Upper Limb Rehabilitation Training Mechanical Arm for Stroke Patients

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Abstract. This paper proposes a mechanical arm that has three degrees of freedom to help patients train and exercise their joints under different modes and intensities to promote the rehabilitation process for stroke patients. Compared with commercial products, our prototype is low-cost, user-friendly and self-operative. We installed three angular velocity sensors to determine the coordinates of the joints, which helps to adjust joints back to their original places via the motors. The motors are connected to the Arduino Mega board so that they can be controlled to move according to the buttons pressed by the patients on the Raspberry Pi interface. The interface is created using python and will transmit messages to the Arduino board through its Serial Port. Testing shows that all proposed functions are realized.

1. Introduction

1.1. Motivation
According to statistical estimation, there are more than 10.36 million patients over the age of 40 with cerebral apoplexy in our country, and the number of new cases is more than 1.5 million each year. Among the many sequelae of cerebral apoplexy, the incidence of hemiplegia is the highest, and the rehabilitation of the upper limb function is the most difficult during the process of hemiplegia recovery. The restoration of the upper limb function determines the well-being of the patients’ lives, and that is one of the most difficult problems in the rehabilitation treatment. Medical theory and clinical medicine prove that, in addition to surgery, drug therapy and electrical stimulation, scientific rehabilitation training plays an extremely important role in the physical rehabilitation of patients with hemiplegia. At the same time, early intervention in rehabilitation training not only maintains joint activity effectively and prevents joint contracture, but also significantly improves the patient's ultimate recovery. At present, robotics technology has been widely used in the field of rehabilitation, which not only greatly improves the efficiency of rehabilitation training, but also reduces the burden of patients and clinical staff.

According to the problem above, this paper proposes a mechanical arm that has three degrees of freedom to help patients train and exercise their joints under different modes and intensities to promote the rehabilitation process.
1.2. Commercial Products
According to our investigation and online interview with representatives of enterprises that sell rehab training mechanical arms as commercial products (Fig. 1), the ArmeoPower is the world's first robotic arm exoskeleton for integrated arm and hand training, specially designed for arm and hand therapy in an early stage of rehabilitation for patients who suffers from Stoke, TBI, and other neural disorders. It provides intelligent arm support in a large 3D workspace and enables even patients with severe movement impairments to perform functional exercises with a high number of repetitions. However, one piece of mechanical arm can cost over 4 million RMB (0.63 million US dollars), too much for a regular family to afford. It also requires strict control of trained staff and therapists, and is not convenient for the patients to operate by themselves and train whenever they want. The ArmeoSpring is specifically suited for patients who are beginning to regain active movement of the arm and hand. The adjustable exoskeleton of the ArmeoSpring embraces the whole arm, from shoulder to hand, counterbalances the weight of the patient's arm, and facilitates self-initiated and repetitive movements of the patient. The price of this piece of mechanical arm is also very high, as it costs 1.5 million RMB (0.23 million US dollars) per machine.

Figure 1. Commercial Products: (a) ArmeoPower (b) ArmeoSpring.

1.3. Design Considerations
Wearing Convenience. The users are mostly patients, so the whole system should not occupy a large space and light-weight is preferred. The proposed system has a base which the patients put their arms on and it does not require the patient to carry the weight of the mechanical arm.

Data Exchange. The proposed system has a display screen for patients to select the mode and terminate the exercises. Thus, the data exchange between the Raspberry Pi system that controls the display and the Arduino Mega board that the mechanical arm requires is needed.

Effectiveness of Training. According to our previous research, current mechanical arm products are only designed to facilitate and support the movement of the patient, but the proposed machine provides different modes for the patient to select according to their own abilities of movement and do exercises on specific joints or advanced movement, which is relatively more effective regarding the rehab training.

Accuracy of Movement. To get accurate movements for each exercising mode, the accelerometer is used to measure the angle through calculations to determine if the joints are moved under normally. If abnormal positions are detected, the system should automatically correct itself by moving the joint to the right spot.
2. System Overview

2.1. System Diagram
The entire system consists of five different modes that ranges from the most basic modes that exercises a single joint to the advanced modes that exercises multiple joints. The relationship of the components could be shown in Fig. 2.

![System Diagram](image)

**Figure 2.** System diagram.

2.2. Forearm Stretching Movement
The forearm stretching movement uses two stepper motors that moves at the same time and same pace as its power source. The relationship between the angle and height of the arm movement is shown below in Fig. 3. Line AB represents the base of the device, and point B is where the stepper motors are connected to the base through an axle. Line BC is the screw of the stepper motors, where point C is the screw nut and moves in a linear direction as the rotating force of the stepper motors are transformed into a linear force by the screw. The user puts his arm on the device, and his forearm lies on line AC, which will rotate around point A for $\theta$ degrees as C goes to C'. This movement is achieved because AC is equal to AC' during the whole process.

2.3. Wrist Rotating Movement
The wrist rotating movement system is powered by a stepper motor that connects to a smaller gear that is connected to another larger gear. The larger gear is connected to a bearing on one side and the sweeping movement device on the other side. As the larger gear rotates, the inner ring of the bearing rotates with the gear, and the outer part is still connected to the fixed base of the device. The user puts his hand through the bearing and the gear, and holds on a bar. As the stepper motor rotates, the smaller gear goes with it and thus the larger gear with the user’s hand through is powered. The photograph is shown in Fig. 4.
2.4. Wrist Horizontal Sweeping Movement
The wrist sweeping movement is achieved because of the two steering engines that powers this system. The steering engines rotate at the same time, and it is connected on two sides of the bar where the user puts his hand. As the horizontal sweeping mode is selected, the steering engines that are also connected to the larger gear starting rotating, and the bar, which is on a separate structure connected with the rotating part of the steering engines, is moved. The real product is shown in Fig. 5.

2.5. User Interface and Modes
The user interface uses the Raspberry Pi system and it is created using the python language. It is connected to the Arduino Mega 2560 board through its GPIO port, and can transmit signals to the serial port on the Arduino board, which tells the motors to execute the signal. Each mode has a specific button for it on the user interface, and there is also a stop button to terminate the system, a speed up and speed down button to give a higher or lower velocity of movement in all the five modes. By using the functions when each button is clicked, the system can alter the power frequency the wire gives from the Raspberry Pi to the Arduino by setting the GPIO port as true or false, and as soon as the Arduino detects this low or high signal of frequency, it will immediately run the modes. The stop mode is achieved by not giving the Arduino the right frequency, and the speed up, speed down mode alters the variable in each execution system, which determines the rate of work that the motors and engines will output. The user interface is shown in Fig. 6.
2.6. Data Gathering and Exchange
The system uses MPU 6050 module (Fig. 7) as a gyroscope and angle velocity sensor to gather its data to preset the system before initiating the device. It records all the angles that the preset mode has, and controls the motors to turn until they match with the previous angle that was measured before. This function allows the system to be more structured, and avoids the inconsistency that the patients’ training may cause.

3. Project Output and Testing
The testing of the project is optimistic, as it achieves the goal of movement in three degrees of freedom when buttons with five different modes are pressed. One major problem encountered during testing is the stepper motors being unstable, which requires to be debugged in future work. When experimenting with the device, patients can feel the stretching of their joints. With the faster or slower buttons, the prototype meets the initial goal of a user-friendly and self-operative device for rehabilitation training of the upper limb function. The photos of the final project are shown in Fig. 8 without the user’s arm, and Fig. 9 with the user’s arm.
4. Conclusion

The system is designed to help patients rehabilitate from upper limb disfunction, and testing shows that all proposed functions are realized. We first installed three angular velocity sensors to determine the coordinates of the joints, which helps to adjust joints back to their original places via the motors. The motors are connected to the Arduino Mega board so that they can be controlled to move according to
the buttons pressed by the patients on the Raspberry Pi interface. The interface is created using python and will transmit messages to the Arduino board through its Serial Port.

The system is not limited by location and time, which means that users can exercise wherever and whenever they want, without the requirement of a trained therapist. During the user testing process, the speed up and speed down mode can both alter the speed of the movements, by altering the number of rotations that a stepper motor rotates per 800 microseconds. With the help of this entire upper limb rehabilitation system, patients are provided with a self-operative and convenient device that can help them improve their arm function.

References
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