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CONTINUOUS PASSIVE MOTION BASED ON ARDUINO AS A HAND AND FOOT REHABILITATION THERAPY TOOL TO MINIMIZE THE POSSIBILITY OF INFLAMMATION

***Safira Fegi Nisrina[1], Natanael Panega Asi[2]**

Teknologi Elektro Medis Program Diploma Tiga, Universitas Widya Husada Semarang

Email Korespondensi: safira@uwhs.ac.id

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ABSTRACT

Accidents are a significant problem in Indonesia, occurring in various sectors, including traffic, work, and sports. They always have a physical impact on victims. One of the most common problems for accident victims is bone damage, which can occur in the form of injuries and fractures. Therefore, proper treatment is necessary to speed recovery, especially for elbows and knees, which require movement. This study aims to design and test an Arduino-based CPM device applicable for both elbow and knee rehabilitation. Continuous Passive Motion (CPM) is a therapeutic device used repeatedly to move a patient's joints, including the knee and elbow. This device is used in the initial phase of rehabilitation after joint replacement surgery, ligament or tendon reconstruction procedures, fractures, and minor injuries. Existing CPM devices typically only perform one type of therapy. However, this research has developed a CPM that can be used on both the knee and leg in a single device. It is microcontroller-based, driven by a DC motor, and includes infrared features to dilate blood vessels and reduce pain. The device's performance was excellent. The voltage measurement accuracy was 98.07%, the time accuracy was 98.25%, and the degree measurement accuracy was 98.49%, demonstrating its effectiveness and accuracy for knee and elbow joint therapy.
Keywords: Continuous Passive Motion, knees and elbows, infrared, bones, joints, microcontroller

BACKGROUND

In Indonesia, accidents occur very frequently, both at work, in traffic, and in sports. These accidents have many impacts, one of which is physical. The proportion of body parts affected by accidents is 32.7% of the upper limbs, such as the elbows, and 67.9% are lower limbs, such as the knees (1). One type of disease often experienced by accident victims is Traumatic Fracture, also known as broken bones. A broken bone is a condition where the continuity of the bone is broken. Essentially, in cases of broken bones, surgery is needed by medical personnel, where this can remove and remove the shattered bone fragments or reconstruct and stabilize the bone (2) (3). After the surgical process, of course, the patient cannot immediately carry out their normal activities, the patient must undergo several stages to be able to carry out normal activities. In treating patients with fractures in joints such as the elbow and knee (4), the patient requires a treatment that makes the patient's joints move passively and continuously within a certain range. Proper handling is very necessary so that the joint recovery process in patients can be faster and more effective (5).

Therefore, patients need a device called Continuous Passive Motion (CPM). CPM is a continuous passive motion device used during the first phase of rehabilitation after soft tissue surgery or trauma (6) (7). This device has been widely used by patients in post-operative joint therapy (8). One example is a 45-year-old woman who always undergoes CPM therapy every time the patient has had Total Knee Replacement (TKR) surgery (9) . After routine use of CPM, the patient can fully extend her knee and does not feel any discomfort when the patient flexes the knee (10) (11).

In previous research, Contionous Passive Motion could only perform 1 joint CPM therapy, namely the elbow (12) . This CPM combines the arm's Continuous Passive Motion (CPM) device with the CoControl Electromyograph (EMG) to optimize the recovery process of post-surgery and stroke patients (12). Then in the second CPM study, a joint therapy machine for the wrist was designed that can be moved in flexion, extension, ulnar and radial (13). The next research on CPM discussed Portable Continuous Passive Motion using Arduino LoRa as a micro controller, a stepper motor as a driver and using a software application as a controller (14). The design of the continuous passive motion machine in this study was developed with three movement modes, namely manual, automatic and progressive. In this design, the angle sensor used was a rotary encoder sensor (8). Developing a CPM device that can perform two types of joint CPM therapy, namely knee and elbow joints, in one device. With the increasing development of technology, CPM therapy devices are rapidly developing to improve the comfort and effectiveness of their use. For example, the development of CPM therapy devices by adding Infrared (IR) which will produce heat that can help vasodilate blood vessels and increase blood circulation to the area. Thus, pain-causing substances are removed and will reduce pain. The addition of a lifetime countdown for the IR lamp, so that it can be known during the maintenance process, to maintain the quality of the infrared light. The purpose of this research is to create a CPM device that can move the elbow and knee at certain angles and speeds without significant pain.

METHOD

RESEARCH DESIGN

This research employed the Design and Build method. The research design was systematically structured through several stages, including literature review and fieldwork, block diagram and flowchart design, device design, component selection, wiring diagram, and testing. This research utilized a 220V AC power source to supply voltage to all components for optimal operation. Meanwhile, the power supply converted the AC current to DC and distributed the voltage needed by the device's components. The CPM was supported by a microcontroller, the brain of the device, as it served as the central signal processing unit, providing both output and input. The device's core is also equipped with infrared technology, which is used to stimulate the patient's knee.

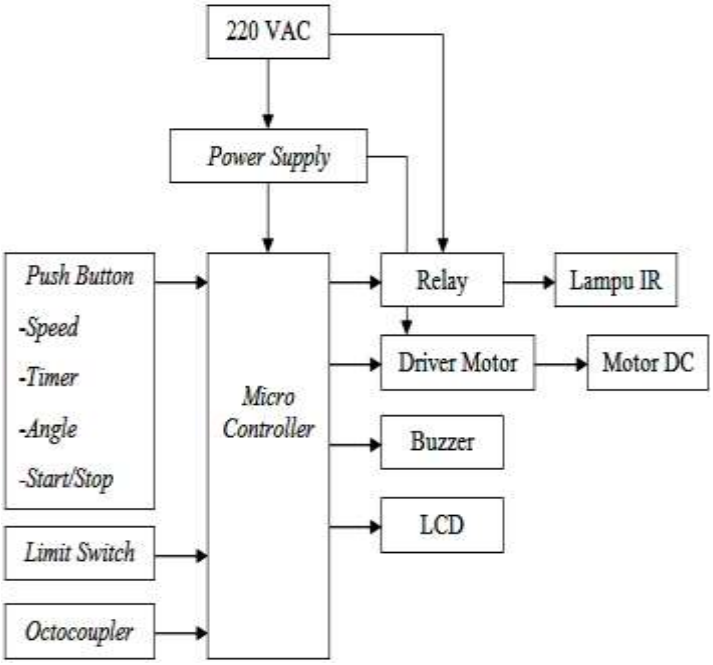

Figure 1 Block Diagram System

A relay is used to turn the infrared light on or off using input from a microcontroller. This device is driven by a DC motor to move the patient's heart, which is held in place by the patient's arm.

TOOL FLOWCHART

The device becomes active when connected to a power source and the switch is pressed. The device will initialize. After initialization, the device settings menu will appear. The user can choose to set or not. If not, the user can reset the IR lifetime during standby. Pressing the reset button will return the IR lifetime to 0.

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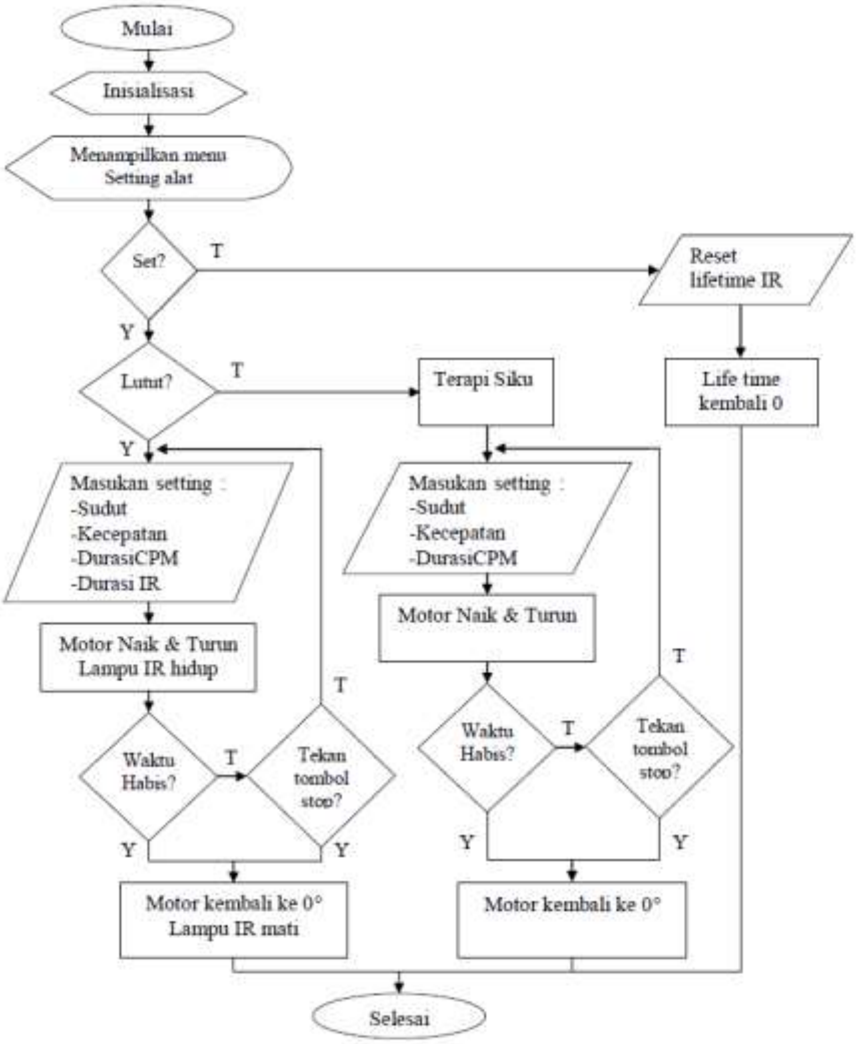

Figure 2 Flowchart System

To begin the therapy process, the user determines the desired treatment. They must enter several parameter settings on the device, including angle, speed, CPM timer, and IR timer. Once the settings are complete, the user can begin the therapy process by pressing the start/stop button.

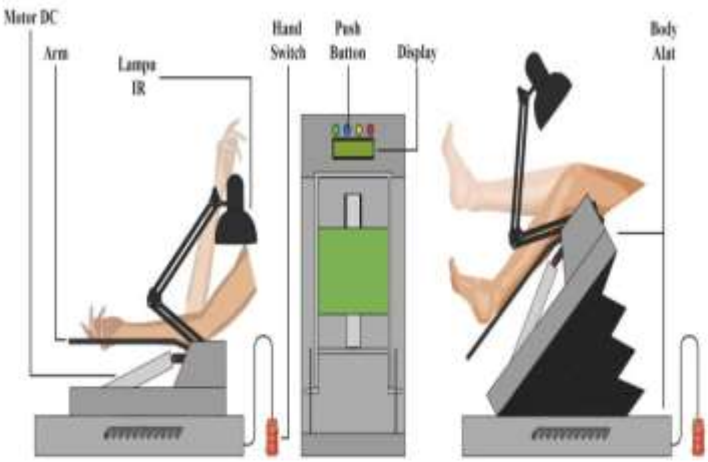

Figure 3. CPM Design

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TOOL DESIGN

a. Power Supply Design

The power supply circuit functions to reduce the voltage from 220VAC to 18VAC.

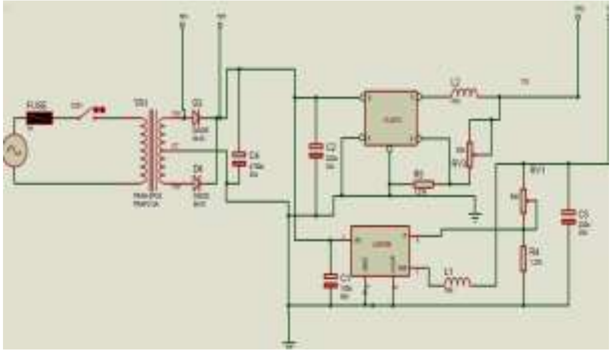

Figure 4. Power Supply Design

After being reduced to 18VAC, the current is rectified to direct current (DC) by a diode connected to a capacitor to reduce the ripple. The LM2596 is used to supply 5VDC. The XL4015 is used to supply 12VDC, specifically for DC motors.

b. XL4015 Step-Down Module Circuit

The XL4015 step-down module is used to generate an output voltage of 12VDC on the device. Below is the XL4015 step-down circuit.

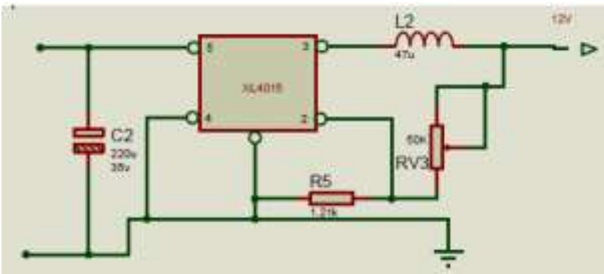

Figure 5. XL2015 Step-Down Design

The output value of the XL4015 is a minimum of 1.25V and a maximum of 32V. To produce an output from the XL4015 IC of 12V, the calculation to produce a voltage value of 12V is as follows:

$$Vout = Vref\ (1 + \text{RV3/R5})$$
$$RV3 = R5\,.Vout/Vref) - 1$$
$$RV3 = 1200\,.\left(\frac{12}{1,25}\right) - 1$$
$$RV3 = 10.320\ \Omega$$

Therefore, to produce 12V, RV3 requires a resistance of 10,320 ohms. Here's the calculation to confirm this:

$$Vout = Vref\ (1 + \frac{RV3}{R5})$$
$$Vout = 1,25.(1 + \frac{10.320}{1200})$$
$$Vout = 12\ V$$

c. LM2596 Step-Down Module Circuit

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The LM2596 step-down module is used to generate a 5V output voltage on the device. The LM2596 step-down circuit is shown below.

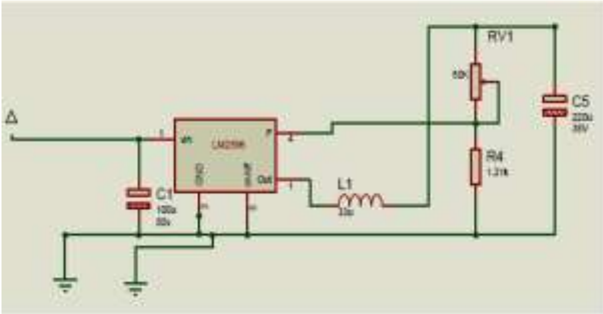

Figure 6. LM2596 Step Down Design

To find out the resistance value of RV1 to produce a 5V output, use the following calculation:

$$Vout = Vref\ (1 + \frac{RV1}{R4})$$

$$RV1 = R4.\left(\frac{RVout}{Vref}\right) - 1$$

$$RV1 = 1200.\ \left(\frac{5}{1{,}2}\right) - 1$$

$$RV1 = 3800\ \Omega$$

To produce a voltage of 5V, a resistance of 3,800 ohms is required in RV1. Here is the calculation to confirm this:

$$Vout = Vref\ (1 + \frac{RV1}{R4})$$

$$Vout = 1{,}2\ .\ (1 + \frac{3800}{1200})$$

$$Vout = 5\ V$$

d. Relay and Infrared Circuit

This relay and infrared lamp circuit is used to turn the IR lamp on and off. The relay receives a 5V input voltage from the input and is connected to pin D7 on the Arduino. Pin D7 controls the infrared lamp's on and off state based on user settings. At the relay output, the lamp is connected to the 220VAC relay output. The lamp's phase is connected through the Normally Open (NO) pin on the relay output.

e. DC Motor Circuit

The DC motor used is controlled using the L298 driver module. This driver gets 12VDC voltage through a 12VDC and 5VDC power supply. To provide command input from the Arduino, connect pins 5 & 6 on the Arduino to the IN1 & IN2 pins on the motor driver. In addition, connect the ENA & ENB pins to 5VDC. As output from the driver, the motor is connected via the OUT 1 & OUT 2 pins.

OVERALL WORKING PRINCIPLE

The device receives 220VAC 50Hz voltage through the PLN grid. The voltage is then converted from AC to DC, and then stepped down to 12VDC and 5VDC. The 5VDC voltage is used to power the Arduino UNO and other components. Meanwhile, the 12VDC is used to power the motor driver to drive the motor. A microcontroller is used as the device's signal processing center, both as an output provider and input receiver. In this case, the microcontroller is used to provide signal input to the relay, LCD, and motor driver. Meanwhile,

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the input signals received by the microcontroller come from push buttons, limit switches, and optocoupler sensors.

The push buttons on this device are used to set parameters such as speed, timer, and angle. They also act as start/stop buttons and reset the IR lifespan. Limit switches provide input to the device about the minimum angle range, which is 0°. Optocoupler sensors are used to detect leg movement; this sensor ensures that the movement of the leg aligns with the user's angle setting. Finally, there are the microcontroller's outputs.

First, the relay turns the IR light on and off according to the user's timer setting. When the IR light is on, the IR light's lifespan is reduced. Second, the motor driver controls the speed, time, and direction of the motor. Finally, the LCD displays the device's settings and indicators.

RESULT AND DISCUSSION

In accordance with the design carried out in this study, the resulting hardware is shown in Figure 3. After surgery, patients enter a rehabilitation phase that cannot be ignored. This phase focuses on restoring joint function, not just bone healing. This is in accordance with research on CPM for post-operative patients, bone disease and age factors (8). Continued at this stage, testing has been carried out, including measurements and accuracy testing as described below:

Measurement Analysis at Points

To identify the location of the measurement points, refer to the wiring diagram for the test points. The measurement points (test points) on the wiring diagram indicate specific locations in the circuit where technicians or developers can measure important variables (voltage). Based on the measurement results, comparing the measurements with the theory, the measurement results are relatively close to the theory. Table 1 serves as a reference for calculating the percentage error:

$$PE = \frac{(actual - measurement)}{actual} . 100$$

The measurement points are as follows:

Table 1. Measurement Points and PK Results

Measurement Point	Actual Result	Measurement Result	PE (%)
Trafo Output	18 VAC	18,6 VAC	3,3
Relay Module	220 VAC	221 VAC	0,45
Infra Red Lamp	220 VAC	221 VAC	0,45
Output XL4015	12 VDC	12,12 VDC	1
Output LM 2596	5 VDC	5,04 VDC	0,8
Low Speed DC Motor	3,3 VDC	3,337	1,12
Medium Speed DC Motor	6,6 VDC	6,85 VDC	3,78
High Speed DC Motor	10 VDC	10,40 VDC	4
output of the rectifier diode	24,84 VDC	24,21 VDC	2,5

From the data of the error percentage calculation results, there are results with an average of 1.93%, with a maximum permissible error value of 5%, so that the average value is still within the tolerance range of the error percentage. From the calculation of the average error at the measurement point, the accuracy of the test can be obtained with the following calculation:

$$Accurate = 100\% - PE$$
$$Accurate = 100\% - 1{,}93\%$$
$$Accurate = 98{,}07\%$$

The voltage accuracy of 98.07% indicates the device’s electrical stability, which is within acceptable tolerance limits (<5%). this test was very successful, because it produced a very high level of degree

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measurement accuracy, This figure shows that the mechanism and angle sensor on the dual-function CPM device (for knees and elbows) can move the patient's joints according to the angle settings desired by the therapist.

Degree Accuracy Testing Analysis

The test used to validate the accuracy of angle (degree) measurements on the CPM involves comparing them with an angle measuring instrument (goniometer). This principle is to determine the angle, as a comparison for measuring the actual angle formed by the CPM movement mechanism (15). This is demonstrated in Figure 6, the results of the degree accuracy measurement.

(a) Setting the angle of 20° is proven by the angle on the goniometer.

180° is the starting point, the measurement result reads 160°. So 180°-160°=20°

(b) Setting an angle of 80° is proven by the angle on the goniometer

180° is the starting point, and the measurement result reads 100°. So, 180°-100°=80°

(c) The 120° angle setting is verified by the angle on the goniometer.

180° is the starti reads 65°. So 180°-65°=115°

Figure 6. (a),(b),(c) Results of degree accuracy measurements For the accuracy measurement of the degree, additional testing is provided in a table for more completeness.

Table 2. Results of the Accuracy Readings of the Degree and PK

Degrees	CPM Setting	Reading Results (Goniometer)	PE (%)
setting angle 20°	20°	20°	0
setting angle 40°	40°	40°	0
setting angle 60°	60°	60°	0
setting angle 80°	80°	80°	0
setting angle 100°	100°	95°	1,69
setting angle 120°	120°	115°	1,74

Referring to Table 2, the average error percentage for the degree accuracy reading is 0.571%. This is a very low figure and is excellent for an electromedical device involving motor control and angle measurement. This confirms that the accuracy testing method using comparison with standard measuring instruments (e.g., a caliper or goniometer) shows that the mechanical and electronic systems operate with high precision.

$$Accurate = 100\% - PE$$
$$Accurate \ = 100\% - 0{,}571\%$$
$$AccurateAkurasi = 99{,}42\%$$

From the calculation of the average error at the measurement point (TP), the test accuracy can be obtained with a calculation of 99.42%.

Time Accuracy Testing Analysis

Testing the time accuracy of the Continuous Passive Motion (CPM) device is a crucial step in verifying that the duration of therapy and the speed of joint movement are in accordance with the programmed settings.

Figure 7: Comparison of the timer and CPM.

This test is generally conducted by comparing the time measured by the CPM system with the reference time measured by a standardized external device. The measurements performed at each specified time interval yielded the following results:

Table 3 Time Accuracy Reading Results

Timer Smartphone	**CPM**	**Therapy Time Smarphone**	**Therapy Time CPM**
00:50:00	00:50:11	00:10:00	00:09:49
00:40:01	00:40:42	00:19:59	00:19:38
00:30:00	00:30:32	00:30:00	00:29:28
00:20:01	00:20:42	00:39:59	00:39:18
00:10:01	00:10:52	00:49:59	00:49:08
01:00:00	00:01:01	01:00:00	00:58:59

Referring to the table of time accuracy results comparing the smartphone timer reading with the CPM display, the average error percentage was 1.74%. This also means the time accuracy level is as follows:

$$Accurate = 100\% - PE$$
$$Accurate = 100\% - 1{,}74\%$$
$$Accurate = 98{,}25\ \%$$

This 98.25% accuracy rate indicates that the CPM device's internal timing system is functioning very well and reliably. This timing accuracy is crucial in rehabilitation therapy because timing is a key component in controlling joint movement speed (degrees per second). Accurate timing ensures that elbow or knee joint movement occurs at a **safe** rate.

CONCLUSION

English: After completing the steps, from module creation to measurement and analysis of the Continuous Passive Motion (CPM) device for the hand and foot, the following conclusions can be drawn: The Continuous Passive Motion (CPM) device for the hand and foot developed by the author functions well. The measurement accuracy of tension, time and degree yields an average for each measurement point of 98.27%. The device demonstrates high accuracy in tension, time, and angle control, making it suitable for the early rehabilitation stage. Suggestions for further development to maximize the functionality of the device include using a motor with greater torque to increase the maximum load of the device. Future work should focus on clinical trials and ergonomic improvements.

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