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Development of Circular Motion Experiment with Belt-Connected Wheels Using Hall Effect Sensor Based on IoT

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ABSTRACT

Innovation in educational tools is crucial for improving the learning experience in physics experiments. This study presents the design and development of an IoT-based experimental tool for analysing wheel dynamics. The tool integrates microcontrollers and sensors to accurately measure both angular and linear velocities. By varying wheel sizes and controlling rotation speeds, students can explore the relationship between speed, size, and motion. Real-time data transmission via smartphones ensures accessibility and efficiency in analysing wheel dynamics during experiments. The system incorporates a KY-024 Hall effect sensor that detects wheel movements through digital signals generated by magnets. Data is collected in real-time and sent to an IoT platform for further analysis, allowing precise comparisons between experimental and theoretical values. The tool supports three configurations: contacting wheels, concentric wheels, and belt-connected wheels, enabling comprehensive exploration of wheel mechanics. Experimental results demonstrate high accuracy, with angular velocity measurements exceeding 98,00% across configurations. Contacting wheels achieve accuracy levels of 97,68% and 98,34%, concentric wheels maintain 98,34%, and belt-connected wheels exhibit slight variations at 98,34% and 97,65%. This IoT-integrated system offers a reliable, precise, and versatile approach to understanding wheel dynamics, making it a significant asset for enhancing educational physics experiments.

1. INTRODUCTION

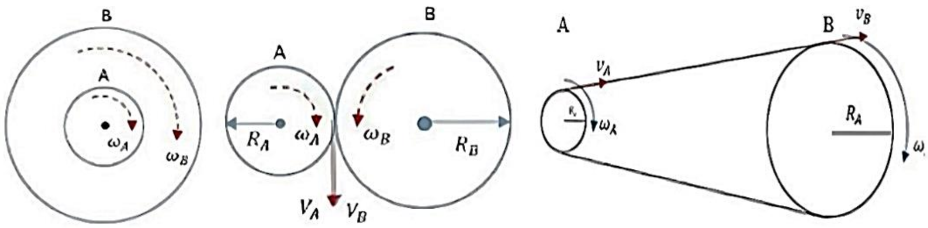
The rapid advancement of information technology has significantly impacted various fields, including education. Information and communication technology has revolutionized data processing and dissemination, simplifying complex tasks and increasing accessibility across time and space (Suryadi, 2019). As technology evolves, it is crucial that educational methods also adapt to ensure they remain effective and relevant, particularly for the digital native generation, who are accustomed to interactive and responsive learning approaches (Azis, 2019). The integration of technology into educational tools can enhance learning experiences, making abstract concepts more accessible and engaging.

In the field of physics education, hands-on practical instruction plays a vital role in enhancing students' understanding of theoretical concepts (Darmaji et al., 2018). Laboratory experiments are essential for students to verify theories and explore the relationships between various physical quantities, such as angular velocity and linear velocity (Asrizal et al., 2018; Kustija & Andria, 2021). Through these practical experiments, students can visualize and understand complex phenomena in real-world contexts, which aids in the retention of theoretical knowledge (Asrizal & Imran, 2019; Nana, 2010). However, not all educational institutions are equipped with the necessary tools to effectively demonstrate certain complex topics, limiting students' ability to fully grasp these concepts (Puspasari, 2017; Saepuzaman & Yustiandi, 2017). The use of an experimental tool in science education can significantly facilitate students' understanding of scientific concepts (Arsyad, 2011; Desy et al., 2015).

One critical concept in physics that requires in-depth understanding is circular motion. Circular motion occurs when an object moves along a circular path, with its direction continuously changing even if the speed remains constant (Widodo, 2009; Abdullah, 2016). This change in direction results in centripetal acceleration, which always points toward the center of the circle (Darmawati, 2014). The relationship between angular velocity (ω) and linear velocity (v) is described by the equation (1).

$$v = \omega R \quad (1)$$

Where R is the radius of the wheel. When multiple wheels are connected within a single system, it is crucial to ensure that the linear velocity at the contact points between the wheels remains synchronized. The interactions between these wheels, which may involve concentric wheels, tangent wheels, and wheels connected by a belt, present an ideal topic for exploration through practical experiments. These experiments allow students to test theoretical models, compare physical quantities, and explore the effects of changes in wheel rotation speed and the influence of varying wheel radii on the interactions between wheels in a circular motion system. These types of wheel interactions can be seen in Figure 1



(a) **(b)** **(c)**

Figure 1. a. Concentric Wheels, b. Tangent Wheels, c. Wheels Connected by Belts

For example, in a concentric wheel system, as shown in Figure 1.a, where multiple wheels share the same axis of rotation, the angular velocity of each wheel may be identical, but the linear velocity at the wheel's circumference will vary according to its radius. A larger wheel will have a higher linear velocity at its edge compared to a smaller wheel, despite having the same angular velocity. This can be explained using Equation (2).

$$\omega_A = \omega_B$$
$$\frac{v_A}{r_A} = \frac{v_B}{r_B} \quad (2)$$

Additionally, when two wheels are in direct contact, as illustrated in Figure 1.b, the linear velocity at the point of contact must be the same for both wheels to ensure proper interaction. The direction of rotation is also crucial: if one wheel rotates clockwise, the wheel in contact with it will rotate counterclockwise. This indicates that a smaller wheel must rotate faster than a larger wheel to maintain the same linear velocity at the contact point. Conversely, in a system where wheels are connected by a belt or chain, as depicted in Figure 1.c, the direction of wheel rotation remains unchanged, and the belt or chain ensures that the linear velocity is consistent across the wheel's circumference, allowing for stable synchronized motion (Nurachmandani, 2019). These interactions can be summarized by Equation (3).

$$v_A = v_B$$
$$\omega_A . r_A = \omega_B . r_B \quad (3)$$

Given the complexity of these interactions, effective and accurate experimental tools are essential for optimizing practical learning. However, existing tools still have limitations, such as restricted visualization and a lack of flexibility. Previous research has explored various advancements in similar microcontroller-based tools and speed control systems. Pamungkas (2018) developed a microcontroller-based device with an LCD interface. Harviyani (2020) and Wicaksono (2023) each focused on speed control using tracking software and a website, respectively. Although these tools offer some solutions, they remain limited in device flexibility and lack variation in wheel size parameters.

To overcome these limitations, this study aims to develop a modern experimental tool that effectively examines the interactions between wheels in circular motion by integrating Internet of Things (IoT) technology and the Hall Effect sensor KY-024. This sensor was selected for its superior accuracy in measuring rotational speed compared to other sensors (Yulkifli et al., 2019; Purwansyah, 2021) and will be used in conjunction with the Blynk mobile app. The app enables users to input varying rotation speeds for the wheels, which are driven by a DC motor. The motor's speed is controlled via a VNH2SP30 motor driver using Pulse Width Modulation (PWM).

Data processing is handled by the NodeMCU ESP32, a microcontroller board equipped with built-in WiFi and Bluetooth capabilities, making it ideal for developing IoT-based systems. This processed data is then transmitted to the Blynk mobile app, which also serves as an intuitive real-time data monitoring interface. The app presents data in a visually accessible format, easily understood through mobile devices. This approach is expected to enhance students' understanding of physics concepts in a more engaging and accessible way.

Moreover, the developed experimental tool aims to improve the effectiveness of science education. This tool, designed to be visually and audibly perceivable, assists educators in making the learning process more efficient. The use of this experimental tool in science education can significantly facilitate students' understanding of scientific concepts (Shinde et al., 2020). A key advancement in this tool is its mechanical aspect, specifically the variation in wheel radius sizes. This variation is crucial in educational contexts as it allows students to adjust the wheel radius through inputs in the application and mechanical components, thereby offering greater flexibility in demonstrating the concept of circular motion, a concept that is often difficult to grasp through theory alone.

The ability to vary the wheel radius not only enriches the experimental experience but also enables students to directly observe how changes in this parameter affect measurement outcomes. By varying the wheel radius, students can physically see how these changes impact the wheel's motion. This process provides a clearer visual representation of how changes in wheel radius affect speed and circular motion. Consequently, students can more easily understand the relationships between key variables in circular motion without being constrained by the physical size of the wheel used.

2. METHOD

This study utilizes the Laboratory Experiment method, which involves applying scientific principles to a specific design in order to achieve the desired performance. The research was conducted starting in September 2023 at the Electronics and Instrumentation Laboratory, Department of Physics, Padang State University. The research process included several stages: preparation, literature review, construction of the demonstration tool, execution of the experiment, testing of the tool, and the final report compilation. The following block diagram illustrates the electronic design that plays an important role in determining the performance and results of the wheel relationship experimental tool under study. The following is a system diagram of the wheel relationships experimental tool.

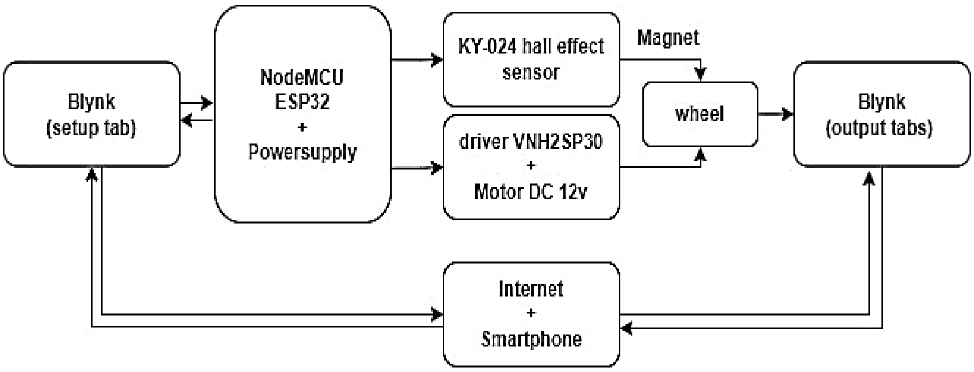


Figure 2. Block Diagram of the Wheel Relationship Experimental Tool

In Figure 2, the tool will be controlled through the Blynk mobile app, allowing users to vary the wheel rotation speeds using a DC motor. The motor's speed will be regulated by a VNH2SP30 motor driver, utilizing PWM for precise control. Data from the sensors will be processed by the NodeMCU ESP32 to generate angular and linear velocity outputs, which are displayed in real-time on the Blynk app. To facilitate this operation, the flowchart in Figure 3 outlines the program design and interaction sequence.

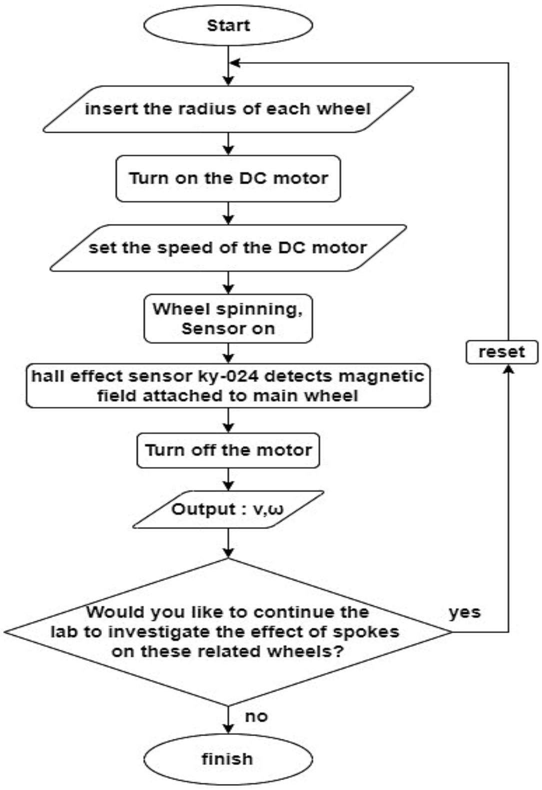


Figure 3. Flowchart of the Wheel Relationship Experimental Tool

This flowchart represents the program for controlling the speed of the DC motor in a mobile-based physics experimental tool for studying wheel relationships. In the initial stage, the tool is operated by adjusting the DC motor speed using the Blynk slider widget. As the DC motor runs, the sensor sends signals to the microcontroller for processing, and the processed results are then displayed on the Blynk app. The results include values and graphical outputs of angular and linear velocities, making it easier to analyze the interactions between the wheels. If the experiment needs to be repeated with different wheel sizes, the same steps are followed. The instrument design plan, integrates mechanical and electronic components for precise experimentation as shown in Figure 4.

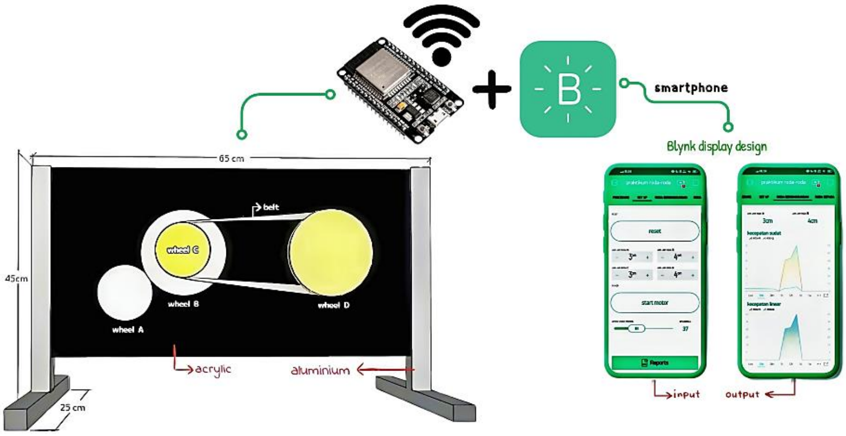


Figure 4. Instrument Design Plan of the Wheel Relationship Experimental Tool

Figure 4 shows the integration of robust hardware design and intuitive software. Various configurations are used to study wheel size effects on motion dynamics. Wheels are labeled for clarity: Wheel A and Wheel B have a tangential relationship, Wheel B and Wheel C are concentric, and Wheel C and Wheel D have another tangential relationship. The tool allows Wheels A and C to be replaced with different diameters (6 cm, 8 cm, or 10 cm), while Wheels B and D remain fixed at 12 cm. The system's adjustable nature fosters hands-on learning, enabling students to manipulate variables and observe real-time effects. This flexibility provides an engaging platform to understand circular motion dynamics, connecting theory with practice. The tool enhances learning and deepens understanding of physics concepts. A systematic development approach ensures its effectiveness and adaptability to various educational needs.

3. RESULTS AND DISCUSSION

The results of this study encompass two primary types of specifications, performance specifications and design specifications. Performance specifications refer to the quality and quantity of system components that contribute to ease of use (Putri Tissos & Kamus, 2014). This includes the capability of the electronic circuitry to operate the experimental tool and process data, the ability of the DC motor to control the rotational speed of the wheel, and the accuracy with which the Blynk application displays measurement data. Based on the instrument design plan, the physical appearance of the experimental tool for analyzing wheel relationships in circular motion is shown in Figure 5.

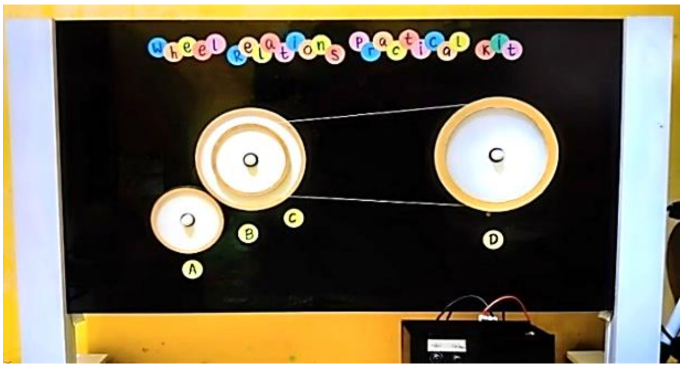


Figure 5. Physical Form of the Wheel Relationship Experimental Tool

Figure 5 illustrates four acrylic wheels that represent three types of wheel relationships: tangent wheels, concentric wheels, and wheels connected by a belt. All components are mounted on a horizontal black acrylic board measuring 65 cm in length and 35 cm in height. This board serves as a base for positioning the wheels. To ensure the stability of the tool, the left and right sides of the acrylic board are equipped with inverted T-shaped aluminum support columns, each measuring 48 cm in height, 5 cm in width, and 3 cm in thickness. The experimental tool operates with an electronic circuit, as shown in Figure 6.

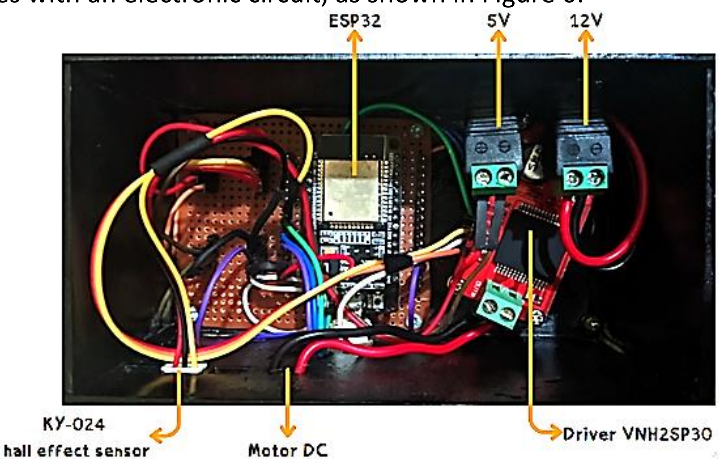


Figure 6. Electronic Circuit of the Wheel Relations Experimental Tool

In Figure 6, the circuit of this tool consists of several key components, including a 12V adapter, a 5V adapter, a DC motor, a VNH2SP30 motor driver, an ESP32 microcontroller, and a Hall Effect sensor KY-024. The wheel's rotation is automatically controlled through a circuit that uses a DC motor connected to the VNH2SP30 driver and a 12V adapter. The VNH2SP30 driver controls the DC motor, while the 12V adapter supplies power to the circuit. When the circuit is powered, the DC motor operates according to the inputs programmed via the ESP32.

The four wheels in this tool are interconnected for analyzing their movement dynamics. Wheel D is equipped with a small magnet, which serves as a magnetic field source detected by the Hall Effect sensor KY-024. This sensor plays a crucial role in determining the rotational speed of Wheel D, ensuring that the physical parameters of the connected wheels are accurately processed. Wheel D also functions as the driving source for the other three wheels. It is powered by the DC motor mounted behind it, while Wheel C is driven by a belt that connects it to Wheel D. Wheel B moves due to its concentric relationship with Wheel C, and Wheel A moves through direct contact with Wheel B. The measured physical parameters of these wheel movements are then visualized as graphs and numerical data in the Blynk application.

The variations in wheel sizes for the experimental tool are designed with specific ratios to facilitate analysis. Different wheels are constructed to simulate the relationships between wheels in circular motion. The wheels are made from 3mm white acrylic, contrasting with the black acrylic board on which they are mounted. The tool features four wheels labeled A, B, C, and D, each representing a different type of wheel relationship: tangential, concentric, and belt-connected. Wheels A and C can be swapped with wheels of different sizes (3 cm, 4 cm, 5 cm), while wheels B and D are fixed at 6 cm in diameter. Testing is conducted using specific wheel sizes, with Wheel A at 4 cm, B at 6 cm, C at 4 cm, and D at 6 cm. The results are based on inputs from the application, assuming accurate outcomes for other variations. Although the test results rely on application inputs, physically swapping the wheels is crucial to demonstrate tangible changes in the system, helping practitioners understand the relationship between theory and practice by observing the direct impact of wheel size variations. On the other hand, the comparison of wheel rotational speed control between the experimental tool and the standard device (tachometer) is illustrated in Figure 7.

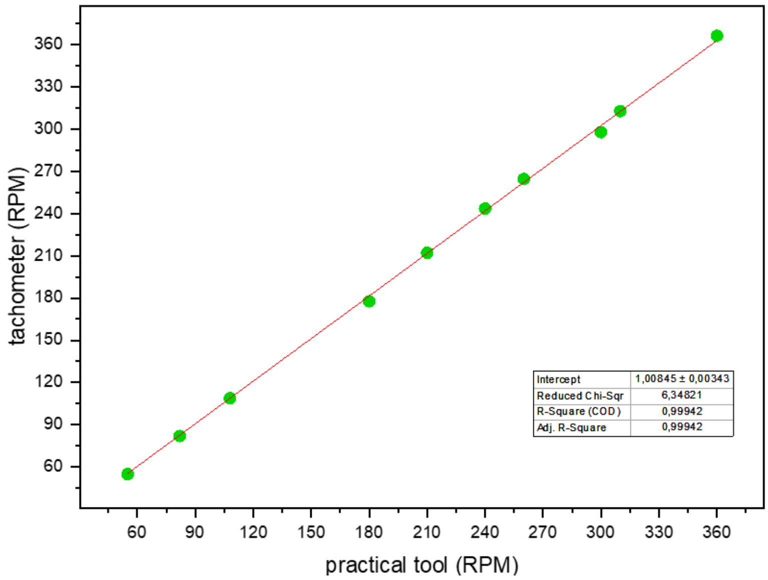


Figure 7. Graph Showing the Relationship between RPM Readings of the Experimental Tool and Those Measured by the Tachometer

Figure 7 presents a comparison between a experimental tool using the KY-024 Hall effect sensor (X-axis) and a tachometer (Y-axis) in measuring the rotational speed of a wheel (RPM). The data reveals a very strong linear correlation between the two devices, as indicated by the regression line closely aligning with the data points. The high R-Square value of approximately 0.98942 suggests that the experimental tool equipped with the Hall effect sensor KY-024 exhibits a level of accuracy nearly equivalent to that of the tachometer. Therefore, this tool can be considered highly precise for measuring wheel rotational speed, as its measurements are consistently in line with those obtained from the standard instrument (tachometer). This experimental tool is operated via the Blynk application, which controls the motor to move the wheels, manages input, and displays output through a smartphone. The application interface on the smartphone screen is shown in Figure 8.

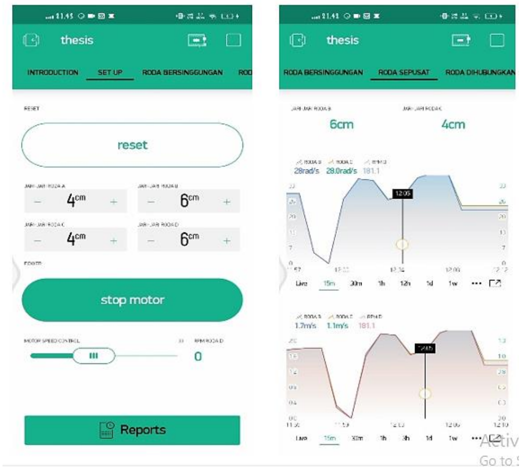


Figure 8. Blynk Interface of the Wheel Relations Experimental Tool

Figure 8 illustrates the setup and output tabs within the Blynk app. The setup tab includes a reset button to reinitialize the experimental tool's values, four numeric input widgets for entering the wheel radii, a motor power button to turn the motor on or off, and a slider widget for adjusting the RPM speed. This tab is also equipped with a report feature that serves as a database for the experimental tool. The output tabs are divided into three sections for analyzing the angular and linear velocity of each wheel: the wheel tangential relationship menu (wheels A and B), the wheel concentric relationship menu (wheels B and C), and the belt-driven relationship menu (wheels C and D). The analysis results are visualized in graphs, which facilitate the understanding of theoretical concepts in line with the experiment objectives.

Design specifications refer to the required performance standards and the operational functionality of the system. These specifications are derived from measurements conducted during the research (Dewadi et al., 2023; Rahmatullah et al., 2023). The design specifications include system accuracy, which is determined by comparing the system's measurement results with those obtained from a standard instrument, the tachometer (Yulkifli & Ramli, 2018). The experimental setup consists of three different wheel configurations: contacting wheels, concentric wheels, and wheels connected by a belt. In each configuration, a tachometer was used to measure the angular velocities of the wheels. The tachometer provided rotational speed readings in RPM, which were subsequently converted to rad/s to align with the SI unit system. The measurements were taken at various speed settings to determine the accuracy of the tool. The collected data were then compared to standard angular velocity calculations to assess the precision of the tool in each setup. Accuracy data for the angular velocity measurements of wheels A and B are presented in Table 1.

Table 1. Angular Velocity Accuracy Data for Contacting Wheels in the Experimental Tool

Rpm Input (RPM)	**Radius wheel A = 4 cm**				**Radius wheel B = 6 cm**			
	ω_A (rad/s)		v_A (m/s)	%Accuracy ω_A	ω_B (rad/s)		v_B (m/s)	%Accuracy $\boldsymbol{\omega_B}$
	Tool	Tachometer			Tool	Tachometer		
55	12,95	12,96	0,52	99,93%	8,64	8,64	0,52	99,95%
100	23,15	23,56	0,94	98,25%	15,01	15,71	0,94	95,56%
160	35,90	37,70	1,51	95,23%	25,07	25,13	1,51	99,77%
180	42,00	42,41	1,70	99,03%	27,94	28,27	1,70	98,82%
190	44,23	44,77	1,79	98,80%	29,46	29,85	1,79	98,71%
200	47,90	47,12	1,88	98,35%	32,20	31,42	1,88	97,50%
220	49,30	51,84	2,07	95,11%	35,05	34,56	2,07	98,57%
240	54,70	56,55	2,26	96,73%	38,51	37,70	2,26	97,85%
Average				**97,68%**				**97,34%**

In Table 1, the accuracy of the measurements for the contacting wheels in the wheel-to-wheel experiment with 8 motor speed variations demonstrates satisfactory results. The average angular velocity accuracy for wheel

A reaches 97,68%, while for wheel B it is 97,34%. This indicates that the designed experimental apparatus provides results very close to the tachometer readings. Additionally, the data show that the angular velocities of wheels A and B differ, but their linear velocities remain the same, despite the difference in wheel radii. A smaller radius wheel produces a higher angular velocity than a larger radius wheel. Therefore, this experimental setup successfully validates the theory of contacting wheels. Next, Table 2 presents data for concentric wheel relationships.

Table 2. Angular Velocity Accuracy Data for Concentric Wheels in the Experimental Tool

Rpm Input (RPM)	**Radius wheel B = 6 cm**				**Radius wheel C = 4 cm**			
	ω_B (rad/s)		v_B (m/s)	%Accuracy ω_B	ω_C (rad/s)		v_C (m/s)	%Accuracy $\boldsymbol{\omega_C}$
	Tool	Tachometer			Tool	Tachometer		
55	8,64	8,64	0,52	99,95%	8,64	8,64	0,35	99,95%
100	15,01	15,71	0,94	95,56%	15,01	15,71	0,63	95,56%
160	25,07	25,13	1,51	99,77%	25,07	25,13	1,01	99,77%
180	27,94	28,27	1,70	98,82%	27,94	28,27	1,13	98,82%
190	29,46	29,85	1,79	98,71%	29,46	29,85	1,19	98,71%
200	32,20	31,42	1,88	97,50%	32,20	31,42	1,26	97,50%
220	35,05	34,56	2,07	98,57%	35,05	34,56	1,38	98,57%
240	38,51	37,70	2,26	97,85%	38,51	37,70	1,51	97,85%
Average				**97,34%**				**97,34%**

Based on Table 2, the accuracy data wheels B and C for concentric wheel relationships in the experimental apparatus demonstrate satisfactory results. The average accuracy obtained for wheel B reaches 97,34%, and the same value is achieved for wheel C, also at 97,34%. These results reflect a good level of accuracy, as the developed experimental apparatus provides outcomes that closely align with the tachometer readings. From these measurements, it can be concluded that in the case of concentric wheel motion, the angular velocities of wheels B and C are the same, while their linear velocities differ. These findings have validated the theory regarding angular velocity in concentric wheel relationships. In continuation, Table 3 will present data regarding the relationships of wheels connected by a belt.

Table 3. Angular Velocity Accuracy Data for Wheels Connected by a Belt in the Experimental Tool

Rpm Input (RPM)	**Radius wheel C = 4 cm**				**Radius wheel D = 6 cm**			
	ω_C (rad/s)		v_C (m/s)	%Accuracy ω_C	ω_D (rad/s)		v_D (m/s)	%Accuracy $\boldsymbol{\omega_D}$
	Tool	Tachometer			Tool	Tachometer		
55	8,64	8,64	0,35	99,95%	5,77	5,76	0,35	99,82%
100	15,01	15,71	0,63	95,56%	10,07	10,47	0,63	96,16%
160	25,07	25,13	1,01	99,77%	17,38	16,76	1,01	96,27%
180	27,94	28,27	1,13	98,82%	18,56	18,85	1,13	98,46%
190	29,46	29,85	1,19	98,71%	19,05	19,90	1,19	95,74%
200	32,20	31,42	1,26	97,50%	20,64	20,94	1,26	98,55%
220	35,05	34,56	1,38	98,57%	22,59	23,04	1,38	98,05%
240	38,51	37,70	1,51	97,85%	24,66	25,13	1,51	98,12%
Average				**97,34%**				**97,65%**

Based on Table 3, the accuracy data for wheels C and D connected by a belt demonstrate satisfactory results. The measurements indicate that the average accuracy for wheel C is 97,34%, while wheel D has an average accuracy of 97,65%. The data obtained is quite accurate, as the experimental apparatus utilizing Hall effect sensors to measure the wheel's rotational speed yields values that closely match those from the standard instrument, the tachometer. From this data, it can also be concluded that in the case of wheels connected by a belt, the angular velocities of wheels C and D are different, while their linear velocities remain the same. Thus, the results obtained have validated the theory regarding angular velocity in the relationship of wheels connected by a belt.

Measurement precision refers to the consistency of values within a set of measurements. The precision of angular and linear velocity for three wheel configurations was determined by repeating measurements ten times at a wheel rotational speed of 180 RPM. The average of these repeated measurements was compared to the actual data to calculate the precision percentage. The precision of the angular and linear velocity data at 180 RPM for contacting wheels is presented in Table 4.

Table 4. Precision of Wheel Rotational Speed at 180 RPM for Contacting Wheels in the Experimental Tool

Data	**Radius wheel A = 4 cm**		**Radius wheel B = 6 cm**	
	ω_A (rad/s)	v_A (m/s)	ω_B (rad/s)	$\boldsymbol{v_B}$ (m/s)
	42,41	1,70	28,27	1,70
1	42,18	1,71	28,30	1,71
2	42,25	1,70	28,32	1,70
3	43,00	1,69	28,56	1,69
4	41,50	1,69	27,90	1,69
5	42,23	1,70	28,15	1,70
6	43,90	1,71	29,20	1,71
7	42,50	1,71	27,80	1,71
8	43,11	1,71	28,51	1,71
9	42,12	1,70	28,70	1,70
10	42,50	1,70	28,74	1,70
Avarage	**42,53**	**1,70**	**28,42**	**1,70**
% Precision	**98,88%**	**99,52%**	**98,80%**	**99,52%**

In Table 4, the measurements indicate the accuracy of the system at a rotational speed of 180 RPM for the wheel in contact with the experimental tool. The data shows consistent angular velocity (ω) and linear velocity (v) for the wheel in contact, with average accuracies of 98,88% and 99,52% for Wheel A, and 98,80% and 99,52% for Wheel B, respectively. These results demonstrate a high level of measurement reliability, supporting the validity of the experimental tool. Subsequently, Table 5 presents data for concentric wheel relationships.

Table 5. Precision of Wheel Rotational Speed at 180 RPM for Concentric Wheels in the Experimental Tool

Data	**Radius wheel B = 6 cm**		**Radius wheel C = 4 cm**	
	ω_B (rad/s)	v_B (m/s)	ω_C (rad/s)	$\boldsymbol{v_C}$ (m/s)
	28,27	1,70	28,27	1,13
1	28,30	1,71	28,30	1,10
2	28,32	1,70	28,32	1,11
3	28,56	1,69	28,56	1,12
4	27,90	1,69	27,90	1,13
5	28,15	1,70	28,15	1,13
6	29,20	1,71	29,20	1,12
7	27,80	1,71	27,80	1,13
8	28,51	1,71	28,51	1,13
9	28,70	1,70	28,70	1,14
10	28,74	1,70	28,74	1,11
Avarage	**28,42**	**1,70**	**28,42**	**1,12**

% Precision	**98,80%**	**99,52%**	**98,80%**	**99,00%**

Table 5 presents the precision of rotational speed at 180 RPM for concentric wheels within the experimental tool. The data reveals consistent angular velocity (ω) and linear velocity (v) measurements for both wheels. The average precision for wheel B is 98,80% for angular velocity and 99,52% for linear velocity. For wheel C, the average precision is 98,80% for angular velocity and 99,00% for linear velocity. These results indicate a high level of measurement reliability, further validating the experimental configuration. In continuation, Table 6 will provide data pertaining to the relationships of wheels connected by a belt.

Table 6. Precision of Wheel Rotational Speed at 180 RPM for Wheels Connected by a Belt in the Experimental Tool

Data	Radius wheel C = 4 cm		Radius wheel D = 6 cm	
	ω_C (rad/s)	v_C (m/s)	ω_D (rad/s)	$\boldsymbol{v_D}$ (m/s)
	28,27	1,13	18,85	1,13
1	28,30	1,10	18,31	1,10
2	28,32	1,11	18,51	1,11
3	28,56	1,12	18,53	1,12
4	27,90	1,13	18,99	1,13
5	28,15	1,13	18,35	1,13
6	29,20	1,12	19,25	1,12
7	27,80	1,13	18,89	1,13
8	28,51	1,13	18,17	1,13
9	28,70	1,14	18,98	1,14
10	28,74	1,11	18,14	1,11
Avarage	**28,42**	**1,12**	**18,61**	**1,12**
% Precision	**98,80%**	**99,00%**	**97,98%**	**99,00%**

Table 6 presents the precision of the wheel rotational speed at 180 RPM for the wheels connected by a belt in the experimental tool. The data indicates consistent angular speed (ω) and linear speed (v), with average precisions of 98,80% and 99,00% for wheel C. For wheel D, the average precision is 97,98% for angular velocity and 99,00% for linear velocity. These results highlight the reliability of the measurements, reinforcing the validity of the experimental configuration.

All of these measurements confirm that the experimental tool reliably provides stable and accurate measurements across all wheel connection configurations. Its ability to replicate real-world dynamics with high accuracy makes it a valuable resource for educational experiments. This tool is particularly effective in demonstrating circular motion and the relationships between wheels, thus making a significant contribution to physics education.

4. CONCLUSION

Based on the results and discussion, The experimental apparatus effectively investigates the relationships between wheels, with the ESP32 microcontroller and the Blynk application ensuring reliable data processing and display. The KY-024 sensor showed high RPM accuracy, closely aligning with tachometer results. Regression analysis is 0,98942 affirms the apparatus's suitability for educational purposes. Accuracy and precision tests further validated the system's reliability in measuring wheel motion. Comparisons with standard tachometer readings and theoretical predictions showed consistent results. Concentric wheels (B and C) exhibited nearly identical angular velocities despite differing linear velocities. In contrast, tangent wheels (A and B) and belt-connected wheels (C and D) displayed similar linear velocities but distinct angular velocities, aligning with theoretical expectations.

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DECLARATIONS

Authorship contribution

Yuhelmi Farah Difa: Conceptualized the research, designed and developed the experimental tool, collected and analyzed data, implemented the software, and drafted the manuscript. **Yulkifli**: Supervised the research, provided feedback to improve it, and validated the manuscript. **Asrizal and Yenni Darvina**: Provided feedback to improve it, and validated the manuscript.

Competing Interest

The authors **declare** no conflict of interest in this study.

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Ethical Clearance

There are no human subjects in this manuscript, and informed consent is not applicable.

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