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Design of an Arduino-Based CPM Elbow Actuator with Optocoupler Angle Sensor: Initial Study with Future Consideration for Rubber and Plastic Components

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Abstract – *The hand is a part of the human body that serves various activities. However, if the hand is injured due to an accident, it can result in a disruption of motor function for an individual. Therefore, a Continuous Passive Motion Elbow device is needed to assist in the rehabilitation of an injured hand's elbow. While rubber and plastic materials are commonly utilized in commercial CPM devices—plastic for lightweight and durable casings, and rubber (elastomers) for flexible, skin-contacting components—this study does not yet integrate these materials in its prototype. However, the design opens possibilities for future incorporation of ergonomic plastic and elastomer components to improve user comfort, device safety, and manufacturability.*

The development of the Continuous Passive Motion Elbow design is necessary to improve the existing design and meet the functional needs of postoperative hand elbow therapy patients. This device is designed using an Arduino microcontroller, a DC motor as the actuator, and an optocoupler sensor as an angle reader. The Optocoupler sensor operates by detecting the gaps in the gear disc located in the device's framework. The photodiode emits infrared light, which is directed towards the phototransistor. This light is then converted into a digital signal by the microcontroller, registering as '1' when the infrared light is obstructed (indicating the absence of light reaching the phototransistor) and '0' when there is no obstruction (indicating the presence of infrared light reaching the phototransistor). These digital signals are subsequently converted into angle values through an Arduino program sketch, and the results are displayed on the LCD.

In this research, the device will be tested by comparing the test results with goniometer measurements. The results of these tests will be displayed on an LCD screen. The device works effectively, exhibiting an error accuracy of 0.8%.

Keywords: *CPM, Elbow, DC motor*

I. Introduction

The upper and lower limbs of the human body are essential for daily activities. However, injuries resulting from accidents can disrupt motor activities. The physiological functions of the human body may experience temporary dysfunction after undergoing surgery [1][2]. This organ dysfunction is only temporary as the body naturally regenerates cells and restores the physiological functions of the organs. However, to restore motor function, the body needs to engage in gradual movement exercises until normal motor function is regained [3][4].

Apart from postoperative conditions, stroke is another cause of reduced motor function in human physiology [5]. Stroke can result in various impacts such as paresis (muscle weakness), paralysis (muscle paralysis), hypoesthesia (reduced skin sensitivity), inability to move the arm and fingers, and more. These effects can significantly diminish the quality of life for post-stroke patients [6]–[8].

Physical and cognitive exercises can enhance the speed of restoring movement functions, thereby increasing functional independence and improving

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the quality of life for patients. Rehabilitation studies on stroke patients indicate that 50-70% of patients can live independently, and there are many other benefits when rehabilitation is promptly and effectively implemented. Therefore, there is a high and urgent need for better medical rehabilitation methods [9]–[12].

In the early stages of therapy, passive rehabilitation often serves as a reference method to reduce swelling, alleviate pain, and restore Range of Motion (ROM) – the degree of joint movement from full flexion to full extension [13][14]. This method involves moving the arm with passive muscles, performed by a physiotherapist. However, the number of physiotherapists in Indonesia is still inadequate, with only about 4,333 registered physiotherapists [15].

The recovery of elbow joint motor function involves moving the arm by folding it towards the chest, known as flexion, and straightening it back, known as extension, with a specific manual angle performed by a physiotherapist [16], [17]. With advancements in medical technology, particularly in physiotherapy, there is a device that facilitates therapists, especially for Osteoarthritis patients. The device is called Continuous Passive Motion Elbow or CPM Elbow, which works by automatically moving the arm in flexion and extension with a specific angular fold, using electric motor power [18][19], [20]. In commercial implementations, plastic and rubber materials play a crucial role in the usability and ergonomics of CPM devices. Plastic is often chosen for its lightweight, durable, and easily moldable properties, making it ideal for casings and structural supports. Rubber or elastomer components are used for areas in contact with the skin, such as straps, padding, and protective grips, due to their flexibility and comfort. Although the current prototype does not yet incorporate specific material engineering using plastic or rubber, the research recognizes their importance in future development. The system presented in this study serves as a stepping stone toward a more complete and patient-friendly CPM device that will eventually combine mechanical, electronic, and material design innovations.

In the research titled "Continuous Passive Motion (CPM) Elbow with Electromyograph (EMG) Control" by [21], the author designed a CPM device that combines it with Electromyogram (EMG) methods. The device utilizes an ATMega16 microcontroller and an angle sensor with a rotary range of 100 to 900 degrees. The angle divisions for movement are set at 100 for weak mode, 600 for moderate mode, and 900 for strong mode. The apparatus consists of an instrument amplifier circuit to capture muscle signals, a filter circuit to refine EMG signals, a gearbox motor, an LCD for displaying angle measurement results, and a supporting mechanical framework.

Based on the study [22], this study aimed to develop an interface instrument for digitalising EMG signals and controlling a CPM machine. The proposed device was designed with the following (1) a signal processing unit which converted the EMGs from analogue to digital for the controller; (2) a personal computer which stored and displayed the EMG signals; (3) an LCD device to display the running angle of the CPM; and (4) a microcontroller unit to control the input/output signals and process the algorithm, driving the CPM. This proposed device was able to digitalise and process EMG signals from eight channels of muscles, and the signals were able to drive a CPM. The validated results showed that the digitalised EMG signals by the proposed device were statistically similar to and correlated with the signals by the Vicon system with a median correlation coefficient of 0.81.

Continuous Passive Machines (CPM) facilitate patients in eliminating joint stiffness after surgery and lead to a faster and more efficient recovery [23]. Its mechanismis designed so that it can be used on the left or right arms interchangeably. It is developed using aluminum, perspex, and steelrods. The electrical part of the machine consists of Arduino Uno to drive the motors and a potentiometer to measure the patients' Range of Motion (ROM). The experimental results show that the machine has successfully provided the repetitive desired motions. The machine realizes elbow flexion-extension and forearm pronation-supinationmovements with 0^{o}-135^{o} and 0^{o}-90^{o} ranges of motion (ROM),respectively.Themachine is also capable of increasing the elbow joint's ROM by 5^{o} increments for the therapy.

Given the importance of this device in assisting physiotherapists, a CPM Elbow therapy device has been created to aid physiotherapists in their work. This device offers several advantages compared to manual therapy, such as working with mechanical power and having a significant range of angle values, allowing physiotherapists to determine the angle range used and facilitating the matching of the range of motion from the therapy performed.

II. Method

The design of a Continuous Passive Motion (CPM) elbow device using an Arduino Uno microcontroller and reading the angles of flexion and extension movements using an optocoupler sensor has a working principle as shown by the block diagram below.

This tool consists of several parts, namely the ON/OFF switch, power supply, relay module, Arduino Uno microcontroller, optocoupler sensor, push button, motor, tool body, and LCD (Liquid Crystal Display) I2C 2x16. The functions of the parts of the tool are as follows:

1. The power supply serves as a power supply for all parts and also the ON/OFF switch as a power on and off tool.
2. The push button serves as a button to start the flexion and extension movements on the tool.
3. The display serves as a display of the type of movement and the magnitude of the sensor reading angle.
4. The relay module serves as a motor driver for alternating rotation.
5. The motor serves as a driver for the frame/tool body for extension and flexion movements.
6. The tool body serves as the place where the therapy process takes place.
7. The optocoupler sensor serves as a reader of the angle of flexion and extension movements.
8. The Arduino Uno microcontroller serves to process the output values of the optocoupler sensor and the buttons that have been set in the Arduino Uno IDE software that will be displayed on the LCD (Liquid Crystal Display) I2C 2x16.

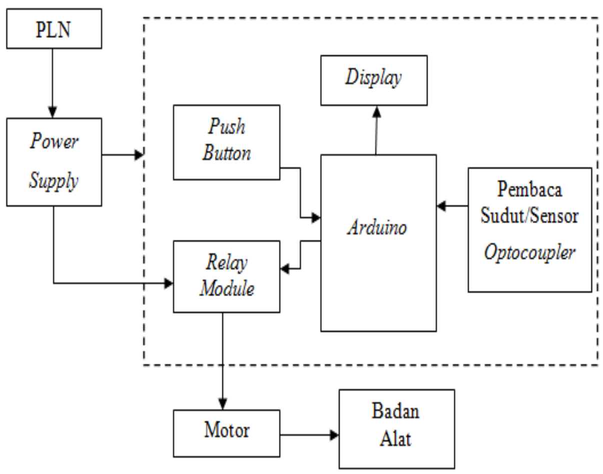

Fig. 1. Block Diagram Continuous Passive Motion (Source: Author's Document)

How the block diagram works as follows. When the main contact is connected to the power from PLN, the power supply circuit will receive 220 VAC voltage, then the voltage is reduced using a step-down transformer and rectified using a diode bridge, that is, AC voltage is converted to DC and the voltage ripple is eliminated and stabilized using a capacitor, there are 2 output voltages that are output by the transformer, namely +5VDC to be distributed to the microcontroller, display, sensor, and push button/keypad. While the second output of +18 VDC will be given to the motor driver and passed to the DC motor.

The microcontroller circuit works to instruct the LCD to display information about the tool's working sequence. When the tool is turned on using the ON/OFF switch, the first process that is done is to press the zeroing button on the push button circuit to find the initial position or zero angle. When the mechanical circuit/tool body is in the initial position, the Push Button for flexion and extension movements can be pressed. When the flexion or extension button is pressed, the button will send a signal to the microcontroller to give a command to the motor driver to move and provide power to the motor to rotate to the right or left, where the rotation of the motor is connected to the threaded iron which results in flexion and extension movements occur on the tool body. The tool body has a half-circular disc attached to the bending part of the tool, where the disc has holes every 100, these holes are read by the optocoupler sensor, when in the flexion movement the degree value that is read will increase and when the extension movement the degree value is read decreasing, the results of the reading are processed by the microcontroller and then displayed on the LCD.

a) Power Supply Circuit Design

The power supply design in this research requires several components such as a nonCT transformer, a rectifier (diode bridge), and a capacitor as a filter. The following is an explanation of the functions of each component.

1. The transformer used is a nonCT 3 Ampere transformer with input voltages of 220 VAC and 240 VAC, and outputs of 6VAC, 9VAC, 12 VAC, 15 VAC, and 18 VAC. This transformer is chosen to meet the power requirements of the secondary voltage devices used in this research, namely 6 VAC and 18 VAC.
2. The rectifier used is a diode bridge packaged in a chip. In selecting the type, a type capable of

rectifying a current larger than the device's requirements, namely 3 A, is used. This is intended to prevent damage due to the shock current that occurs when the power supply is newly operational. The diode bridge types used are KBPC308 3A for DC motor supply and 2WI0 1A for the microcontroller.

3. To obtain a DC voltage close to pure DC voltage, a filter is needed. By installing a capacitor at the output of the rectifier, the pulse shape of the rectifier output will approach a straight line. The capacitors used in the filter section are a 25 VDC 2200 μF capacitor for DC motor supply and a 12 VDC 1000 μF capacitor for the microcontroller supply.

The power supply circuit block functions as the overall power supplier for the device, requiring two power sources: 5 VDC for the microcontroller circuit, keypad, LCD, and motor driver, and +18 VDC for the motor power supply. The working principle of the designed power supply is that when the step-down transformer receives AC voltage in the primary winding of 220 VAC, this voltage passes through the secondary winding, where the winding is fewer turns than the primary winding, resulting in a lower voltage at the secondary winding compared to the primary winding. After the voltage is reduced, it passes through diodes to rectify into DC voltage. After rectification, the voltage then passes through a capacitor to filter it, making the voltage required for other circuit components more stable. The power supply circuit can be seen in Figure 2.

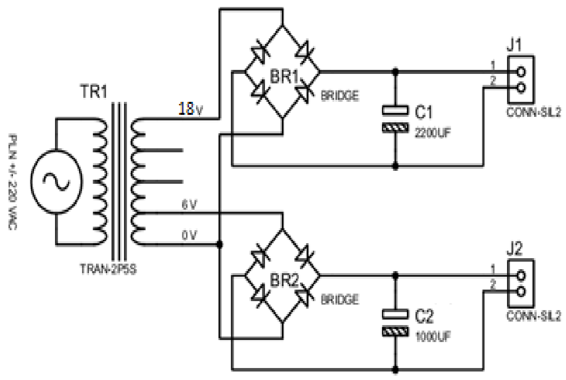

Fig. 2. Power Supply Circuit
(Source: Author's Document)

b) The Arduino Uno microcontroller

The Arduino Uno microcontroller is a microcontroller board that uses the ATMega328 IC. The Arduino Uno board has a working voltage range between 5 to 18 VDC. If the supplied voltage is below 5 VDC, the Arduino board will be unstable, and its performance may be erroneous. Supplying a voltage exceeding 12 VDC can cause the Arduino board to overheat and potentially damage it. The Arduino features input and output pins, including 6 pins usable as PWM outputs, 13 digital pins, 6 analog input pins, a 16 MHz crystal oscillator, USB connection, power jack, ICSP header, and a reset button. The Arduino Uno microcontroller is depicted in the figure 3.

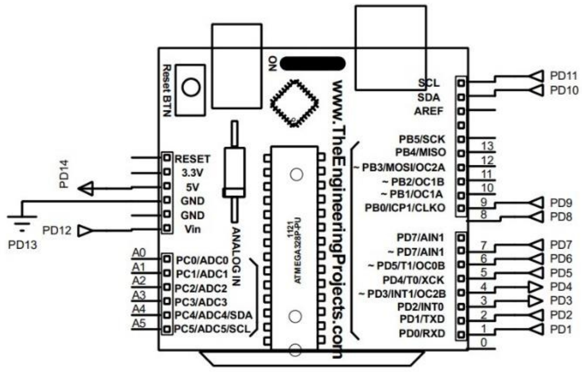

Fig. 3. Arduino Uno Microcontroller
(Source: Author's Document)

The following are the pins on the Arduino Uno used in the design of the CPM Elbow device:

1. VCC Pin: Functions as the output voltage from the Arduino board to supply power for the optocoupler sensor, keypad, and Liquid Crystal Display.
2. Ground Pin: Functions as the neutral or negative pole for the optocoupler sensor, keypad, and Liquid Crystal Display.
3. SCL Pin (Serial Clock): Represented by input PD 11 in Figure 3, it serves as the data line used by the I2C LCD to identify that the data is ready for transfer.
4. SDA Pin (Serial Data): Represented by input PD10 in Figure 3, it is a two-way data line used by the I2C LCD.
5. Digital Pin Number 9: Represented by input PD 9 in Figure 3, it functions as the input pin for the flexion movement Push Button output.
6. Digital Pin Number 8: Represented by input PD 8 in Figure 3, it functions as the input pin for the extension movement Push Button output.
7. Digital Pin Number 7: Represented by input PD 7 in Figure 3, it functions as the input pin for the zeroing Push Button output.
8. Digital Pin Number 6: Represented by input PD 6 in Figure 3, it functions as the input from the

optocoupler sensor for the angle measurement reduction sensor.

9. Digital Pin Number 5: Represented by input PD 5 in Figure 3, it functions as the input from the optocoupler sensor for the angle measurement increase sensor.
10. Digital Pin Number 4: Represented by input PD 4 in Figure 3, it functions as the input from relay 1.
11. Digital Pin Number 3: Represented by input PD 3 in Figure 3, it functions as the input from relay 2.
12. Digital Pin Number 1: Represented by input PD 1 in Figure 3, it functions as the input from the limit switch for zeroing.
13. VIN Pin: Represented by input PD 12, it functions as the voltage input for the Arduino board with a voltage of 6 VDC.

c) Optocoupler

Optocoupler is a combination of an infrared LED and a phototransistor encapsulated into a single chip. Infrared light falls within the electromagnetic spectrum that is not visible to the naked eye, as it has a wavelength beyond the range of human visual response. Infrared light has a frequency range of 1×10^12 Hz to 1×10^14 GHz or a frequency range with a wavelength of 1 µm – 1 mm.

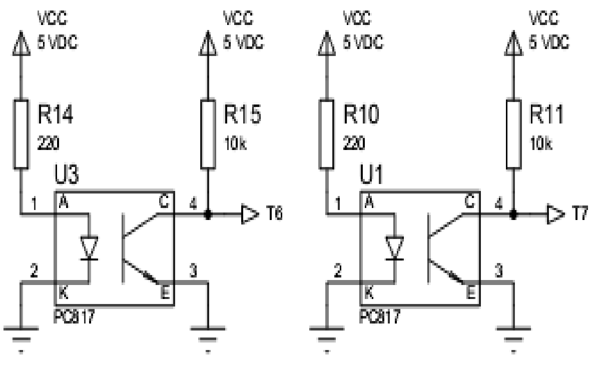

Fig. 4. Optocoupler Sensor Circuit
(Source: Author's Document)

The pins used by the optocoupler sensor on the Arduino Uno board are as follows:

1. VCC Pin (5V): Connected to a 220-ohm resistor, and the output from the resistor is then connected to the anode of the diode. The cathode of the diode is connected to the Ground Pin on the Arduino board.
2. VCC Pin (5V): Connected to a 1000-ohm resistor, and the output from the resistor is then connected to the collector pin of the phototransistor. The emitter pin of the phototransistor is connected to the Ground Pin on the Arduino board.
3. Digital Pin Number 6: Connected to the output of the collector pin (PD 6) as a digital signal input.
4. Digital Pin Number 5: Connected to the output of the collector pin (PD 7) as a digital signal input

d) Liquid Crystal Display

LCD (Liquid Crystal Display) I2C 2×16 is an electronic display used in the design of this device to showcase the processed output values from the sensors on the Arduino Uno microcontroller. The advantages of the I2C-based 2×16 LCD include:

The LCD 2×16 utilizing the I2C interface provides ease in shorter programming, and the pins used in the Arduino Uno microcontroller are reduced, requiring only the SCL (Serial Clock) pin as the data line used by the I2C LCD to identify that the data is ready for transfer, and the SDA (Serial Data) pin as a two-way data line used by the I2C.

The displayed data on this I2C LCD includes the type of movement (flexion or extension) and the angle reading values obtained from the optocoupler sensor. The circuit diagram and pins used on the I2C LCD can be seen as follows.

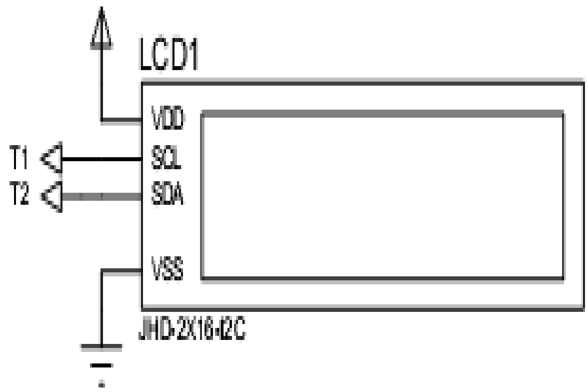

Fig. 5. I2C 2x16 LCD
(Source: Author's Document)

e) Push Button (Keypad)

In the design of the continuous passive motion elbow device with angle measurement using the optocoupler sensor, the keypad functions as the microcontroller input to determine the movements that the device will perform, such as flexion and extension. The microcontroller pins used to connect to the keypad include three buttons: PD 5 (Digital Pin 5) for flexion movement, PD 6 (Digital Pin 6) for extension movement, and PD 7 (Digital Pin 7) as the Power button for the keypad and LCD. The keypad circuit used can be seen in the figure 6.

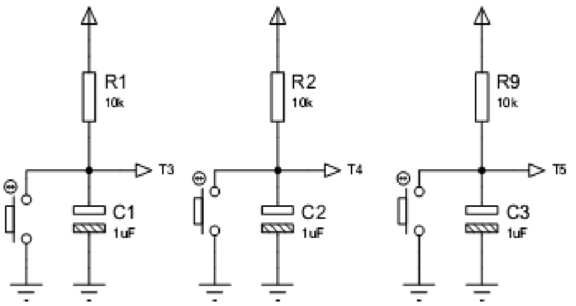

Fig. 6. Keypad Circuit
(Source: Author's Document)

f) Motor Driver
The motor driver circuit in this device functions as a controller for the rotation of the DC motor regulated by the microcontroller. The motor driver used is a 2-relay module, where these relays act as inverters of electrical polarity, allowing the motor to rotate clockwise and counterclockwise. The motor driver circuit can be seen in the figure 7.

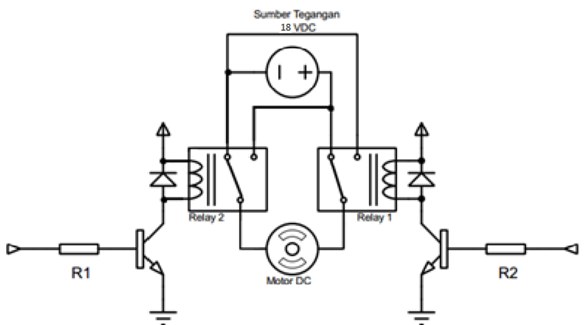

Fig. 7. Motor Driver Circuit
(Source: Author's Document)

Image Description:
a. The motor phase cable is connected to the COM of relay 1.
b. The motor ground cable is connected to the COM of relay 2.
c. The 18 VDC power from the power supply is connected to the NO pin of relay 1 and the NO pin of relay 2.
d. The ground from the power supply is connected to the NC pin of relay 1 and the NC pin of relay 2.
e. The VCC pin of the relay is connected to the VCC pin of the Arduino board.
f. The Ground pin of the relay is connected to the Ground pin of the Arduino board.
g. Pin In 1 (PD 1) of the relay is connected to digital pin number 4 of the Arduino board.
h. Pin In 2 (PD 2) of the relay is connected to digital pin number 3 of the Arduino board.

g) Limit Switch
Limit switch is a switch or electromechanical device that has an actuator lever as a position changer for terminal contacts (from normally open/NO to close or conversely from normally close/NC to open). In this device, the used limit switch is a normally closed contact, functioning as the zeroing relay module, ensuring that the device is in its initial position when about to be used. The limit switch circuit and the construction of the limit switch can be seen in the figure 8.

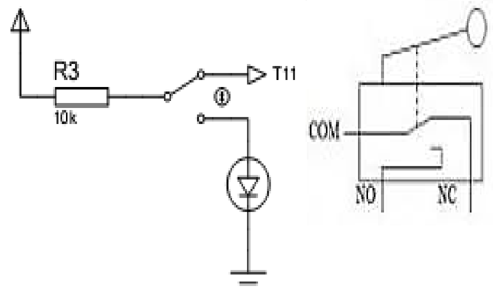

Fig. 8. Limit Switch Circuit and Construction
(Source: Author's Document)

III. Results and Discussion

In this chapter, testing and data analysis were conducted on the simulation of the device with the aim of determining the performance and operation processes of each designed circuit.

1) Circuit Power Supply Testing
The testing of the circuit in this power supply aims to ensure that the output voltage from the power supply matches the required voltage. The testing circuit can be seen in figure 9. Meanwhile, the results of the voltage output measurements can be seen in figure 9.

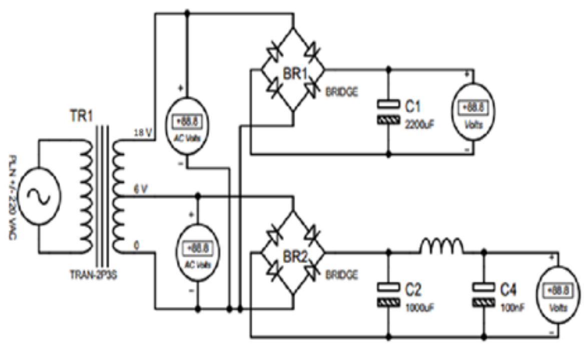

Fig. 9. Power Supply Testing Circuit
(Source: Author's document)

TABLE 1. MEASUREMENT RESULTS OF INPUT-OUTPUT ON THE POWER SUPPLY

Measure-ment Point	Expected Voltage (Volt)	Measurement Results (Volt)	Error(Volt)
Input Trafo	18VDC	17,52 VDC	0,48 VDC
Intput Trafo	6VDC	5.81 VDC	0,19 VDC

The measurement results of the output voltage from the power supply with a secondary coil point of 18 VDC produced an output voltage of 17.52 VDC with an error of 0.48 volts. For the output voltage with the measurement point at the 6 VDC secondary coil, it resulted in an output voltage of 5.81 VDC with an error of 0.19 volts. After measurement, it was found that the error results were not more than the tolerance value, which is 10%. Therefore, it can be used by microcontroller circuits and motor circuits.

2) Motor Driver Testing

Testing of this circuit can be done by triggering the base of transistor relay 1 and relay 2. By providing a trigger to the base, the transistor works to pass the voltage, and at the same time, the Vcc voltage is already on standby, so the DC relay receives a 5 V voltage and is connected to the ground. This condition causes both DC relays to work or become active. Measurements are taken at the source voltage, base, and collector pins in the transistor using a voltmeter.

With the activation of the DC relay in the light source control circuit, the direction of the motor rotation is controlled, and the contactor on the DC relay is in the NO (normally open) position. In other words, the contact inside the relay moves to another position, connecting the 18 VDC voltage to the DC motor. The activation of each relay is controlled by a microcontroller, where the relays will activate alternately, and each relay has a different polarity. In other words, relay 1 has the opposite polarity to relay 2 when active, resulting in different motor rotation directions. The motor rotation control circuit can be seen in Figure 10.

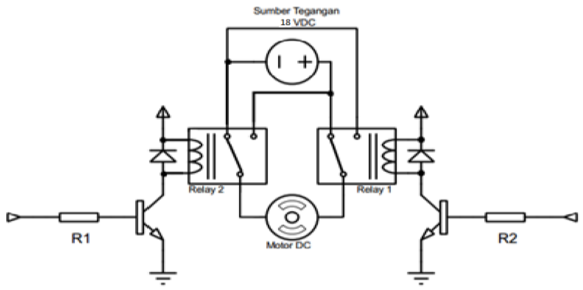

Fig. 10. Motor Rotation Direction Control Circuit (Source: Author's document)

The test results of the motor rotation direction control circuit (motor driver) can be seen in Table 2.

TABLE 2. RESULT OF MOTOR ROTATION CONTROL CIRCUIT

Relay	State	Transistor voltage (Volt)					
		Source		Basic		Collector	
		H	T	H	T	H	T
1	ON	5	4,7	1	0,98	1	0,96
	OFF	5	5	0	0	5	5
2	ON	5	4,8	1	0,98	1	0,96
	OFF	5	5	0	0	5	5

Table 2 indicates that the transistors in the light source control circuit function properly. This can be observed in the measurement data of the base pin (Vb) and collector pin (Vc) in the transistor. When there is no trigger from the microcontroller to the base pin of the transistor, the voltage at the base (Vb) is 0 V, and the voltage at the collector (Vc) is 5 V. This indicates that no voltage is flowing from the emitter pin to the collector pin, and the relay is in the OFF state. On the other hand, when the base pin of the transistor receives a trigger from the microcontroller, the voltage at Vb is 0.98 V, and the voltage at Vc is 0.96 V. This indicates that there is voltage flowing from the emitter pin to the collector pin, causing the relay to be in the ON state. Following is the Result of The Design Of The Passive Hand Joint Actuator.

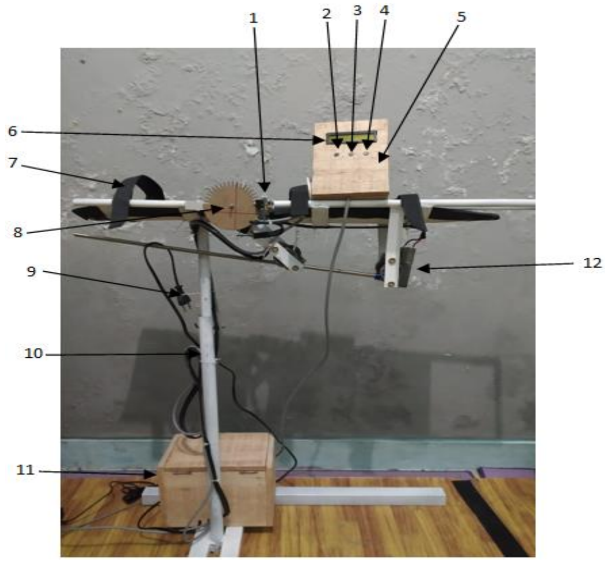

Fig. 11. The Result of Instrument

Image description:

1. Optocoupler Sensor functions to read holes in each gear.
2. Flexion Button on the keypad serves as a command input to move the device to the flexion condition.
3. Extension Button on the keypad serves as a command input to move the device to the extension condition.
4. Supination/Zeroing Button on the keypad serves as a command input to move the device to the supination condition or the initial condition, i.e., 00 on the device.
5. Remote Casing functions as protection for the circuitry on the remote.
6. Display on this device serves as an angle indicator, where the LCD 2 x 16 display is used.
7. Strap functions to secure the patient's hand in the predetermined position.
8. Gear on this device is made of acrylic and serves as a reading medium for the Optocoupler sensor.
9. Power Cable serves as a conductor for 220V electrical voltage from the source to the circuitry on the device.
10. Support Pillar functions to support the continuous passive motion elbow device.
11. ON/OFF Button functions to turn the device ON from the OFF condition or vice versa to turn off the device.
12. DC Motor in this device functions as the main drive, using a 12V DC motor with a rotation speed of 30 rpm and a torque of 7-10 kg

Testing has been conducted on the device, particularly on the sensor used. The Range of Motion (ROM) is obtained by measuring from the initial position of flexion to the final position of extension, where the distance is measured in degrees of a circle to assess the joint's ability to perform extension and flexion. Therefore, the testing was carried out in the following positions.

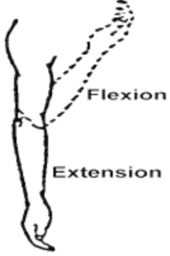

Fig. 12. Illustration of Flexion and Extension Angle Measurement

The testing of this sensor is conducted by comparing the range of motion (ROM) measurement tool, namely the Goniometer on the device frame, with the angle readings from the Optocoupler sensor displayed on the LCD. The data and analysis results are obtained, as shown in Table 3, and the corresponding graphs are presented in Figure 13.

TABLE 3. COMPARISON OF LCD ANGLE AND GONIOMETER

No	Viewing Angle on the LCD (^{0})	Average Angle on the Goniometer (^{0})
1	10	10,2
2	20	19,6
3	30	30,2
4	40	39,8
5	50	49,6
6	60	59,8
7	70	69,8
8	80	79,8
9	90	89,6
10	100	99,8
11	110	109,6
12	120	118,6
13	130	128,2
14	140	138,2

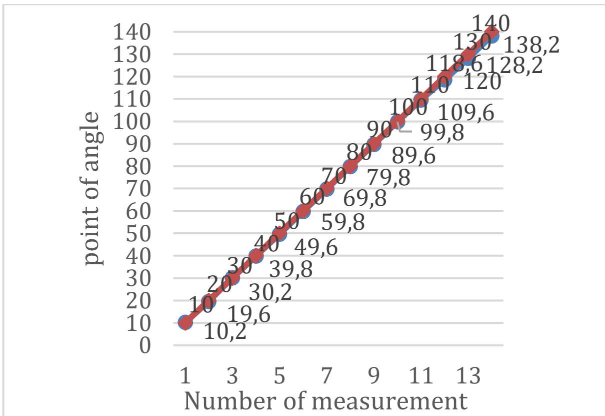

Fig. 13. Graphic Angle of Number Measurement

The testing results of angle readings by both the sensor and the Goniometer on the frame of the Continuous Passive Motion (CPM) device for the elbow produced angle measurement data. This was carried out through the following steps:

1. The sensor and goniometer were both placed in the same position.
2. The mentioned position refers to point 1 as shown in Figure 12.
3. The test subject performed flexion and extension movements as illustrated in Figure 13.
4. The measured angle results from the developed device were displayed on both the LCD and the Goniometer.

. The sensor displayed angle values on the LCD as 10^0, 20^0, 30^0, 40^0, 50^0, 60^0, 70^0, 80^0, 90^0, 100^0, 110^0, 120^0, and 130^0. For the Goniometer measurements, the average angle measurements for each 100 increment were $10{,}2^0$, $19{,}6^0$, $30{,}2^0$, $39{,}8^0$, $49{,}6^0$, $59{,}8^0$, $69{,}8^0$, $79{,}8^0$, $89{,}6^0$, $99{,}8^0$, $109{,}6^0$, $118{,}6^0$,$128{,}2^0$, dan $138{,}2^0$. Factors influencing error values include variations in the measurement location using the Goniometer, which is not always consistent due to the length of the Goniometer arm, leading to different placements compared to the sensor. Other factors include visual acuity and the viewing direction for the angle scale on the Goniometer. As an example, data obtained from accuracy calculations for an angle of 100, with 5 experiments, resulted in an average of 10.20, absolute error of 0.20, and relative error of 0.0200, with an error accuracy of 2%.

IV. **Conclusion**

After the design and testing of the Continuous Passive Motion Elbow device with the Optocoupler sensor angle reader, the following conclusions can be drawn:

The Optocoupler sensor's angle readings on the angle disc located in the mechanical frame allow the device to read angles from 00 to 1400 effectively. The angle values displayed on the LCD, when compared to the angle readings by the Goniometer, exhibit significant differences. These variations are attributed to the differing positions during scale readings on the Goniometer and the changing placement of the Goniometer device due to its shape being incompatible with the device frame.

The operation of the Optocoupler sensor for angle readings involves detecting gaps in the gear disc located in the device frame. The photodiode emits infrared light, which is then directed to the phototransistor and converted into a digital signal by the microcontroller. The signal has a value of 1 when the infrared light is obstructed, indicating that the light does not reach the phototransistor. It has a value of 0 when there is no obstruction, meaning that the infrared light reaches the phototransistor. These digital signals are then converted into angle values using the Arduino program sketch, and the results are displayed on the LCD

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