SEMARAK ILMU PUBLISHING

Semarak International Journal of Public Health and Primary Care

Journal homepage:
https://semarakilmu.online/index.php/sijphpc/index
ISSN: 3083-8401

Angle-of-Pull (AOP) Resistor Point Locator Prototype for Application in Physiotherapy

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ARTICLE INFO

Article history:
Received 26 December 2024
Received in revised form 15 February 2025
Accepted 1 March 2025
Available online 15 March 2025

Keywords:
Physiotherapy; angle of pull; goniometer

ABSTRACT

The increasing prevalence of musculoskeletal disorders necessitates the development of precise and user-friendly tools in physiotherapy to improve rehabilitation outcomes. Traditional methods for determining the Angle of Pull (AOP) and locating resistance points in clinical settings often lack accuracy and accessibility. To address this issue, this study introduces the Angle Assist (A^2) device, aimed at enhancing the precision and effectiveness of rehabilitation exercises by accurately identifying the resistance point where the line of pull generates maximal muscle torque. The primary objective of this research was to design and develop a prototype for an AOP resistor point locator equipped with a precise angle reading display, aimed at reducing the time required to determine the AOP and pinpoint the resistance point by at least 10%. The methodology involved the integration of an MPU6050 sensor, an OLED display and laser pointers, all controlled by customized firmware. The device was subjected to a series of tests, including accuracy, reliability and time improvement test. The results demonstrate that the A^2 device achieves high accuracy, with an R^2 value of 0.9991 when compared to true angles. Additionally, the device exceeded the initial objective by reducing the time required to determine the AOP and pinpoint the resistance point by 16.92%. In conclusion, the A^2 device represents a significant advancement in physiotherapy practices by providing precise angle measurements and improving the accuracy of resistance point placement.

1. Introduction

Musculoskeletal disorders are a significant and growing concern worldwide, necessitating the development of precise, user-friendly tools to enhance physiotherapy practices. Rehabilitation plays a critical role in restoring, improving or maintaining physical function following injuries, surgeries or chronic conditions [1]. Central to many rehabilitation programs is the concept of the angle of pull

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https://doi.org/10.37934/sijphpc.3.1.8196

(AOP), which is the angle formed between the vector of muscle force and the straight line from the joint's centre of rotation to the muscle's insertion point. This angle is crucial because it determines the effectiveness of muscle contractions during therapeutic exercises which directly influencing the patient's recovery outcomes.

Thus, the identification of the AOP is critical for patient-specific rehabilitation, especially for those with musculoskeletal injuries, neurological damage or surgeries [2,3]. A precise AOP enables healthcare professionals to target specific muscles more effectively, optimize the force applied during exercises and minimize the risk of further injury. Muscle strength is the key area in rehabilitation. It is crucial to regain and reconstruct muscle function for a successful rehabilitation process [4]. In rehabilitation, tailoring exercises to align with ideal AOP improve muscle activation and also enhance overall joint flexibility and function [5]. By improving muscle strength through tailored exercise at specific AOP, patients with muscle injuries can recover and improve the ROM of the affected muscle [6]. Three principles are critical to the process of identifying and implementing the AOP in physiotherapy which includes Range of Motion (ROM), Base Muscle Strength and Resistor Point.

ROM refers to the full movement potential of a joint, typically its range of flexion and extension [7]. It is essential to take an accurate ROM measurement in order to determine the AOP so that therapeutic exercises are aligned with the patient’s physical capabilities [8]. To facilitate movement and locomotion, both humans and animals produce joint moments by transferring forces from muscles to bones. The ability of muscles to generate force at different joint angles is primarily influenced by the muscle's optimal length which also known as the midpoint [9,10]. The midpoint, also known as the muscle's optimal length or resting length is the position where a muscle can generate the maximum force during contraction [11]. Identifying the midpoint, where a muscle can generate the most force, is especially important as it directly impacts the muscle's efficiency.

Baseline Muscle Strength provides a reference point to assess the effectiveness of rehabilitation exercises and monitor the rehabilitation progress [8]. Understanding the baseline strength allows for the precise calibration of exercises to match the patient’s current capabilities and minimized the risk of overexertion or underutilization of muscles [12].

The Resistor Point where maximum resistance occurs during a therapeutic exercise is crucial for determining the exact AOP. When aiming to produce maximal torque from a muscle, it is essential to position the joint so that the muscle being worked has a 90° angle of pull on the extremity. This principle ensures that the muscle exerts maximum force which is critical for effective rehabilitation and strengthening exercises.

However, despite the critical importance of accurate AOP determination, current methods, such as the use of traditional goniometers, exhibit significant limitations [13,14]. These methods are often plagued by issues such as difficulty in pinpointing the exact resistance point, inconsistencies in measurement accuracy and the time-intensive nature of the process. Furthermore, existing tools do not adequately integrate the assessment of Range of Motion (ROM), Baseline Muscle Strength and the Resistor Point into a single, user-friendly device. This gap in the current physiotherapy tools limits the effectiveness of rehabilitation programs and poses challenges for healthcare professionals seeking to deliver precise and efficient patient care.

The significance of this research lies in its potential to address these limitations by developing a novel device that can seamlessly integrate these critical elements into the process of AOP determination. By enhancing the accuracy, efficiency and ease of use of AOP measurements, this research aims to significantly improve the quality of rehabilitation programs, ultimately leading to better patient outcomes.

The objectives of this project are twofold: first, to design an angle of pull resistor locator which have precise angle reading display and can pinpoint the resistance point. Second, to develop a prototype of an angle of pull resistor locator, with a 10 %-time percentage improvement when determining the AOP and pinpointing the resistor location point. By overcoming the limitations of traditional methods, the A² device has the potential to significantly improve patient outcomes, making it a valuable addition to modern physiotherapy practices.

2. Methodology

This research followed a systematic process in designing a physiotherapy tool named Angle Assist (A²) that can improve the AOP determination and locate the resistor point of a patient. The methodology was structured into six key stages: Conceptual Design, Computer-Aided Design (CAD), Electronic Design, Firmware Development, Prototyping and Prototype Testing.

2.1 Conceptual Design

The conceptual design phase began with a comprehensive literature review, which identified limitations in existing methods for AOP determination. The need for a device that could integrate accurate AOP measurement, Range of Motion (ROM) assessment and resistance point identification into a single, user-friendly tool was established. Based on these needs, four initial designs for the Angle Assist (A²) device were proposed as shown in Figure 1 (Design 1), Figure 2 (Design 2), Figure 3 (Design 3) and Figure 4 (Design 4). Design 1 as shown in Figure 1 is an extendable ruler with a round display unit at the top, containing the MPU6050 sensor and an OLED screen. The device extends from 25 cm to 44 cm, with a laser box at the end for pinpointing the resistance location.

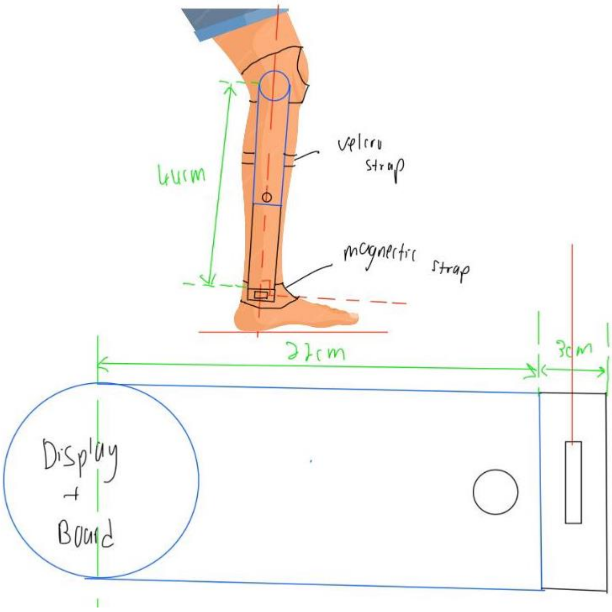


Fig. 1. Design 1 for A²

Design 2 as shown in in Figure 2 had working mechanism as design 1 but featured a scissor mechanism to enhance portability to allow the device to retract to 10 cm when not in use and extend beyond 44 cm to accommodate varying leg lengths.

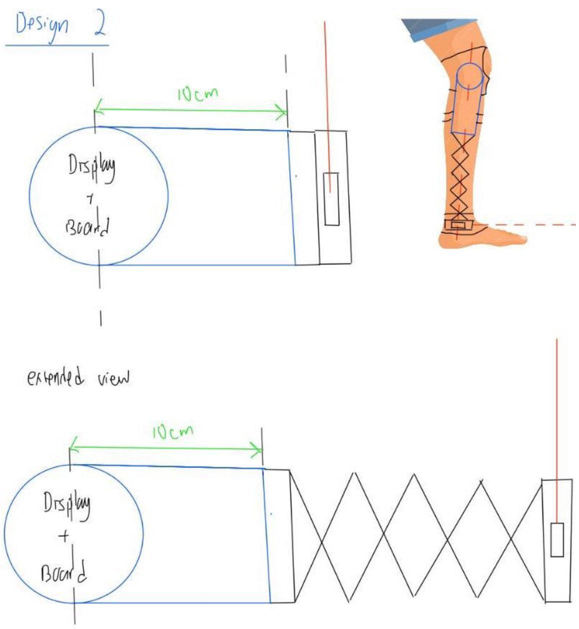


Fig. 2. Design 2 for A²

Design 3 as shown in Figure 3 introduced wireless connectivity, separating the measurement unit and laser box to increase the range and flexibility of use.

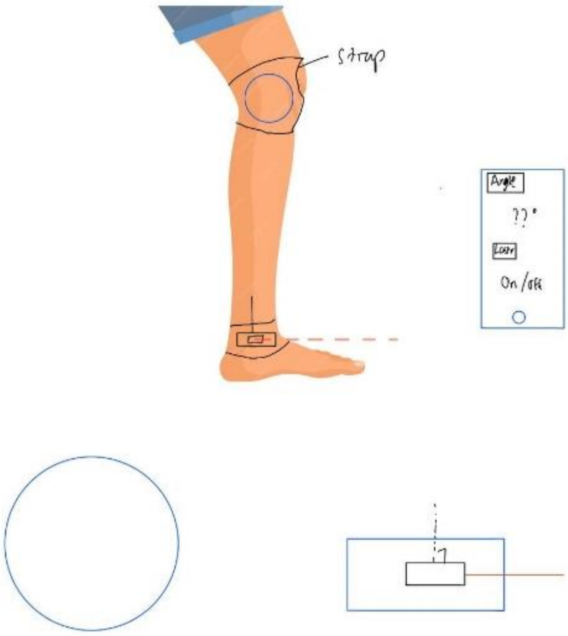


Fig. 3. Design 3 for A²

Design 4 as shown in Figure 4 combined the measurement unit and laser box into a single structure, attached directly to the ankle for enhanced stability and ease of use, consolidating all components into one compact unit.

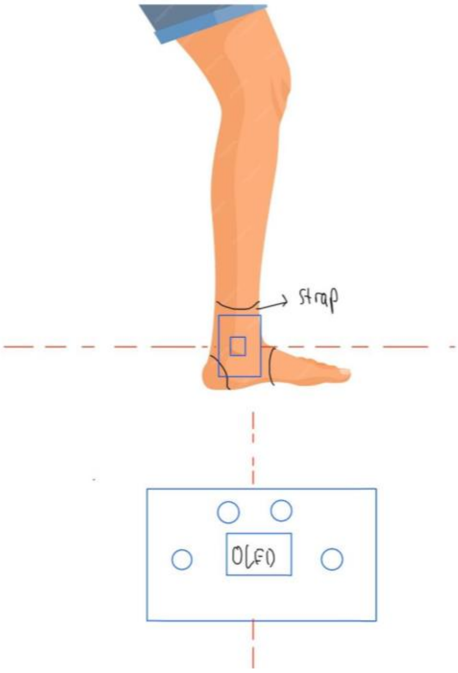


Fig. 4. Design 4 for A²

These designs were evaluated using a decision matrix, with criteria such as safety, range of use, cost, ease of use, ease of storage and compatibility as shown in Table 1. The result show Design 4 have the best score.

Table 1
Decision matrix for proposed design

	Proposed Design Alternative				
Criteria	Weightage	Design 1	Design 2	Design 3	Design 4
Safety factor	4	2	2	4	4
Range of Use	5	2	4	4	4
Fabrication cost	5	4	4	3	3
Ease to Use	3	3	3	3	4
Ease to Store	2	3	3	4	4
Compatibility	3	1	1	2	3
Total		56	66	74	80

2.2 Computer-Aided Design (CAD)

In this phase, the selected design (Design 5) was developed using SolidWorks as shown in Figure 5 which a dimension of 106 x 66 x 22 mm. Detailed CAD models was created to define the dimensions, materials and assembly instructions for the device. The design emphasized compactness, user-friendliness and ergonomic functionality, ensuring that all components fit seamlessly into the device's structure.

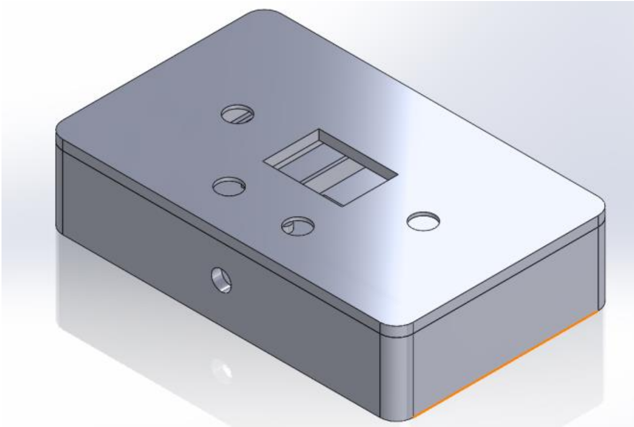


Fig. 5. CAD model of the prototype

The CAD model of the device consisted of two main parts which is the main body and the lid. The main body, measuring 106 x 66 x 22 mm, included a base in the centre to secure the MPU6050 sensor and a slot on the right side for battery placement. The right-side wall featured a slot for the on/off switch. The front side wall had a centrally located hole for the laser, flanked by two slots for the charging port and technical service port. Additionally, there were another hole at the far end of the main body for the laser as shown in Figure 6.

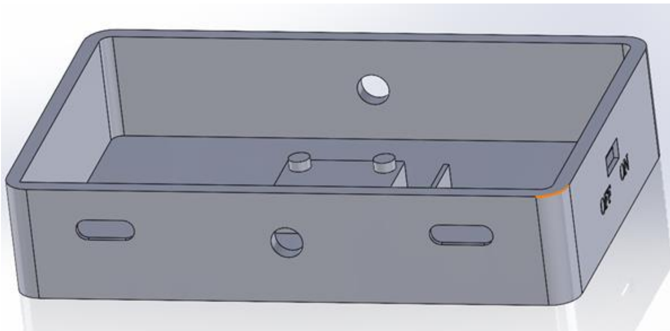


Fig. 6. Main body of the casing

The lid was designed with one square hole to contain the OLED screen and four holes for the buttons. This design ensured that all components were securely housed and easily accessible for operation. The arrangement of these features is shown in Figure 7. It is significant to highlight that this careful mechanical design is instrumental in ensuring that the Angle Assist A² is functional, user-friendly and effective.

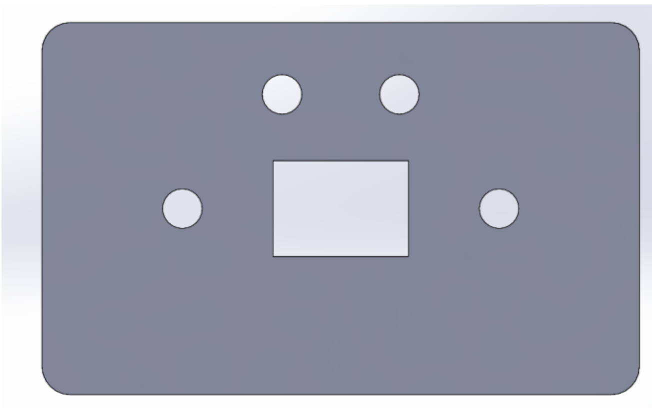


Fig. 7. Lid of the casing

2.3 Electronic Design

The electronic design phase involved selecting and integrating key components necessary for the device's functionality. The MPU6050 sensor was chosen for angle detection due to its accuracy, while an OLED display was selected for real-time data visualization. KY-008 laser modules were included for precise resistance point identification. Additionally, a 3.7V Lithium-Ion rechargeable battery was added to the system to enhance the device's mobility. Moreover, two buttons were used to control the laser module, while the other two act as the calibration and Menu button. The components were assembled according to detailed circuit diagrams as shown in Figure 8, ensuring reliable and accurate performance.

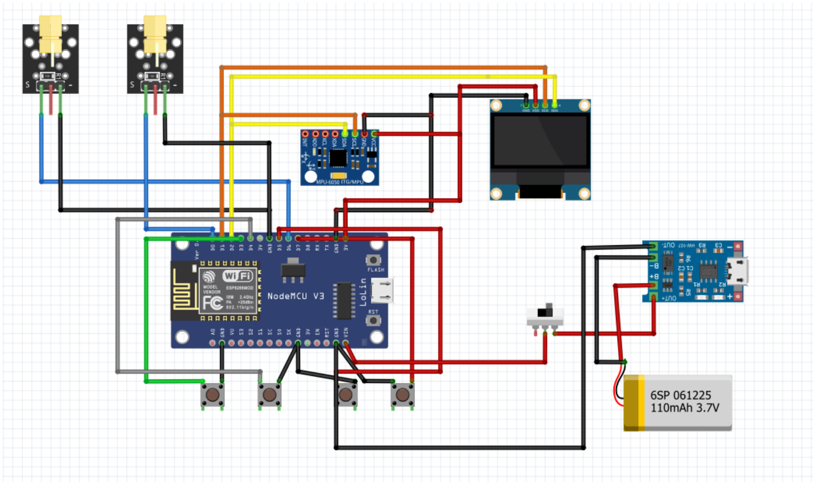


Fig. 8. Circuit diagram designed using fritzing

2.4 Firmware Development

Firmware development was carried out using the Arduino Integrated Development Environment (IDE), ensuring seamless communication between the microcontroller, MPU6050 sensor, OLED display and laser modules. The firmware continuously processed real-time data from the sensor to measure angles and displayed them on the OLED screen. It also enabled user interaction through buttons for menu navigation, laser control and calibration. Calibration routines were included to fine-tune sensor offsets for accurate measurements, with data stored in the EEPROM for persistence. The laser modules were controlled based on user input, allowing precise resistance point identification. Overall, the firmware focused on providing accurate, reliable and user-friendly operation to meet the project's goals.

2.5 Prototyping

In the prototyping phase, the conceptual and electronic designs were brought together to create a functional prototype of the Angle Assist (A²) device. This involved the physical assembly of all mechanical and electronic components, following the detailed specifications developed in the CAD and Electronic Design phases. The prototype was built using 3D-printed parts for the casing and precise soldering of electronic components onto a circuit board as shown in Figure 9. The assembly process was carried out with high precision to ensure the device's operational integrity. Once assembled, the prototype was subjected to initial functional tests to verify that all components worked cohesively as intended.

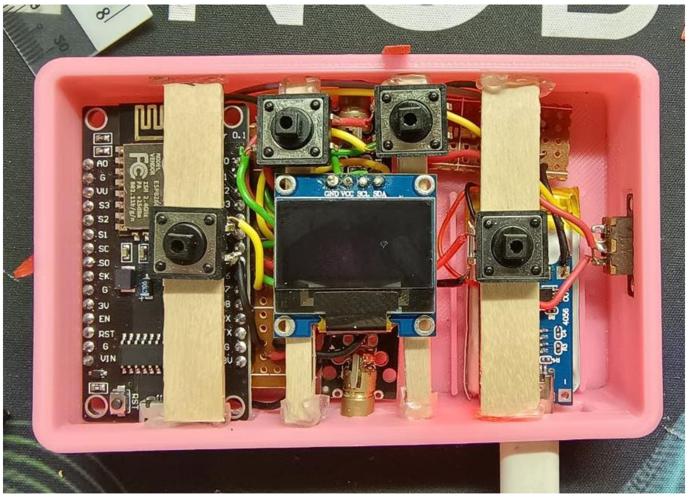


Fig. 9. Fully assembled part

2.6 Prototype Testing

The final phase involved rigorous prototype testing to validate the performance and functionality of the Angle Assist (A²) device. Testing was conducted in three key areas:

2.6.1 Angle accuracy test

A comparative analysis of angle measurement accuracy between the newly developed Angle Assist A² and the traditional goniometer was made. The test was conducted on a subject's lower limb to determine the Range of Motion (ROM) and Angle of Pull (AOP) of knee flexion in sagittal axis as shown in Figure 10. Traditional goniometer measurements were used as the reference (true angles) and compared with the readings obtained from the A² device. The precision of the A² were assessed by determining the angle error comparing to the true angle. According to Journal "Effects of stretching intensity on range of motion and muscle stiffness" by Fukaya *et al.,* [15], the normal knee flexion ROM ranging from −5 to 15° of hyperextension to 120°. Hence, the analysis had been done on angle ranging from $0^{\circ}$to 120°, with 5° interval. The angle error, mean and standard deviation of the error were determined and analysed. The graph of true angle against A² angle also been plotted and the R^2value had been determined.

(a) (b)

Fig. 10. Determination of AOP using (a) Goniometer (b) Angle Assist, A² prototype

2.6.2 Reliability test

The reliability test was conducted to evaluate the consistency and repeatability of the Angle Assist A^2 in accurately measuring angles on a patient's lower limb by using a goniometer as the reference standard. The angle measure by A^2 will be taken 3 time and mean will be determined. The tests were conducted in a controlled setting to minimize external variables such as environmental temperature and lighting conditions.

In each trial, the patient's lower limb was positioned at angle from $30^{\circ}$to 120°, with 15°interval. The A^2 was then used to measure these same angles. Each predefined angle was measured multiple times across several trials to assess the repeatability and reliability of the device.

The collected data was compared to the goniometer readings to calculate the error and standard deviation of the measurements. This provided a comprehensive assessment of the device's reliability. The practical setup ensured that the Angle Assist A^2's performance could be evaluated in realistic usage scenarios which demonstrate its effectiveness and consistency in practical applications.

2.6.3 Time improvement test

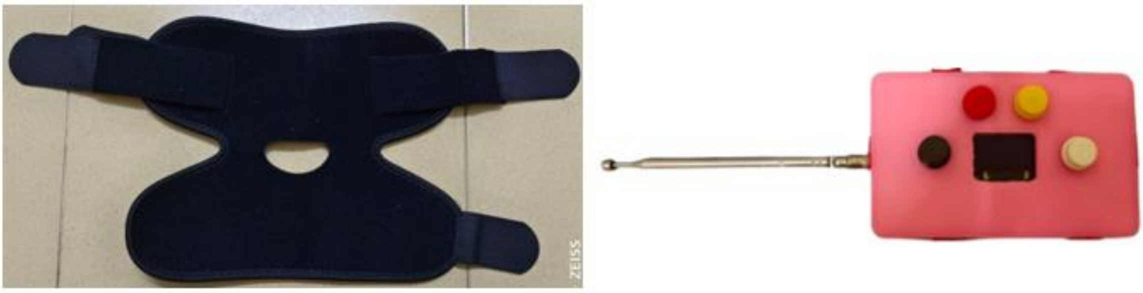
An analysis was performed to evaluate the efficiency of Angle Assist A^2 device in term of the time taken to complete the whole process from determining the AOP to pinpoint the resistor location. In this prototype testing, an individual with minimal knowledge of physiotherapy and the device was selected to participate in the experiment. This choice was made to demonstrate that the A^2 device can be easily used by anyone, regardless of their level of expertise, ensuring that the entire process can be conducted with ease and efficiency by a broad range of users. The experiment began by determining the full range of motion of the patient's leg which bended it until it reached its maximum flexion. This range of motion was then divided by two to find the midpoint. The patient's leg was then bent to this specific midpoint angle, which represents the angle of Angle of Pull (AOP) which the maximum muscle torque exerted. At this angle, the goniometer was set to 90 degrees and placed on the ankle, The resistor point was found by finding the location of the resistor which is perpendicular to the goniometer. Same process has been conducted using A^2 and the time taken to complete the whole process using both methods has been recorded and compared where the time taken using goniometer as reference and the percentage of time improvement using A^2 was calculated using formula as shown Eq. (1). The experiment had been conducted 5 times and the average data had been analysis.

$$\text{Percentage improvemnet} = \left(\frac{\text{Time using goniometer} - \text{Time using } A^2}{\text{Time using goniometer}}\right) \text{x } 100 \tag{1}$$

3. Results

3.1 Final Assembly

The final prototype of the Angle Assist (A^2) device was completed with a focus on functionality, usability and portability. As shown in Figure 11, the final prototype consisted of 2 main components which is the ankle strap and A^2 device.



(a) (b)

Fig. 11. (a) Ankle strap (b) A² device

Key components of the device included the MPU6050 sensor for angle detection, an OLED display for real-time data visualization and dual laser modules for precise resistance point identification. Additional features such as an On/Off switch, four control buttons which are calibration button(yellow button); menu button (red button) and laser control (black and white buttons), a USB charging port and technical port were integrated to ensure ease of use as shown in Figure 12. The device also included a retractable antenna for alignment with the tibia, enhancing measurement accuracy. This configuration provided a user-friendly and efficient tool for physiotherapy applications.

(a) (b)

Fig. 12. (a) On/OFF switch (b) Charging and technical port

3.2 Accuracy Test

Table 2 presents the error values, which are the absolute differences between the true angles and the A² angles measured by the A² Resistor Point Locator. Most of the error values are small, typically around 1 degree or less, with a few exceptions at the lower end of the measurement scale and at certain higher angles. Notably, the error values at 0 and 120 degrees are higher, both at 3 degrees. However, for the most part, the error values are low, indicating that the device is precise and reliable.

Moreover, the standard deviation of the errors for each measurement further shows that the device is accurate. The mean standard deviation of all the angles is relatively low, demonstrating the device's consistent performance. The A² device exhibits excellent performance, with minimal error, indicating high accuracy. This accuracy across the range of angles makes the A² Resistor Point Locator a valuable tool for applications requiring precise angle determination.

Table 2
Table of accuracy test

True Angle (Goniometer) (°)	A^2 Angle (°)	A^2 Angle Error (°)	Mean	Standard Deviation
0	3	3.0	1.5	1.5
5	6	1.0	5.5	0.5
10	12	2.0	11.0	1.0
15	16	1.0	15.5	0.5
20	21	1.0	20.5	0.5
25	24	1.0	24.5	0.5
30	31	1.0	30.5	0.5
35	36	1.0	35.5	0.5
40	41	1.0	40.5	0.5
45	44	1.0	44.5	0.5
50	51	1.0	50.5	0.5
55	56	1.0	55.5	0.5
60	61	1.0	60.5	0.5
65	65	0.0	65.0	0.0
70	71	1.0	70.5	0.5
75	75	0.0	75.0	0.0
80	81	1.0	80.5	0.5
85	86	1.0	85.5	0.5
90	90	0.0	90.0	0.0
95	94	1.0	94.5	0.5
100	101	1.0	100.5	0.5
105	104	1.0	104.5	0.5
110	109	1.0	109.5	0.5
115	116	1.0	115.5	0.5
120	123	3.0	121.5	1.5

The graph (Figure 13) illustrates the comparison between the true angles and the angles measured by the A² Resistor Point Locator. The data points representing the A² angles closely follow the line of true angles, with an R^2value of 0.9991. This high correlation indicates a strong linear relationship between the measured and true angles, demonstrating that the device can reliably measure angles within the expected range.

Generally, the A² demonstrates accurate performance as the error is within the acceptable range. The device proves this by recording relatively lower mean of the standard deviation and minimum error. This consistency and precision make it a suitable instrument for physiotherapy applications where accurate angle measurement is crucial.

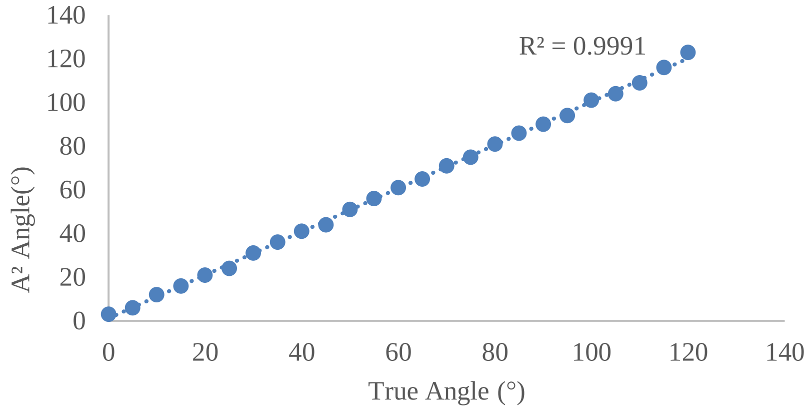


Fig. 13. Graph of A² angle vs. true angle

3.3 Reliability Test

The reliability of the A² Resistor Point Locator was evaluated by measuring angles at various times and comparing how consistent the measurements were. The results are summarized in Table 3.

Table 3
Table of reliability test

Angle (°)	Goniometer Reading (°)	A² Reading 1 (°)	A² Reading 2 (°)	A² Reading 3 (°)	Mean (°)	Error (°)	Standard Deviation
30	30	32	31	31	31.33	1.33	0.723
45	45	44	45	47	45.33	0.33	1.090
60	60	60	62	59	60.33	0.33	1.090
75	75	78	76	75	76.33	1.33	1.234
90	90	90	90	90	90.00	0.00	0.000
105	105	107	105	106	106.00	1.00	0.837
120	120	121	118	123	120.67	0.67	1.804

The Table 3 and Figure 14 shows how reliable the device is with the A² reading closely aligning with the goniometer and the true angle.

In the graph, as shown in Figure 14, the goniometer reading and the mean A² reading were plotted. The two lines are closely aligned indicating that the readings from the A² device are consistent around the various angles. The mean A² readings closely match the goniometer readings with only slight deviations observed at certain angles. This alignment shows that the device reliability.

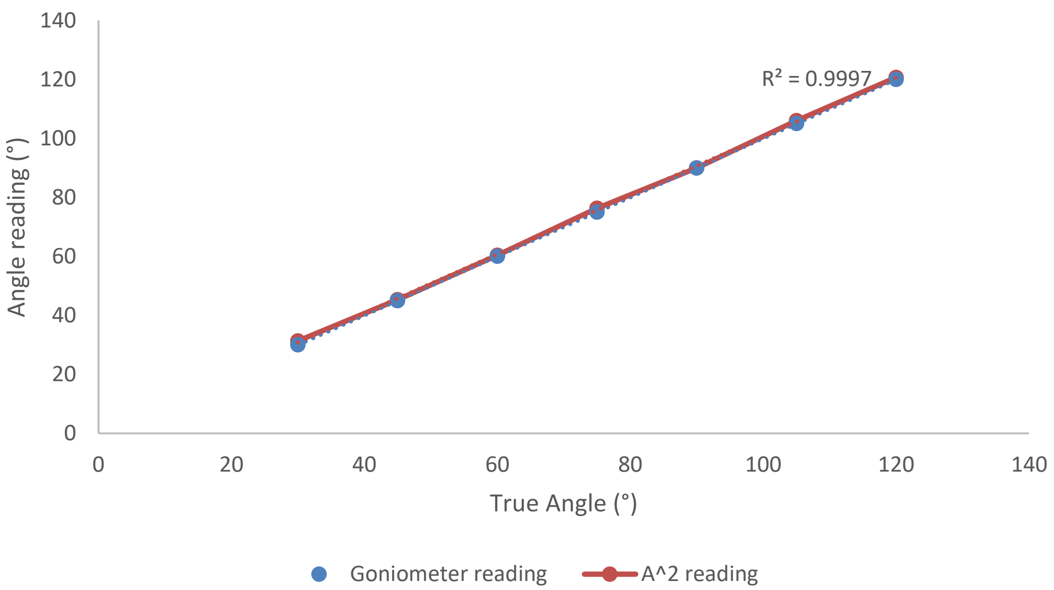


Fig. 14. Graph of angle reading vs true angle

Overall, the A² demonstrates high reliability in angle measurement. The consistency of the readings with small standard deviations further confirms the device's reliability for applications requiring precise and repeatable angle measurements.

3.4 Time Improvement Test

The time taken to complete the whole process from determining the AOP to pinpoint the resistor location using goniometer and A² had been recorded and summarized in Table 4.

Based on Table 4, the data indicates that the Angle Assist (A²) device significantly improves the efficiency of determining the Angle of Pull (AOP) and pinpoint the resistor location compared to the traditional goniometer. The average time taken to complete the whole process using the goniometer was 53.2 seconds, while the A² device only took an average of 44.2 seconds. This indicates time taken to complete the whole process using A² significantly reduce the time when using the traditional way which is the goniometer.

Table 4
Table of time taken to complete whole process

Attempt	Time taken using Angle Pro (seconds)	Time taken using A² (seconds)	Difference in time (seconds)	Percentage improvement (%)
1	50	45	5	10.00
2	55	44	11	20.00
3	53	43	10	18.87
4	54	44	10	18.52
5	54	45	9	16.67
Average	53.2	44.2	9	16.92

From Figure 15, the time savings by using A² ranged from 5 to 11 seconds across different attempts which indicate the efficiency of the A² device. The time saves by using A² is averaging at 9 seconds.

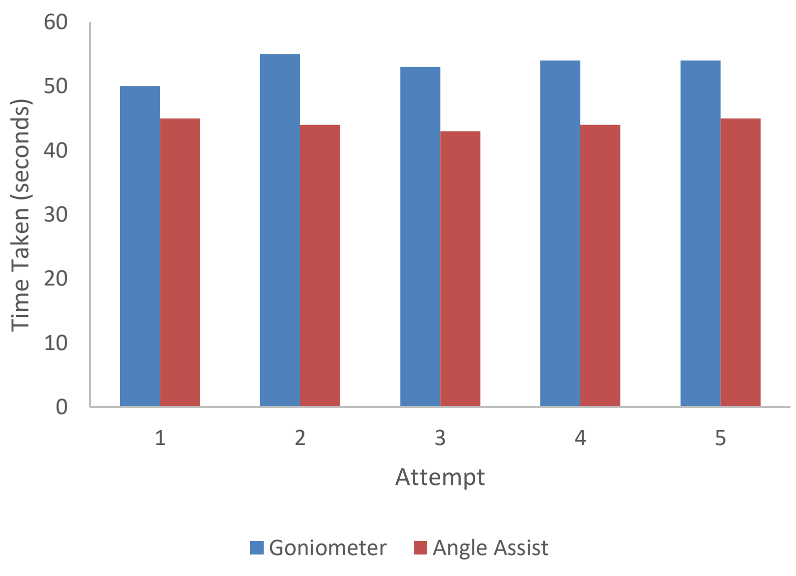


Fig. 15. Time taken in 5 attempts

Figure 16 highlighted the percentage improvement in term of time for each attempt when using the A² compared to the goniometer. The percentage of improvement ranged from 10.00% to 20.00%, with an overall average improvement of 16.92%. This demonstrates that the A² device not only reduces the time required for the whole process from determining angle to pinpointing the resistor point location. Moreover, the result also shows that A² achieve the objective of 10% improvement in time.

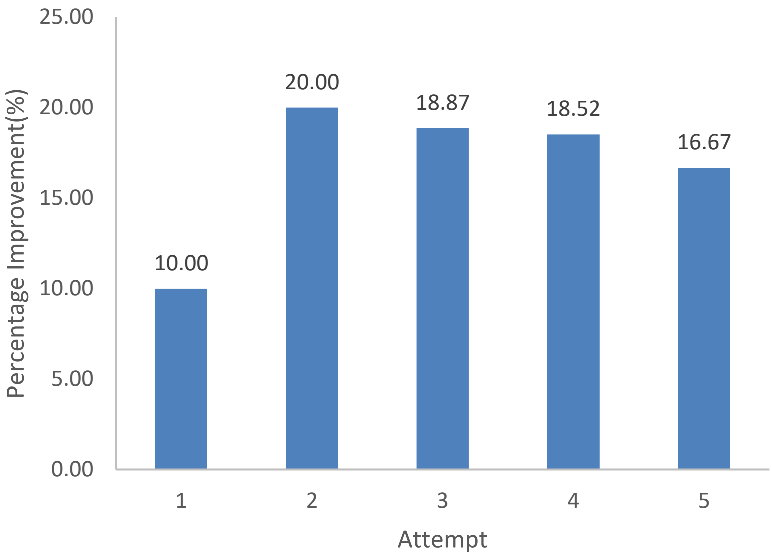


Fig. 16. Percentage improvement in time

4. Conclusions

This project had successfully addressed the design improvement and implementation of the Angle-of-Pull (AOP) Resistor Point Locator for application in physiotherapy. The objectives had been achieved where a AOP resistor Point Locator prototype named Angle Assist A^2 that can measure the angle precisely, pinpoint the resistor location and reduce the time from determine the AOP to pinpointing the location for resistor by 16.92 % had been develop.

The project began with extensive research to understand the importance of AOP and to identify the requirements for the device. Following this, the design phase involved brainstorming initial ideas, selecting features and components and choosing the final design using Pugh charts and decision matrices. The casing was designed using SolidWorks and 3D printed. The electrical circuit and coding were developed.

In prototyping phase, all the electrical component was soldered and assembled into the 3D printed casing. After the prototype was built, the device undergoes initial testing under the supervision of two senior physiotherapy lecturers, Puan Rabiatul and Tuan Haji Bahman, at UiTM Cawangan Pulau Pinang. Based on their feedback, improvements were made, resulting in the final prototype. Further testing included accuracy, reliability and time improvement tests was carried out. Moreover, the device was demonstrated in a video and sent to physiotherapy students, practitioners and lecturers to collect further feedback.

Following testing and improvement according to the feedback, the prototype successfully met all three objectives. According to the result in accuracy and reliability test and also the device demo operation step, the first objective of design and build a prototype of an AOP resistor locator with a precise angle reading display and can pinpoint the resistor point had been achieved. In the accuracy test, the A² device achieved high precision in angle measurement where the R^2 of the graph of A² angle vs true angle achieve 0.9991 which indicate that strong linear relationship between the measured and true angles, demonstrating that the device can reliably measure angles within the expected range. The reliability test also confirmed the device's precision, consistently measuring angles within a small margin of error. The results showed that the A² device had an accuracy of ±1 degree, ensuring reliable readings for clinical use.

Moreover, creating a prototype which capable of pinpointing the resistance point was achieved. This was accomplished by integrating a laser pointer where in the demonstration and the user feedback, it showed that the laser function is the most liked feature by the respondent and can pinpoint the resistor point which then enhance the effectiveness of rehabilitation exercises by allowing physiotherapists to locate the resistor location accurately before further assessment for the rehabilitation process.

The second objective, which was to reduce the time by 10% when determining the AOP and pinpointing the resistor location point, had been achieved. The percentage reduction was about 16.92% was considerably higher than the expected reduction in the time. Thus, the device would support the determination of the AOP and pinpoint the resistor's location faster.

In conclusion, the purposes behind the construction of the A² device have been effectively achieved. Specifically, that the device has been able to provide accurate measurements of angles to accurately identify the positions of resistance and reduce time for patient assessment. This project makes a great contribution to the field of rehabilitation and a tool has been created to improve accuracy and efficiency of measurement and to simplify the process. The A² device is a valuable step along the road of motion analysis technology and it may be further improved to make it more portable as well as expand the list of exercises available with the device.

Acknowledgement
This research was not funded by any grant.

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