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Rotary Speed Control On Continuous Passive Motion (CPM) Therapy Machine Device With PI Control

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Abstract

Continuous Passive Motion (CPM) machine is a therapeutic device that is used to assist the process of therapy and recovery of a patient after having joint surgery or injury of the ankle. In this research, a CPM machine will be developed for ankle joint therapy. The rotation speed of the CPM machine will be controlled by a DC motor which is used to drive the ankle joint therapy device. Speed control for DC motor is used on a therapeutic device (CPM machine) to determine the level of the therapeutic process; therefore this device can be adjusted to the needs of the patient who will use the therapeutic device. Speed control of the DC motor that will be carried out in this research is using Proportional Integral (PI) control. With the PI control, the result of output will always be compared with the set point value. The result of this comparison will provide an error value, which later the error value will be processed by PI control. The PI values used in this research are Kp 5 and Ki 15. The test results of the CPM movement speed show that the difference between the set point and the resulting movement is 1 RPM. Where the speed tested on this tool is 3 RPM and 5 RPM. So, the output of this device will be as expected. In brief of this research, a therapeutic device that can be adjusted the rotational speed as expected.

Keywords:
Continuous passive motion machine, PI control, speed control, DC motor, microcontroller.

1 Introduction

Motor rotational speed control is an important step in Continuous Passive Motion (CPM) machine. Rotational speed control can be done using many methods that produce Pulse Width Modulation (PWM) values. This PWM signal will later be used to regulate motor rotation. The PWM concept is a more effective technique and is more commonly used in the motor speed regulation[1].

Many athletes experience ankle injuries with varying seriousness. First aid that can be given to patients with ankle injuries is to provide movement exercises to the patient [2]. Providing this exercise helps speed up recovery from injuries experienced by patients[3]. One tool that can be used to assist in providing this training is the CPM machine.

CPM machine is a therapeutic device that is used to assist the therapeutic process of a patient who has joint injury[4]. A therapeutic process is done by moving the joint continuously with constant movement. This activity is intended to avoid joint stiffness that may occur when the patient is reluctant to move his joints [5][6]. Therapy for joints can be replaced by robots, as a substitute for the work of the therapist [7]. CPM machine is a device that has a rehabilitation method for damaged joints [8].

In research [9], produce a prototype of a therapeutic device that can move the ankle joint for a range of motion in plantar and dorsiflexion up to 60 degrees.This device is used for passive mobilization for patients. The result of therapeutic device is used to provide therapy to a stroke patient who requires mobilization. So, the device can help the patient's movement.In this research [10], produce a rehabilitation device that can use as a CPM machine with plantar movement and dorsiflexion movement for 20 to 45 degrees. In this research, the resulting device utilizes a pneumatic actuator to move the patient's ankle joint. This system can be run semi-automaticallydepending on the patient's needs. In this research [7], produce a rehabilitation device that can be used for inversion–eversion movement. This device utilizes Proportional Integral Derivative (PID) control to control the movement of the device.

In the research that will be carried out, an ankle joint therapy device with rotational movement will be designed. Rotational movements in the ankle joint can accommodate plantar, dorsiflexion, inversion and eversionmovements. Thus, with rotational movements can reach the angles of movement in the ankle joint therapy process. In the rotational movement, the movement will be set at a speed of 3 RPM and 5 RPM.

The CPM machine therapy device requires an actuator that can assist the joint movement. The actuator that can used in CPM machine is various kinds. In this research, the type of actuator that will be used is a Direct Current (DC) motor, specifically the DC motor that will be used is a wiper motor.

The use of the wiper motor on the CPM machine requires testing stages, one of the tests required on the wiper motor is the speed test of the motor. The rotational speed of the DC motor is needed in the CPM machine, in determining the level when therapy is carried out. Based on the research that has been done, speed control of DC motor can be done using fuzzy logic, PID, and PWM methods [11]. In this research, the rotational speed of the motor will be controlled using the Proportional Integral (PI) method. The PI method was chosen in this research because PID control under certain conditions will has the result in unwanted speed and overshoot [12]. PI control is a motor speed control that utilizes the proportional and integral setting of the PID method. The use of PI method is expected to produce a rotating speed of the device in accordance with the given set point.

2 Methods

The research method used in this research is the development method. Therefore with this method, a CPMmachine will be produced by testing the accuracy of the tool's rotational speed. The developments carried out in this research include improving the speed control of the DC motor used to drive the therapy tool so that the rotation speed of the therapy tool can be regulated.

2.1 Injury of the Ankle

Ankle joint injuries occur due to damage to joint tissue or after joint surgery. Movement exercises are needed to prevent stiffness in the joints [6]. Joint stiffness can occur when the patient is reluctant to do movement exercises in the joints because of the pain they feel. Joint exercises can be done with the help of a therapist or with a CPM machine. Movement training with assistive devices can be done by providing movements in stages.

Fig. 1 shows the movements that the ankle joint can make. These movements include abduction, plantar flexion, dorsiflexion, inversion and eversion. In this research, a therapeutic device that is moved rotationally will be developed, which can accommodate the movement of the ankle joint.

The device that will be designed in this research will provide gradual training by setting the rotational speed of the motor. The first stage is given at a speed of 3 RPM and the next stage is at a speed of 5 RPM. By providing this gradual exercise, it is hoped that the patient will not feel too much pain in the joint when carrying out movement exercises on the ankle joint.

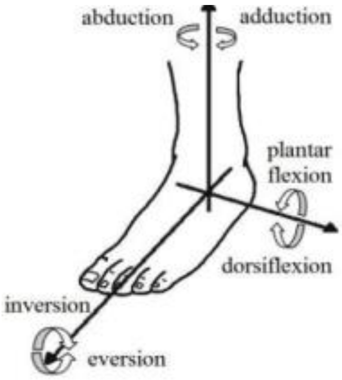


Fig. 1. Ankle and foot rotation axes.

2.2 Control System

A control system is a method that used to control actuator from the device. The control system in this research uses a closed loop method, as shown in Fig. 2,where the closed loop is a method that has feedback as a comparison between the set point and the output that generated from the output [13][14].The input in the diagram in Fig.2, is the value that will be achieved by the device. The input value will be compared with the feedback value, so that the difference in value from this comparison will be processed by the control section and produce a PWM value to be used to control the output.This PWM value will be used to control the rotational speed of the DC motor. The input value in the system is the speed of the DC motor that will be used to move the ankle. The feedback from the system is also the rotational speed of the DC motor which is read by the rotary encoder sensor.

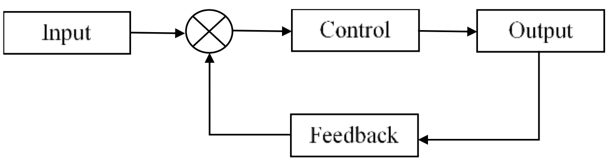


Fig. 2. Close loop system [13].

One of control method that uses close loop is PI control. Where, the PI control will utilize proportional and integral parameter setting to produce the desire rotational speed. The proportional value in PI control is intended to provide the amount of gain provided by the controller, while the integral value in PI control is used to eliminate steady state errors from the resulting output.Feedback from the system is used as a comparison to determine the error value that generated, so the rotation speed from this system will be equal to that given set point [15][16]. The block diagram of PI control is shown in Fig.3.

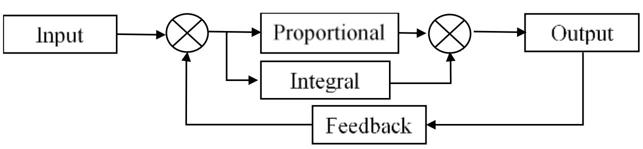


Fig. 3. PI control system [17].

2.3 Microcontroller

The microcontroller used in this tool is an Arduino Nano board based on the ATMEGA 328. The software used for programming is the Arduino IDE.The Arduino IDE is open-source software used to do programming on microcontrollers.

The program used to control the rotational speed of this tool is to provide an input value (set point) which is used as a reference value for the movement speed of the tool. The input value will be compared with the feedback value obtained from the rotary encoder sensor. The value from the rotary encoder sensor is converted into a rotational speed value, so that it can be compared with the speed reference value on the tool. The results of the comparison between the reference value and the read value of the rotary encoder sensor are then processed with PI control which will produce a PWM value. This PWM value will be used by the system to regulate the rotational speed of the tool. The PWM value given will always change according to the value resulting from the comparison between the reference and the feedback (error) that occurs on the device, so that the resulting motor speed will be the same as the reference given. The system will always repeat until the process is complete.

2.4 Rotary Encoder

Rotary encoder is a transducerused to calculate rotation speed from the device [18]. Based on the rotary encoder specification data used in this device, it provides 360 pulses in one rotation (Fig. 4). To evaluate rotational speed of the device, a speed calculation will be carried out every 0.5 seconds (Eq. 1).

$$\text{Speed} = \left(\frac{\text{Total pulse of rotary encoder}}{\text{Rotation angle}} \div 0{,}5\right) \times 60\ \text{rpm} \qquad (1)$$

Fig. 4. Rotary encoder.

2.5 Motor Driver

The motor driver is an interface that can be a liaison between the controller and the actuator. The controller uses low power, while the actuator tends to use high power. So, with the motor driver, a microcontroller with 5 volt can control the DC motor with 12 volt of voltage source. The principle of speed regulation the with motor driver is to provide PWM to the driver, so the rotational speed can be adjusted according to the given PWM [19].The motor driver shown in Fig. 5 uses an H-Bridge circuit configuration, where the driver can be used to regulate the direction of rotation of the motor. A supplied to the driver is 43 A, so it is safe for driving the DC motors.

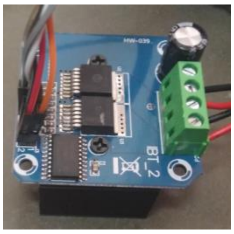


Fig. 5. Motor driver.

2.6 DC Motor

The DC motor shown in Fig. 6, serves as an actuator utilized to move the foot support in the developed therapeutic device. The type of DC motor employed is a wiper motor with a torque of 50 Nm.

Fig. 6. DC motor.

2.7 Liquid Crystal Display (LCD)

A LCD screen that will be implemented in this therapy tool is Nextion LCD. The Nextion LCD can be used as an interface between the user and the device. It is a display and also a means of interaction panel between a user and the device. By the Nextion LCD, user can adjust the rotation speed of the tool.

2.8 Implementation

2.8.1 Hardware

The hardware in the deviceis designed by composing of input, process and output parts (Fig. 7). The input section there is a rotary encoder sensor as a reader of motor rotation and a push on button. In the process section there is an Arduino Nano Board with an ATMega328 microcontroller IC which functions as a tool controller. In the output section there is a DC motor which is used to drive the tool and an LCD as a display.

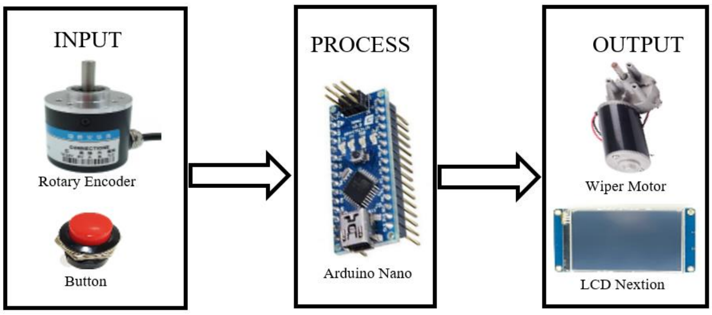


Fig. 7. System blokdiagram.

The input ofthe device consists of a rotary encoder sensor as a measure of the rotational speed of the motor and buttons as a regulator of the set point of the device. On the process side, this device uses Arduino Nano as a control on the device. On the output side, there is a motor driver as the interface between the microcontroller and the DC Motor. DC motor is used for driver of the device. To show the information from this device, the system used LCD as a viewer. The whole of the device is shown in Fig. 8.

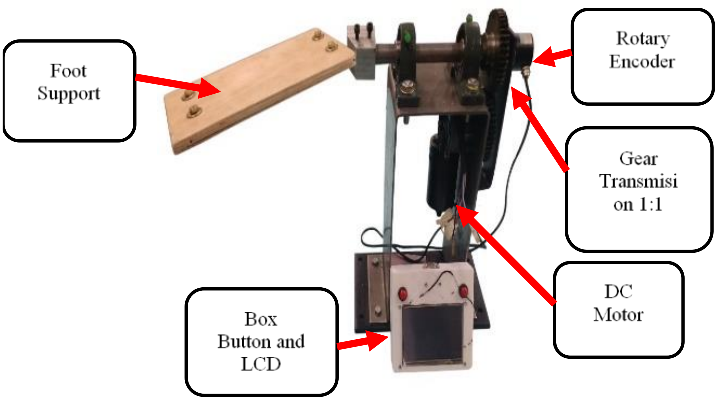


Fig. 8. Ankle joint therapy device.

In the device there is a 1:1 transmission gear that functions as a connector to channel the motor rotation at the foot support rotation. So that the rotational speed of the foot support will be the same as the rotation of the DC motor.The foot support on the device is used to support the feet of the patient undergoing therapy.

2.8.2 Software

As explained in the method, programming this tool uses ArduinoIntegrated Development Environment(IDE) software. This therapy tool program applies PI control as a device speed controller. The PI variable in programming uses the values P=5 and I=15, according to Table 1. The PI value variable will be used to determine the level of precision of the tool being made by comparing the device speed reference value with the speed feedback value generated from the device sensor.The rotary encoder sensor will be processed by the microcontroller according to Eq. 1, which will produce a magnitude in the form of the rotational speed of the motor. The results of this calculation will be used as a comparison against the set point which will produce an error value. The error value resulting from the comparison will be processed with PI control by the microcontroller and will produce a large PWM value to control the rotational speed of the motor. Table 1 shows the PI parameters used to control the rotational speed of the motor.

Table 1. Parameter PI

Parameter	Value
Proportional (P)	5
Integral (I)	15

3 Results and Discussion

Tool testing is carried out by applying the PI control parameters in accordance with Table 1. Where the test is carried out with 2 speed settings, namely 3 RPM and 5 RPM.The results of the experiment for speeds of 3 RPM and 5 RPM are shown in Fig. 9and Fig. 10.

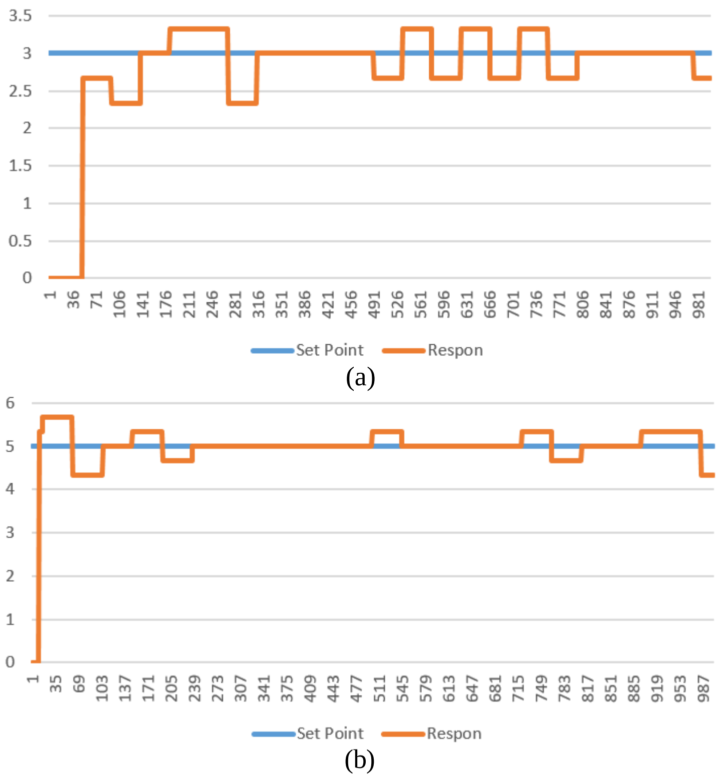
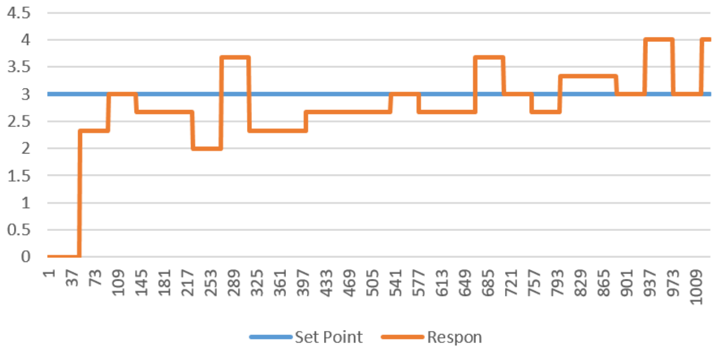


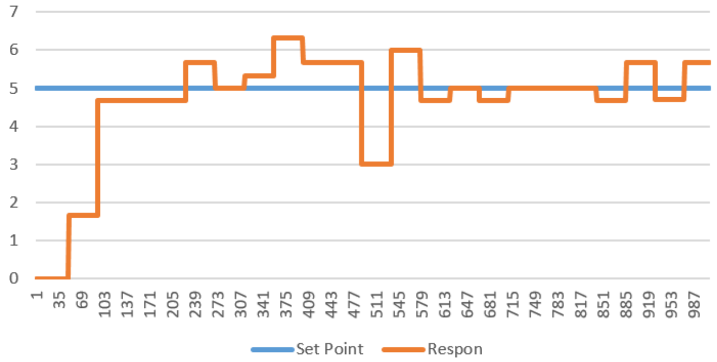
Fig. 9. First try speed response. (a) 3 RPM and (b) 5 RPM.

Experiments were carried out with different loads. In the first experiment, it was carried out by people weighing 75 kg, while in the second experiment it was carried out by people weighing 85 kg. Tool testing was carried out using two movement speed experiments, namely 3 RPM and 5 RPM. The graph shows the set point value and the results of reading the speed of movement of the tool using a rotary encoder sensor which has been converted into RPM values.

Fig. 9(a) and Fig. 10 (a) is a graph of the 3 RPM speed response and Fig. 9 (b) and Fig. 10 (b) is a graph of the 5 RPM speed response, the graph shows the rotation which is still unstable. There are still many overshoots and errors resulting from controlling the rotating speed of the device.The overshoot and error generated are occurrences caused by hardware that is unable to center properly during its rotation, potentially leading to instability in the device's rotation.



(a)



(b)

Fig. 10. Second try speed response (a) 3 RPM and (b) 5 RPM.

In the second experiment, overshoot was greater than in the first experiment. This incident is caused because the system will work more when it is under a heavy load.According to existing results, this tool can be used by rotating the ankle joint, so all angles of movement can be done with this tool. Besides being able to perform rotational movements at the ankle joint, this tool also still requires development in the transmission of rotation from the DC motor to the tool. In brief, the tool can rotate more smoothly and have smaller overshoot and error.

4 Conclusion

Based on the results of the tests that have been carried out, it is concluded that in general controlling the motor rotation speed of the CPM therapy device can be carried out. The motor can move at a speed according to the setting. However, from the results obtained, the rotation speed is still not stable at the given speed settings. On the device, overshoot and error values often appear with a value of approximately 1 RPM. It is necessary to develop the transmission of rotational movements from the motor to the tool, so that the rotation can be more stable and smoother.

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