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**RESEARCH PAPER**

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# Comparison of PID and Fuzzy Methods in Motor Gearbox Control for Enhancing Accuracy of Angle on CPM Elbow Tool

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## ABSTRACT

**Continuous Passive Motion (CPM) is a medical rehabilitation device used to passively move joints through a certain range of motion, helping in the healing process and improving patient mobility. In previous research, the tool still used Fuzzy Logic Control simulation to control DC Servo Motor using Matlab/Simulink. This study compares the PID and Fuzzy control methods to enhance the accuracy of angle control in the Continuous Passive Motion (CPM) Elbow tool, which is used for joint rehabilitation. The Fuzzy control system was developed to control the gearbox motor for moving the arm of the CPM tool. The system utilizes an encoder sensor to ensure that the arm reaches and stops at a predetermined angle, ensuring smooth movement and precise positioning. The system takes into account changes in speed and angular error to control the motor. In parallel, a PID control system was also implemented to improve the angular accuracy. The system uses an Arduino Uno microcontroller to control the motor based on real-time feedback from the encoder sensor. Both methods aim to move the CPM arm to specified angles of 45°, 90°, and 130°, with the ability to operate at speeds of 40°/minute, 90°/minute, 150°/minute, 210°/minute, and 270°/minute. The results indicate that both the PID and Fuzzy control methods can achieve good angular accuracy with a low average error. The system's current remained stable at 2.5mA during operation. When compared to a goniometer, the error for the 45° angle was 5°, for 90° it was 1°, and for 130° it was 5°. The results show that the Fuzzy method provides better accuracy in angle control than conventional methods. This level of accuracy is essential to prevent over-extension or under-extension of the patient's joints, which can affect the rehabilitation process. The study suggests that both PID and Fuzzy control methods can effectively improve the performance of the CPM tool, with Fuzzy control offering slightly better precision. Furthermore, the research highlights the potential for further development by integrating a higher torque motor, more precise angle sensors, and platforms like Raspberry Pi for more complex control. These improvements would further enhance the CPM tool's effectiveness in patient rehabilitation.**

## PAPER HISTORY

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## KEYWORDS

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## 1. INTRODUCTION

Postoperative therapy, also known as postoperative rehabilitation, is a medical treatment process to help a person's physical and functional recovery after undergoing a surgical procedure. The goal of postoperative therapy is to maximize recovery, improve mobility in activities, reduce pain, prevent complications and allow individuals to return to optimal function in daily activities. Physiotherapy (PT) is an important component of the postoperative recovery journey that helps patients restore strength, mobility and self-confidence. This involves a variety of methods that focus on body parts, including stretching activities, physical exercises, manual therapy, and using other methods [1]. Continuous Passive Movement Therapy (CPM) uses a device to move the joint passively or the patient without using any force, with a motorized device to move the joint repeatedly referring to the provisions of the degree and speed of movement determined by the physiotherapist. CPM devices are often applied to the knee, there are also other versions for joints such as the hip, shoulder and elbow [2]. CPMs are also external devices that allow a joint to move passively along a predetermined arc of motion [3]. Rehabilitation involves both active and passive therapies to restore joint strength and mobility. Therapy physique such as Continuous Passive Motion (CPM) helps in movement passive [4], while exercise Range of Motion (ROM) focuses on maintaining ability joint For move optimally [5].

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The tool commonly used to measure Range of Motion (ROM) is a goniometer. The goniometer was first developed in France in the early 20th century. This tool consists of from three components : axis as pivot point, a moving arm that indicates the patient's ROM, and a stationary arm that marks position beginning as well as parallel with axis [6]. However, there are weaknesses in making manual measurements using this goniometer. Research by Shih-Miao Huang and colleagues develop a portable goniometer for measure corner movement wrist hand with accelereometer and gyroscope sensors (type GY-521). However, the tool This experience constraint in reading angle whose sensitivity is below 1.566 o [7]. Low level of accuracy Because usually There is error eye gauge in placement point center joints compared to use other methods such as electrogoniometer [8].

In 2017, Mohd Zul Fahmi Bin Mohd Zawawi, et al. studied motor function disorders in the lower extremities caused by stroke or spinal cord injuries. They explored the use of lower extremity exoskeletons for rehabilitation, finding that fuzzy logic controllers effectively manage exoskeleton control in real-time. The study presented a simulation of Fuzzy Logic Control for DC Servo Motors using Matlab/Simulink[9]. In 2022 Yutthana Pititheerahab, et al. research "Design and Construction of Continuous Passive Motion (CPM) For Arm Rehabilitation Device" The test results have shown that this device is capable of performing speed, angle and time control settings accurately and can be further developed by referring to the design [9]. In the Patent research by I. Jeffrey, et al. and P. Examiner, T. A. Stanis is the result of the design of the Arm and Leg Therapy device that has been patented [11] [12]. Joint stiffness, often resulting from joint trauma, can be alleviated through Continuous Passive Motion (CPM) training, which helps maintain the joint's range of motion (ROM). A portable elbow joint device has been designed for CPM training, featuring adjustable speed, time, and movement angles controlled using an Arduino Nano. [13].

Furthermore, in 2023, I Wayan Angga Wijaya Kusuma and Sugeng Santoso, with the research "Performance Analysis of Hy-2750b Motor, Mg995 Motor, Ds3225mg Motor and 24h2a4428 Motor as Portable Continuous Passive Motion (CPM) Drivers" on this tool compared the performance of 3 types of DC motors that can be used as drivers in CPM design. The DC motors used are the Hy-2750b Motor, Mg995 Motor, and 24h2a Motor. The results of the study can be used as a reference for the type of motor that can be used as a Portable CPM [14] . In 2021, Antonius Hendro Noviyanto, et al. with the research "Design of a Continuous Passive Motion (CPM) Machine for Wrist Joint Therapy" this tool uses an ATmega328 Microcontroller as a system controller and uses a Nema 23 stepper motor as wrist joint drive and is based on the torque requirements of the requirements used to move the wrist [15]. Ho, Hung-Jung, et al. studied CPM and CAM physiotherapy devices for joint rehabilitation, proposing a computerized CPM/CAM system without mechanical restraints like springs. Controlled by a sliding mode fuzzy neural network (FNN), the system uses motor-driven resistance to mimic a damped spring, guided by force sensors under the patient's feet. This PC-based system enables adaptive physiotherapy, high sensitivity, speed, data recording, analysis, and remote patient monitoring[16].

The previous CPM elbow device lacked the ability to measure angles with precision, leading to potential errors. To address this, an Encoder sensor was implemented to ensure movement stops accurately at predetermined angles. This study compares two control methods—Fuzzy and PID—for the Motor Gearbox Control System designed to improve angle accuracy on the CPM elbow device. The system aims to prevent body part damage during joint movements and relax muscles with movements tailored to the basic needs of the hand.

## 2. MATERIALS AND METHOD

In the section This containing method used writer in study This.

### A. EXPERIMENTAL SETUP

This study evaluates the accuracy of a CPM elbow tool by comparing its angle measurements to a Protractor or Goniometer. Testing is conducted with angle settings of 45°, 90°, and 130°, both with and without load, as well as at varying PWM-based speed settings of 40°/min, 90°/min, 150°/min, 210°/min, and 270°/min. The encoder sensor monitors the tool's movement and position, while the ACS712 sensor measures the current entering the Gearbox motor. Data, including angle values, current values, and current error values, is collected via the Arduino Serial Monitor and displayed on a Nextion TFT LCD.

The tool design is tested to measure its angle accuracy, with results compared against a Goniometer to identify errors in measurements. The encoder sensor provides feedback for controlling motor movement and ensuring precise positioning, while the ACS712 sensor records current values. The Arduino UNO processes data to evaluate motor control accuracy using both PID and Fuzzy methods. The results are graphed to analyze the response, accuracy of angle control, and compare the performance of the two methods. The independent variable is the CPM angular position, the dependent variable is the Nextion Display showing the angle, and the control variable is the Encoder Sensor for position monitoring.

### B. MATERIALS AND DEVICES

Study This discussing Continuous Passive Motion (CPM) tools which consist of from a number of component main Work synergistic for provide movement passive on the joints (Fig. 1). Components key is Arduino Uno as center control, DC Gearbox motor for movement precision, and Encoder as a sensor for monitor corner as well as speed. ACS712 is used for monitor consumption motor power. This tool powered by battery and assembled in frame plastic or metal light, purposeful for

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help rehabilitation with movement passive controlled in a way electronics on the part injured body.

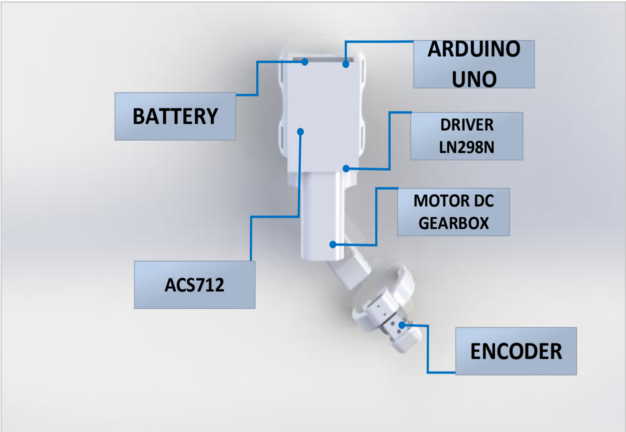


Fig. 1. **Mechanical diagram**

### C. THE BLOCK DIAGRAM

The block diagram of the system consists of several key components (Fig. 2). The Encoder Sensor measures the movement or position of the CPM tool, while the ACS712 Sensor monitors the current entering the Gearbox motor. An Emergency Switch is included to stop the tool's operation immediately in case of emergencies. At the core of the system is the Arduino UNO, which serves as the central data processor and controller, managing the tool's operations. The Motor Gearbox acts as an actuator to drive the mechanism of the CPM tool, providing passive motion to the patient's elbow joint. The system also includes a Nextion LCD, which displays essential information such as operation status, sensor readings, and parameters set by the user through the Settings Panel. This integrated design ensures efficient and safe operation of the CPM tool while providing a user-friendly interface for monitoring and adjustments.

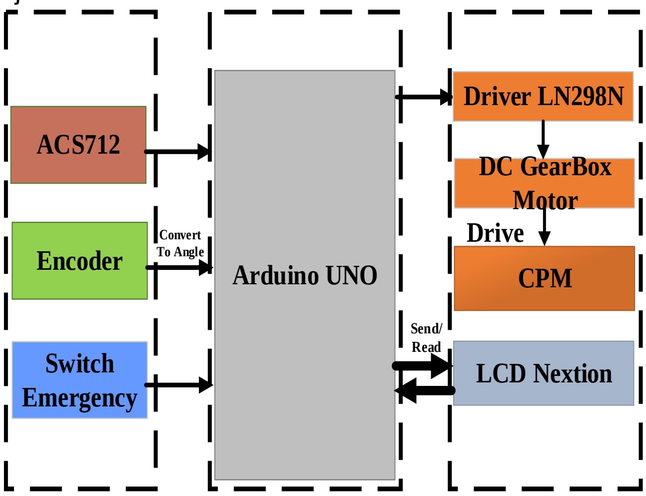


Fig. 2. **System Block Diagram**

### D. FLOW CHART

Fig. 3 presents the flow diagram illustrating the operation of the system controlling the movement of the CPM (Continuous Passive Motion) tool using Fuzzy control. The system begins with initialization, followed by reading the desired setting values. After this, the system enters the main loop where the motor is activated to drive the CPM tool mechanism. During operation, the system continuously monitors sensor readings to track the position or movement of the CPM tool. Once the desired angle is reached, the motor is turned off. The system then checks if the specified operating time has been completed. If not, the loop repeats from the beginning. If the operating time is completed, the program terminates. This process ensures the accurate and timely operation of the CPM tool, maintaining the set parameters throughout the cycle.

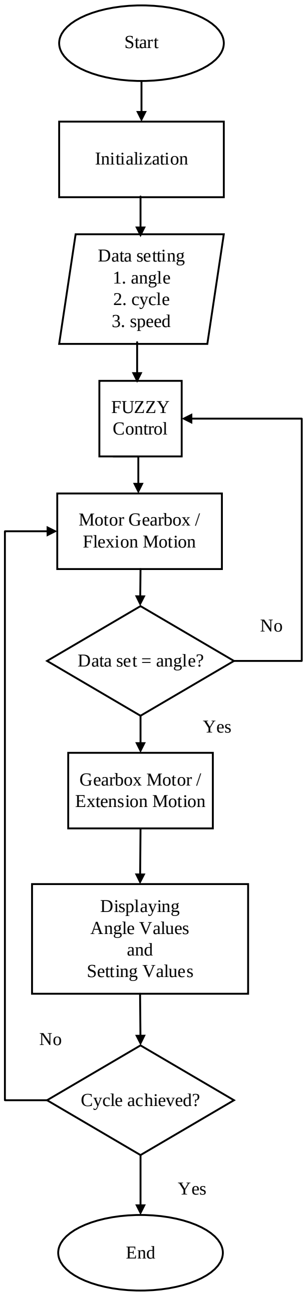


Fig. 3. **Flowchart for fuzzy Control**

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Fig. 4 is a flowchart that uses a PID control system. The process begins with initialization, followed by reading the desired setting values. After that, the system enters the main loop, where the motor is activated to drive the CPM tool mechanism. During operation, the system continuously monitors sensor readings to track the position or movement of the CPM tool. Once the desired angle is achieved, the motor is turned off. The system then checks if the specified operating time has been completed. If not, the main loop repeats from the beginning. If the operating time has been reached, the program terminates.

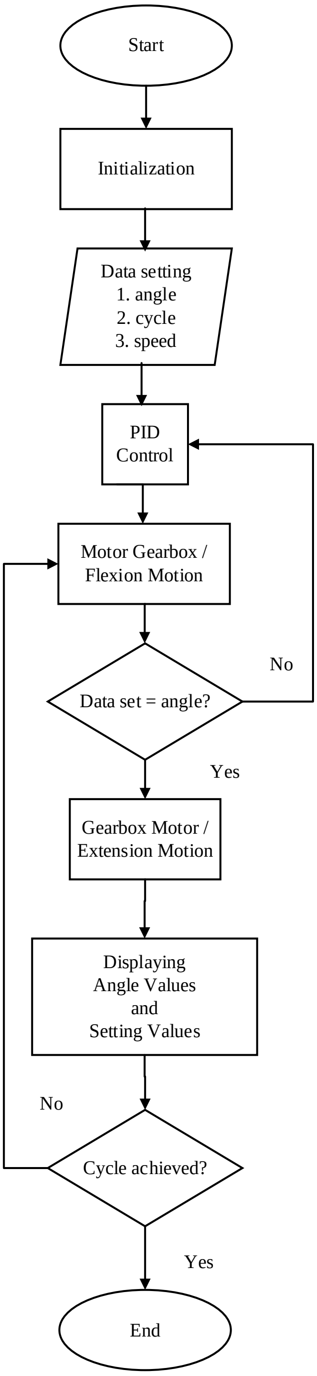


**Fig. 4. Flowchart for PID Control**

## 3. RESULTS

In research this, has done testing module with comparator in the form of a Protractor and testing with load and without the respective loads are carried out at each angle setting, namely 45 °, 90 °, and 130 ° degrees. In FIG. 5 is results design get up from module study This:

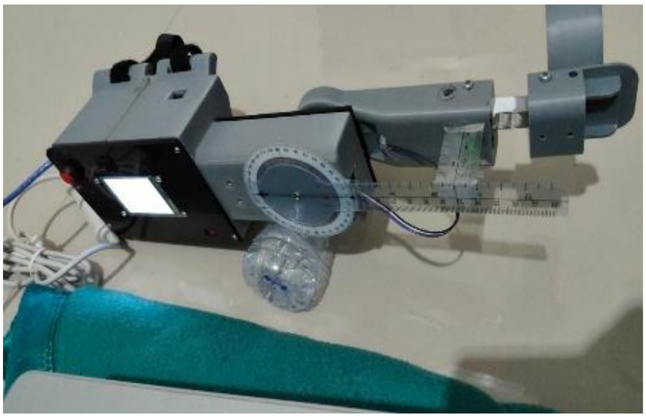

**FIG. 5. Research Module Result Design**

The cuffs are located on the part on arm exoskeleton functioning as retainer arm exoskeleton so that it can attached to the patient with OK. The switch is working For turn on CPM module, there is also a battery box designed be on the arm on CPM and there is a circuit box microcontroller in the arm above. While For circuit on the tool use using the encoder sensor used as bait come back For control Motor Gearbox movement and position monitor For ensure movement tool in accordance with desired settings. Also the ACS712 sensor for measure current on incoming current to the Gearbox motor. Then the Arduino UNO will used as microcontroller For process the data and the data results will be displayed on the Nextion TFT LCD.

Testing tool This done For know whether mark angle read on the tool has accurate with reference mark from Goniometer. Here is results comparison readable angle from tool compared to with Goniometer.

**TABLE 1. Comparison Reading Corner with Protactometer**

| Reading Corner | Corner Protactometer | Error |
|---|---|---|
| 0 | 0 | 0 |
| 45 | 40 | 5 |
| 90 | 89 | 1 |
| 130 | 125 | 5 |
| | **Average Error** | 2.75 |

TABLE 1 shows comparison between angle read by the encoder with measured angle use protactometer, and show level error or error in every measurement. At 0 °, no happen difference between second tool, so the error is 0°.

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However, at an angle of 45°, the tool read own difference by 5° compared to with protactometer. In the measurement 90° angle, relative error small, namely only 1°. While That is, at an angle of 130°, there is an error of 5°. By Overall, the average error of all over measurement is 2.75°, which illustrates level difference between tool reading and protactometer. The average error is show that although There is A little difference in a number of corner certain, in particular general tool read own level sufficient accuracy Good in measure corner compared to with protactometer as tool reference.

## A. MEASUREMENT RESULTS WITHOUT LOAD

In FIG. 5 and FIG. 6 below is example results retrieval of data that shows chart arrangement 45° angle with speed start from 40 degrees per minute and 270 degrees per minute during the therapy process use system motor control.

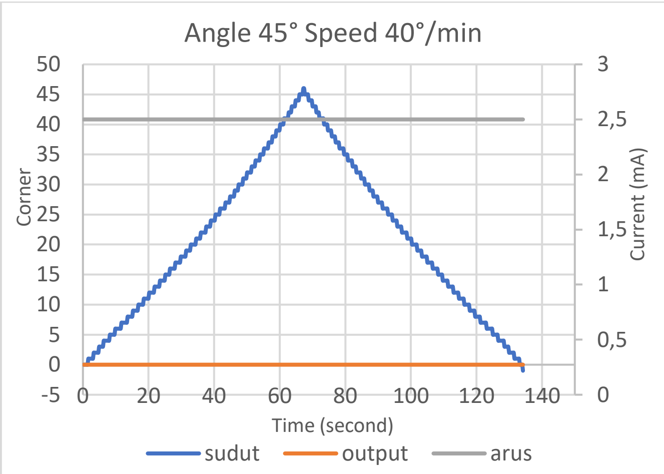


**FIG. 5. 45° Angle Setting Graph with 40 deg/min Speed Setting**

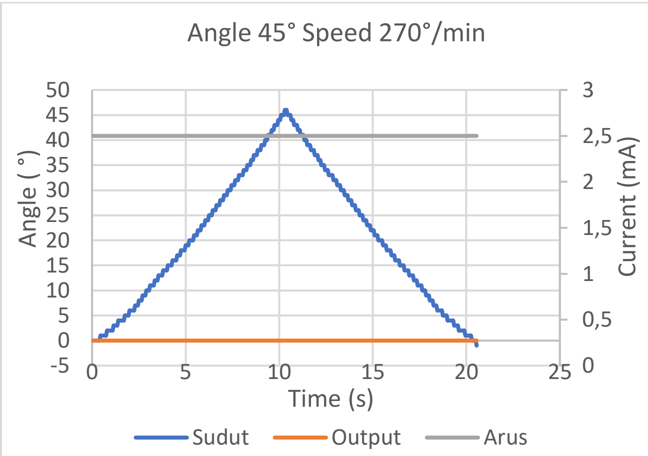


**FIGURE 6. 45° Angle Setting Graph with 270 deg/min Speed Setting**

At the beginning graph, angle start from 0° and slowly increase in a way gradually until reaching 45°, lasting during about 67 seconds at 40 speed and 11 seconds at 270 speed. After reach corner maximum, angle decrease return in a way gradually until to position initial 0° in almost time same. The orange line representing the Fuzzy error remains flat and close zero throughout graph, shows that system Fuzzy control works very well and keep errors to a minimum throughout overall cycle. On the other hand, the current electricity looks stable at about 2.5 mA for the whole process, shows that consumption Power relatively constant moment arm move from position 0° to 45° and back Again.

From the experiment Data collection using a 45º angle setting using Fuzzy dan PID with some speed settings obtained data results as following :

**TABLE 2. Result Data for Setting Angle 45 ° Without Load**

| Speed (deg/min) | Max Angle(º) | Fuzzy Error | PID Error | Current (mA) | Time 1 cycle(s) |
|---|---|---|---|---|---|
| 40 | 46 | 0 | 0 | 2.5 | 135 |
| 90 | 46 | 0 | 0 | 2.5 | 62 |
| 150 | 46 | 0 | 0 | 2.5 | 38 |
| 210 | 46 | 0 | 0 | 2.5 | 27 |
| 270 | 46 | 0 | 0 | 2.5 | 21 |

From the results in TABLE 2, it can be seen that the data collected for the 45º angle setting with speed settings of 40, 90, 150, 210, and 270 deg/min shows a Fuzzy error value of 0 with a stable current at 2.5 mA. The results indicate that the Fuzzy method can effectively control the error, keeping it at a value of 0. Similarly, the PID method also demonstrates the same results, with the error remaining at 0 and the current remaining stable at 2.5 mA, highlighting that both control methods Fuzzy and PID are able to maintain high accuracy in angle control while keeping the current consistent.

In FIG. 7 and FIG. 8 below is example results retrieval of data that shows chart arrangement 90° angle with speed start from 40 degrees per minute and 270 degrees per minute during the therapy process use system motor control.

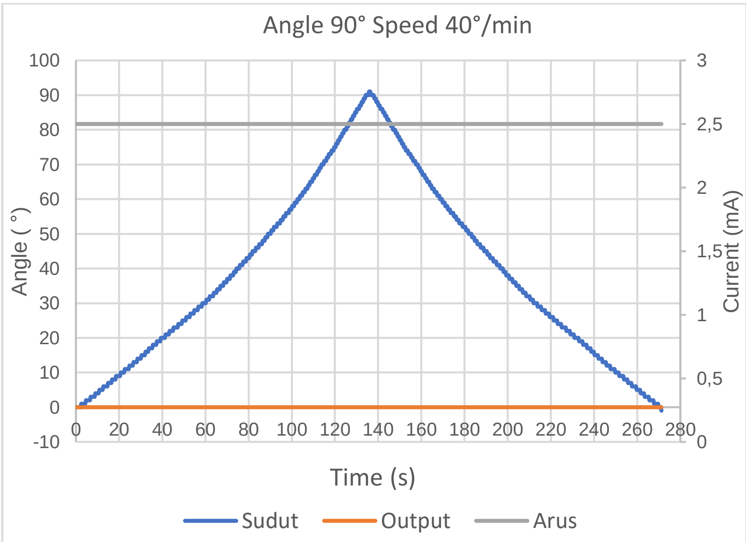


**FIG. 7. 90◦ Angle Setting Graph with 40 deg/min Speed Setting**

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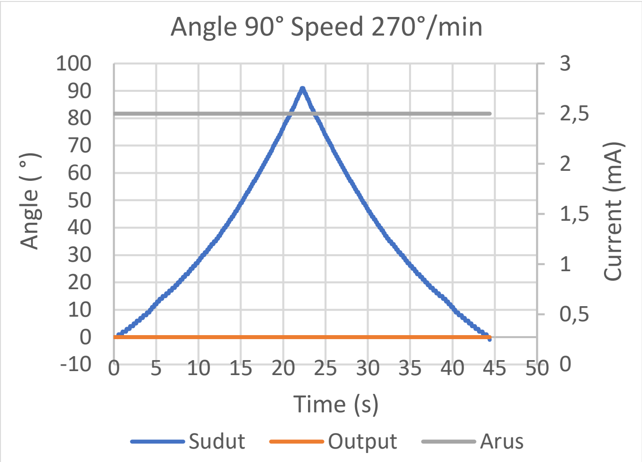


**FIG. 8. 90° Angle Setting Graph with 270 deg/min Speed Setting**

At the beginning graph, angle start from 0° and slowly increase in a way gradually until reaching 90°, lasting during about 136 seconds at 40 speed and 22 seconds at 270 speed. After reach corner maximum, angle decrease return in a way gradually until to position initial 0° in almost time same. The orange line representing the Fuzzy error remains flat and close zero throughout graph, shows that system Fuzzy control works very well and keep errors to a minimum throughout overall cycle. On the other hand, the current electricity looks stable at about 2.5 mA for the whole process, shows that consumption Power relatively constant moment arm move from position 0° to 90° and back Again.

From the experiment data collection using 90º angle settings using Fuzzy with some speed settings obtained data results as following :

**TABLE 3. Result Data for Setting Angle 90 ° Without Load**

| Speed (deg/min) | Max Angle (º) | *Fuzzy* Error | PID Error | Current (mA) | Time 1 cycle (s) |
|---|---|---|---|---|---|
| 40 | 91 | 0 | 0 | 2.5 | 270 |
| 90 | 91 | 0 | 0 | 2.5 | 120 |
| 150 | 91 | 0 | 0 | 2.5 | 72 |
| 210 | 91 | 0 | 0 | 2.5 | 49 |
| 270 | 91 | 0 | 0 | 2.5 | 44 |

From the results in TABLE 3, it can be seen that the data collected for the 90º angle setting with speed settings of 40, 90, 150, 210, and 270 deg/min shows a Fuzzy error value of 0 with a stable current at 25 mA. The results indicate that the Fuzzy method can effectively control the error, keeping it at a value of 0. Similarly, the PID method also demonstrates the same results, with the error remaining at 0 and the current stable at 25 mA, showing that both Fuzzy and PID control methods are equally effective in maintaining accurate angle control and stable current levels.

In FIG. 9 and FIG. 10 below is example results retrieval of data that shows chart arrangement 130° angle with speed start from 40 degrees per minute and 270 degrees per minute during the therapy process use system motor control.

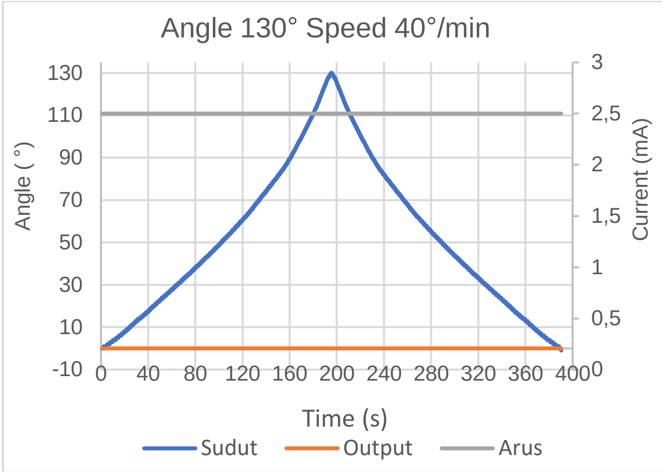


**FIG. 9. Angle Setting Graph 130° with Speed Setting 40 deg/min**

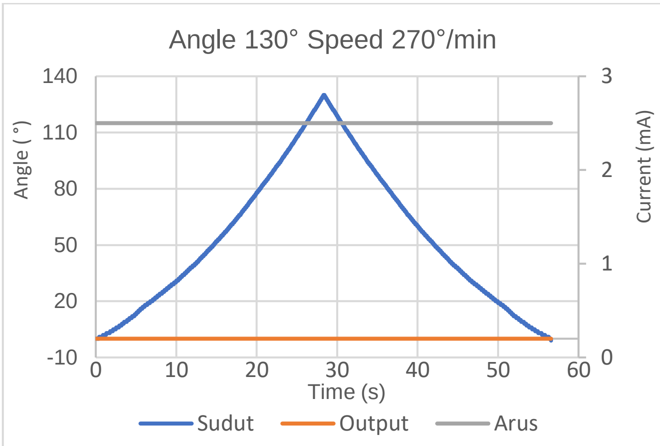


**FIG. 10. Angle Setting Graph 130° with Speed Setting 270 deg/min**

At the beginning graph, angle start from 0° and slowly increase in a way gradually until reaching 130°, lasting during about 195 seconds at 40 speed and 28 seconds at 270 speed. After reach corner maximum, angle decrease return in a way gradually until to position initial 0° in almost time same. The orange line representing the error remains flat and close zero throughout graph, shows that system Fuzzy control works very well and keep errors to a minimum throughout overall cycle. On the other hand, the current electricity looks stable at about 2.5 mA for the whole process, shows that consumption Power relatively constant moment arm move from position 0° to 130° and back Again.

From the experiment Data collection using a 130º angle setting using Fuzzy with some speed settings obtained data results as following:

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**TABLE 4. Result Data for Setting Angle 130º Without Load**

| Speed (deg/min) | Max Angle (º) | Fuzzy Error | PID Error | Current (mA) | Time 1 cycle (s) |
|---|---|---|---|---|---|
| 40 | 131 | 0 | 0 | 2.5 | 390 |
| 90 | 131 | 0 | 0 | 2.5 | 173 |
| 150 | 131 | 0 | 0 | 2.5 | 102 |
| 210 | 131 | 0 | 0 | 2.5 | 73 |
| 270 | 131 | 0 | 0 | 2.5 | 56 |

From the results in TABLE 4, it can be seen that the data collected for the 130º angle setting with speed settings of 40, 90, 150, 210, and 270 deg/min shows a Fuzzy error value of 0 with a stable current at 25 mA. The results indicate that the Fuzzy method can effectively control the error, keeping it at a value of 0. Similarly, the PID method also demonstrates the same results, with the error remaining at 0 and the current stable at 25 mA, confirming that both Fuzzy and PID control methods are highly effective in maintaining accurate angle control and consistent current levels.

### B. RESULTS OF FLOW DATA MEASUREMENT

Current data from the ACS712 sensor is used For read servo current or gearbox motor current. Current data measurement done with use device software that can read data from ACS712 sensor.

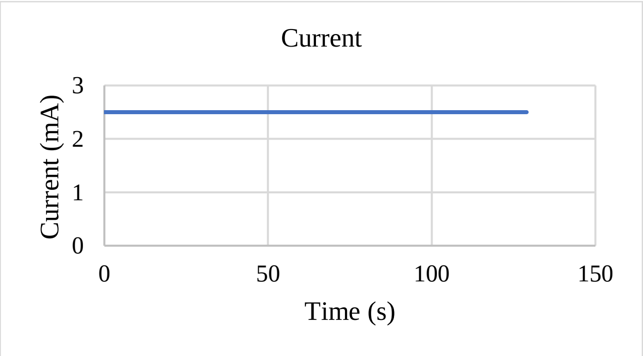


**FIG. 11. Chart Measurement Current (angle: 45, speed: 40)**

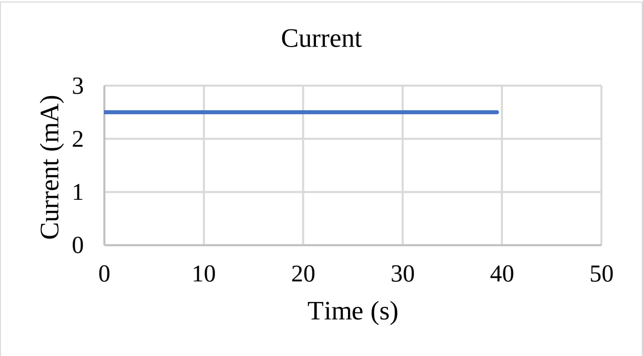


**FIG. 12. Chart Measurement Current (angle: 90, speed: 270)**

From the results measurement of current data shown in FIG. 11 and FIG. 12, it can be seen that the current flow remains stable over time. This result shows that the current flow is relatively stable at 2.5 mA. Similarly, the PID method also yields the same results, with the current flow remaining stable at 2.5 mA, demonstrating that both the Fuzzy and PID control methods provide consistent and stable current values throughout the operation.

## IV. DISCUSSION

This study compares the use of two control methods, namely PID and Fuzzy, to improve the angle accuracy of the CPM Elbow tool. Based on the test results and data collection, it can be seen that the Fuzzy method can control the system well, where the CPM motor maintains a constant current of about 2.5 mA from the beginning to the end of operation. This current remains stable during operation, indicating that the motor is working at maximum power and can maintain constant operation despite load changes, which is very important for the consistency of CPM tool performance.In addition, this research also explores the use of the PID method to control the gearbox motor, which requires optimization of the PID constants-Kp, Ki, and Kd. Through experiments, the optimal PID constants Kp = 2, Ki = 2, and Kd = 1 were obtained, which resulted in an average error of 0, indicating that the system can control the angle with very high accuracy.

In the comparison between the two settings, 45:40 and 90:270, there is a significant difference in the angle change of the tool. In the 45:40 setting, the tool operates at a low speed, so the angle change occurs gradually until it reaches the target, followed by a gradual return. In contrast, at the 90:270 setting, the higher speed causes the angle to increase rapidly, reaching the target faster. While high-speed settings speed up the process, they may sacrifice precision. The low-speed setting (45:40) provides more stable and accurate results, allowing the system to complete the motion cycle with more precision.

The results from FIG. 11 and FIG. 12 also show that the current remains stable at 2.5 mA throughout the operation, even when the motor reaches maximum load due to tool resistance or mechanical system load. This stability indicates that the motor maintained its performance despite the change in load, as no significant change in current was observed. In addition, the angle change analysis showed a significant difference between the no-load and loaded conditions. In the no-load condition, the motor showed a rapid angle change, quickly reaching the 90° target and returning to 0°.

## V. CONCLUSION

This research compares PID and Fuzzy control methods to control the gearbox motor on the CPM Elbow tool to improve angular accuracy. The test results show that both methods are effective in maintaining current stability and angular accuracy, with a fixed error value of 0 and a stable current of about 2.5 mA. The PID method with constants Kp = 2, Ki = 2, Kd = 1 also produced an average error of

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0, indicating accurate control. In tests with angles of 45°, 90°, and 130°, the difference between no-load and loaded conditions affected the speed of angle change. In the loaded condition (80 kg arm), the motor took longer to reach the target angle. Overall, both PID and Fuzzy control showed good results in controlling the angle of the CPM Elbow tool. The low speed setting provided better stability and accuracy. This research highlights the importance of load factors in system design for rehabilitation applications, and both control methods have the potential to improve CPM tool performance.

## REFERENCES

[1] "What Is Post Surgery Rehabilitation And Why Is It Necessary_ _ Miracle Rehab Clinic."
[2] "Gerakan Pasif Berkelanjutan (CPM) - Fisiopedia."
[3] T. A. F. Lenssen *et al.*, "Effectiveness of prolonged use of continuous passive motion (CPM), as an adjunct to physiotherapy, after total knee arthroplasty," *BMC Musculoskelet. Disord.*, vol. 9, pp. 1–11, 2008, doi: 10.1186/1471-2474-9-60.
[4] S. W. O'Driscoll and N. J. Giori, "Continuous passive motion (CPM): Theory and principles of clinical application," *J. Rehabil. Res. Dev.*, vol. 37, no. 2, pp. 179–188, 2000.
[5] "Rentang Gerak - Fisiopedia."
[6] "Cara Mengukur Range of Motion (ROM) - HaloFisioterapi."
[7] S. M. Huang, P. Y. Gi, and P. Y. Wu, "A design of wearable goniometers for measuring carpal angular movement," *Proc. 2018 IEEE Int. Conf. Adv. Manuf. ICAM 2018*, pp. 1–4, 2019, doi: 10.1109/AMCON.2018.8615058.
[8] H. Lestari, D. N. Izzhati, N. Rachmat, D. Setyawan, E. Saputra, and R. Ismail, "Pengukuran Jangkauan Gerak pada Lutut Orang Indonesia sebbagai Data Awal Perancangan Kaki Tiruan Atas Lutut," pp. 64–69, 2012.
[9] Y. Pititheeraphab, T. Angsuwatanakul, C. Pintavirooj, and T. Khemanuwong, "( CPM ) FOR ARM REHABILITATION DEVICE," vol. 15, no. 2, pp. 19–27, 2022.
[10] I. Jeffrey, S. Radcliffe, E. M. Marti, R. T. Kaiser, and N. J. Us, *( 12 ) United States Patent*, vol. 2. 2021.
[11] P. Examiner and T. A. Stanis, "( 12 ) United States Patent," vol. 2, 2022.
[12] L. . Ku *et al.*, "Development of portable elbow joint device for stroke patient rehabilitation," *Phys. Ther. Rehabil.*, vol. 5, no. 1, p. 5, 2018, doi: 10.7243/2055-2386-5-5.
[13] I. W. A. W. Kusuma and S. Santoso, "Analisa Performa Motor Hy-2750b, Motor Mg995, Motor Ds3225mg, dan Motor 24h2a4428 sebagai Penggerak Portable Continuous Passive Motion (CPM)," *Elektrika*, vol. 15, no. 1, p. 49, 2023, doi: 10.26623/elektrika.v15i1.6362.
[14] A. H. Noviyanto, L. D. Septilianingtyas, D. Rahmawati, P. Mekatronika, and S. Dharma, "Design of a Continuous Passive Motion ( CPM ) Machine for Wrist Joint Therapy," vol. 2, no. 4, 2021, doi: 10.18196/jrc.2498.
[15] J. Rosen, D. Milutinović, L. M. Miller, M. Simkins, H. Kim, and Z. Li, *Unilateral and Bilateral Rehabilitation of the Upper Limb Following Stroke via an Exoskeleton*. 2014.
[16] Baharuddin, "Sistem Kendali Kecepatan Motor DC berbasis PWM(Pulse Width Modulation )," p. 17, 2012.
[17] Q. Hidayati, "Pengaturan Kecepatan Motor DC dengan Menggunakan Mikrokontroler Atmega 8535," *J. Sains Terap.*, vol. 4, no. 1, pp. 1–5, 2012.
[18] W. Resti *et al.*, "Perancangan Portable Continuous Passive Motion (CPM) sebagai Alat Bantu Rehabilitasi Fraktur Lutut Pasca Operasi Berbasis Internet of Things (IoT)," pp. 14–19.
[19] M. Yanuar Rifa and T. Prahasto, "Pengembangan Perancangan Alat Terapi Sendi Lutut Continuous Passive Motion Untuk Pasien Pasca Operasi, Penyakit Tulang Dan Faktor Usia," *J. Tek. Mesin S-1*, vol. 11, no. 3, pp. 442–449, 2023.
[20] R. K. C. J. B. Lowe., "Anatomy, Shoulder and Upper Limb, Elbow Joint - StatPearls - NCBI Bookshelf." .
[21] P. F. Nugraha, *Pengembangan desain CPM (Continuous Passive Motion) elbow sebagai alat orthose aktif bagi pasien pasca operasi tulang siku tangan menggunakan kendali ….* 2010.
[22] M. Achmad, *GERAK SENDI*. .
[23] R. G. Siku, P. Genggaman, R. Skapula, and R. Eksternal, "Latihan Pasca Operasi Penggantian Bahu."
[24] R. Garmabdari, S. Shafie, A. Garmabdari, H. Jaafar, and A. K. Aram, "Labview based flow rate monitoring and measurement algorithm for rotary encoder," *J. Eng. Sci. Technol.*, vol. 9, no. Spec. Issue on Applied Engineering and Sciences (SAES2013), October 2014, pp. 66–75, 2014.
[25] T. Ratnasari and A. Senen, "Berbasis Mikrokontroler Arduino Dengan Sensor," *J. Sutet*, vol. 7, no. 2, pp. 28–33, 2017.
[26] M. Taif, M. Y. Hi. Abbas, and M. Jamil, "Penggunaan Sensor Acs712 Dan Sensor Tegangan Untuk Pengukuran Jatuh Tegangan Tiga Fasa Berbasis Mikrokontroler Dan Modul Gsm/Gprs Shield," *PROtek J. Ilm. Tek. Elektro*, vol. 6, no. 1, 2019, doi: 10.33387/protk.v6i1.1009..

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