The design and implementation of an instrument for converting angular velocity to linear velocity based on arduino atmega 2560

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Abstract. The experiment tool of converting angular velocity into linear velocity has been built to support the physics education in the Physics Department of Tadulako University. In this project, the experimental tool has been designed, manufactured, and tested to convert the angular velocity value to linear velocity based on Arduino ATmega 2560. The stages of this research begin with the design and manufacture: mechanical system, optical sensor circuit, stepper motor circuit, the circuit of LCD and keypad controlled by Arduino ATmega 2560. The next step is the building controlling program as the brain of this instrument. This experimental tool has been tested and working properly. It operates for a rotation speed range of 1 rpm - 112 rpm. The value of converted linear velocity both theoretically and measured value is relatively the same.

1. Introduction
In the field of physics, there are some topics of learning need to be supported by practicum activities to improve students’ understanding. Deslaurier points out that the use of deliberate practice teaching strategies can improve both learning and involvement in large introductory physics courses compared with what is obtained by lecture methods [1]. In addition, science educators have suggested that the rich benefits of learning are derived from the use of lab work in the laboratory [2]. However, some practicum activities are not supported by adequate equipment.

The absence of equipment in the laboratory is usually caused by several things. First, the instrument for the practicum is essentially non-existent. Second, equipment is difficult to find or rarely produced. In addition, the equipment has an expensive price that is not appropriate for the existing budget.

One of the topics of physics lab that do not have practicum equipment is mechanical experiment especially tool that can correlate angular velocity and linear velocity in one instrument. However, there have been several studies concerning the arrangement of these two velocities. The first, Mutaqin has designed the digital speed measuring devices based on microcontroller AT89S51[3]. Furthermore, Nugraha has designed the dc motor rotation speed regulation system [4]. In addition, Nisa has implemented the time and speed measuring instruments using DT-Sense infrared proximity detector [5]. Basically, the research done by Mutaqin is to identify the linear velocity of moving objects on a
straight line digitally using Light Dependent Resistor (LDR) and ultrasonic sensors. Disadvantages of this tool are the use of LDR that is affected by light conditions at the time of measurement. Thus the measurement results may vary if the lighting conditions change. On the other hand, Nugraha's research controls the rotation of a DC motor-related dodging mixer. This research uses Arduino Uno microcontroller and optocoupler as speed gauge of DC motor. Nugraha uses a proportional-integral deferential control system (PID) as a motor rotation controller. While research conducted by Nisa identifies time and velocity of objects through voltage regulation using DT-Sense Infrared sensor. This instrument uses the microcontroller-based system Atmega 8 and Liquid Crystal Display (LCD) for display.

Based on the above studies it is seen that there is no instrumentation that can show the conversion of angular velocity into linear velocity. In this paper, we present a study on the design and implementation of practicum instrument that able to show the correlation between the angular velocity and the linear velocity. This instrument also use to prove the relationship between the linear velocity based on the measurement and linear velocity which mathematically calculated using angular velocity. This instrument is made based on a simple principle and low cost, however, it can be operated and functioned properly. Thus it can improve the quality of the lab and optimize the time of student practicum activities.

As mentioned earlier that in this study the tool made will determine the relationship of linear velocity and angular velocity. The object rotates at a constant speed within one period \((T)\) then the angle taken is \(2\pi\) radians. The relationship between angular velocity \((\omega)\)and linear velocity \((v)\) in circular motion formulated as:

\[
v = \omega R \quad \text{atau} \quad v = \frac{2 \pi R}{T}
\]

where \(\omega\) = angular velocity and \(R\) = radius rotated object.

At the linear velocity, the object moves on a straight path and it is constant in value. The linear velocity of an object should gives the equality of its average velocity and its instantaneous velocity. The average velocity is the ratio of total displacement \(\Delta x\) took overtime interval \(\Delta t\). Mathematically, it is given by

\[
v = \frac{\Delta x}{\Delta t} = \frac{x_2 - x_1}{t_2 - t_1}
\]

where \(t_1\) and \(t_2\) are the time at \(x_1\) and \(x_2\), respectively.

2. The Electric Components, Design and Method

This velocity converter instrument uses an infrared optocoupler to detect angular velocity and combination of infrared LEDs with infrared photodiode to detect the velocity of objects. In this case, the sensors used are not affected by visible light. For electronic systems are supplied with two outputs of 9 Volt and 12 Volt. The first output for the controller and the second output powering circuit for the stepper motor driver circuit. In addition, there are 4 pieces of optical sensor circuit using infrared LED as transmitter and infrared photodiode as receiver. All these sensors are mounted on the existing track board on the mechanical part. Each sensor circuit is connected to ATMega 2560 microcontroller as controller. The monitor unit uses a liquid crystal display (LCD) 16x4. The input value of angular velocity sends through 4x4 keypad. This input will control the stepper motor which is connected to the pulley. The schematic of the block diagram of the whole system shown in figure 1.

The program controller and data processing on microcontroller made by using open source software Arduino IDE which facilitate writing code and uploaded to ATMega 2560 microcontroller on Arduino board. This program is based on the Java program. This program will control and record the time when the sensor is blocked by step-driven markers. The linear speed of a marking device can be determined from the distance between two pairs of sensors divided by the time difference recorded between the two sets of sensors (compare with equation 2). Theoretically, linear velocity can be calculated by using angular velocity data and gear radius according to equation 1.
3. Results and Discussion

Figure 2 shows the structure of a pair of sensors, the sensor contain with infrared LED as transmitter (A) and photodiode as a receiver (B). The structure must be installed face to face, thus the light given by the LED is only accepted by the photodiode straight in front of it. In this research, the distance between the transmitter and the receiver is 1 cm.

The optocoupler and the encoder is installed to determine the angular velocity of a step motor as shown in figure 3.
Figure 3. The position of optocoupler and encoder

Figure 4 shows the block diagram of the whole electronic system of the instrument, which contains with optical sensors 1 circuit to optical sensors 4 circuits, LCD circuit, keypad, and steps motor driver. The signal from each sensor circuit are the input to the digital pin of ATMega 2560.

Figure 4. The block diagram of whole electronic circuits

Table 1 shows the comparison between the given angular velocity and the measured angular velocity using a digital encoder. The maximum angular velocity that can be reach is 112 rpm. The speed of the motors haven't been able to move with a high angular velocity because the source voltage required DC stepper motor must be in a stable condition. Both angular velocities are relatively the same if the angular velocity between 4 and 82 rpm which gives the highest error of 0.16%. However, the error becomes higher if the angular velocity beyond this velocity range. The maximum difference between the inputted and measured value is 11.11 rpm which given a maximum error of 9.91%.

In the other hand, the conversion of angular velocity data into linear velocity is shown in table 2. It can be seen that the calculated data and the measured data of the linear velocity are mostly given the value of error below 10%. The magnitude of this error can be caused by instability in controlling the
stepper motor. The error can also accumulate from mechanical problems such as friction and the imperfection of the mechanical system.

Table 1. The experiment data of the input angular velocity and the measured angular velocity using digital encoder

| No. | Angular velocity (rpm) | Error (%) |
|-----|------------------------|-----------|
|     | Input | Measured |         |
| 1   | 4     | 3,81     | 4,75     |
| 2   | 10    | 10,00    | 0,00     |
| 3   | 16    | 15,99    | 0,06     |
| 4   | 22    | 22,00    | 0,00     |
| 5   | 28    | 27,99    | 0,04     |
| 6   | 34    | 33,99    | 0,03     |
| 7   | 40    | 39,99    | 0,03     |
| 8   | 46    | 45,97    | 0,06     |
| 9   | 52    | 51,96    | 0,08     |
| 10  | 58    | 57,99    | 0,02     |
| 11  | 64    | 63,91    | 0,14     |
| 12  | 70    | 69,89    | 0,16     |
| 13  | 76    | 75,96    | 0,05     |
| 14  | 82    | 79,98    | 2,46     |
| 15  | 88    | 87,43    | 0,65     |
| 16  | 94    | 90,82    | 3,38     |
| 17  | 100   | 95,69    | 4,31     |
| 18  | 106   | 99,66    | 5,98     |
| 19  | 112   | 100,89   | 9,91     |

Table 2. Comparison of the angular velocity value which is inputted through the keypad and measured by the digital encoder (left) and comparison of the linear velocity value which is calculated from measured angular velocity and measured by the system.

| No. | Angular velocity (rpm) | Error (%) | Linear velocity (cm/s) | Error (%) |
|-----|------------------------|-----------|------------------------|-----------|
|     | Input | Measured | ∆ | Calculated | Measured | ∆ |         |
| 1   | 1     | 1,0     | 0,0 | 0,13 | 0,12 | 0,01 | 7,7     |
| 2   | 10    | 10,1    | 0,1 | 1,32 | 1,24 | 0,08 | 6,1     |
| 3   | 20    | 20,1    | 0,1 | 2,63 | 2,47 | 0,14 | 5,3     |
| 4   | 30    | 29,9    | 0,1 | 3,91 | 3,71 | 0,20 | 5,1     |
| 5   | 40    | 40,1    | 0,1 | 5,25 | 4,94 | 0,31 | 5,9     |
| 6   | 50    | 50,1    | 0,1 | 6,55 | 6,17 | 0,38 | 5,8     |
| 7   | 60    | 60,2    | 0,2 | 7,88 | 7,42 | 0,46 | 5,8     |
| 8   | 70    | 69,9    | 0,1 | 9,15 | 8,01 | 1,14 | 12,5    |
| 9   | 80    | 80,0    | 0,0 | 10,47 | 9,83 | 0,76 | 7,3     |
| 10  | 90    | 90,0    | 0,0 | 11,78 | 10,62 | 0,16 | 1,4     |
| 11  | 100   | 100,1   | 0,1 | 13,10 | 11,71 | 1,29 | 9,8     |
| 12  | 110   | 108,6   | 1,4 | 14,21 | 12,15 | 2,06 | 14,5    |

4. Conclusion
In this research, the physical instruments have been made to convert angular velocity into linear velocity based on infrared sensors. This instrument has been tested, calibrated and operated by
obtaining good results. The conversion of angular velocity to linear velocity can only be operated at a speed of 1 rpm - 112 rpm. The error between the calculated and measured value of linear velocity is quite high. Therefore this equipment needs to be developed to be able to operate with higher motor rotation speed.

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