of 10, 20, 30 and so on. The result from all those parameters will be indicated as performance of patient ability in joint movement and were used for further analysis.

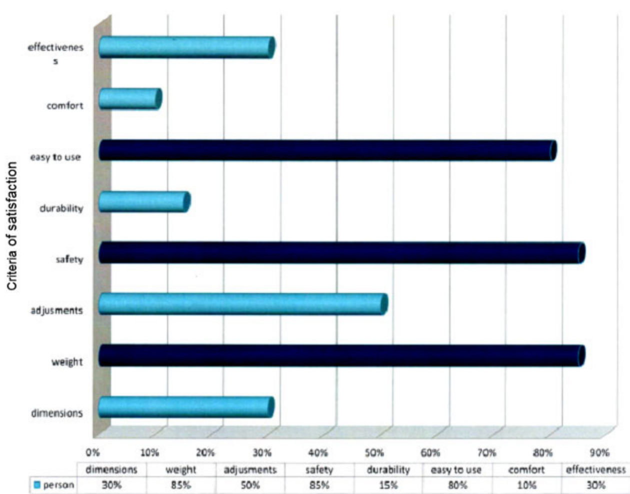

Figure 7. Feedbacks by users on the usage of the device during rehabilitation therapy.

Result and discussion

The result in **Figure 7** shows that safety is one of the criteria that are given priority, followed by its weight and easy to use. Patients also indicated that using the device is comfortable as it fits well to their paretic arm. They felt that device did not make any physical strain due to its light weight in nature. The device must in safety condition when a device in running time. In addition, being user friendly is also one of the appealing criteria. The effectiveness of the product and its weight also need to be considered in upgrading the design. A clinical trial was conducted on post stroke patients to evaluate the performance of the Portable Elbow Joint Device, how it saves manpower and to evaluate the usage of device for active assistive therapy.

Conclusion

The elbow joint is a compound synovial joint, with several smaller moving parts, or separate articulations. Joint stiffness will occur after joint trauma problem and with the Continuous passive motion (CPM) exercise, the joint stiffness can be reduced and helps to maintain the range of motion (ROM) of the joint. The Portable Elbow Joint Device will provide continuous passive motion exercises with controllable speed, timer and the angle of movement by using Arduino Nano (microcontroller) [7]. Furthermore, a rechargeable battery is added to the device which enables the device to operate on DC power supply. Besides, as this product is portable and provides comfort, it allows the patients to move around during elbow therapy.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

Authors' contributions	KLC	MR	AZ1	AZ2	NM1	NM2	MI
Research concept and design	✓	✓	✓	✓	--	--	--
Collection and/or assembly of data	--	--	✓	✓	✓	✓	✓
Data analysis and interpretation	✓	✓	--	✓	--	--	--
Writing the article	✓	✓	--	--	--	--	--
Critical revision of the article	✓	✓	--	--	--	--	--
Final approval of article	✓	✓	--	--	--	--	--
Statistical analysis	✓	✓	--	✓	--	--	--

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