JOURNAL OF SOCIAL SCIENCES AND TECHNICAL EDUCATION
Jurnal Sains Sosial dan Pendidikan Teknikal 1(1) (2020), 128-135

The Implementation and Calibration a Low Cost Propeller Type Current Meter in the Laboratory

*Diana Ringgau[1], Martin Anyi[2]
Department of Electrical Engineering, Politeknik Mukah[1]
Faculty of Engineering, Universiti Malaysia Sarawak[2]

Abstract

Propeller type current meter or horizontal-axis rotor meters is an equipment that is used to estimate flow velocity in various fluids such as air, water, and oil. Several standard propeller-type current meters had been produced by companies are to cater to the demands, but these products are costly and limited in accuracy of the real-time during data recording. The design and implementation of the proposed propeller-type current meter are for river or stream application and thus, the Velocity-area method was used. The current meter was implemented by manipulating mechanical performance which is more reliable and stable in measurement. The propeller type current meters are compact with Analogue to Digital Converter (ADC) that is embedded in the microprocessor board for data processing. Meanwhile, the Real-Time Clock (RTC) module is used to maintain the accuracy of the real-time during data recording via Security Digital (SD) card and rechargeable Li-Po battery with DC/DC converter for power supply. The cost to build the propeller-type current meter is 44.95% cheaper than a commercial current meter. The testing and calibration process were conducted at the laboratory. The propeller-type current meter is tested in an 8-meter-long Flow Channel that varied from 0.3 m/s to 0.6 m/s and the result shows an average error is 1.0%. Therefore, the device shows an acceptable error and extremely useful to reduce research or operation costs.

Keywords: Flow velocity, velocity-area method, horizontal-axis rotor meters

Received: August 05, 2020; **Accepted**: September 22, 2020; **Published**: October 20, 2020

* Corresponding author: dianaringgau@pmu.edu.my

INTRODUCTION

In renewable technology such as wind, hydrokinetic and hydropower energy, the important to estimate flow velocity of air or water is undeniable. The velocity's data identify the potential of energy provide by natural resource where the system will be installed. Besides, monitoring the flow velocity in open channels such as river and stream are vital for assessing water availability (Shaw et al., 2010). Flow velocity measurement also commonly used in industrial sectors such as food and beverage, petroleum, chemical, and many other industries to measure velocities of various gases and fluids (Tumanski, 2006). There are many techniques to measure flow in open channels for example hydraulic structures, velocity-area methods, and dilution techniques. Hydraulic structures are usually applied in flume and weirs. The structure controlled the flow and permit a highly accurate measurement of discharge (Adeogun & Mohammed, 2012). Velocity-area methods are mostly employed in stream such as current meters, acoustic Doppler devices and floats. These methods involve the measurement of flow velocity and area components of a measurement section in a stream (Fowles & Boyes, 2009). Meanwhile, Dilution techniques or dye-tracing methods, commonly determine the discharge in a stream by measuring the dilution and dispersion of a suitable dye tracer. Even though there are many flow velocity techniques in open channel, velocity-area method is the most commonly used estimating river flow. The method offers mobility without any fixed installation needed (Herschy, 2011).

Current meter such as mechanical or electromagnetic, are divided into groups based on the orientation of the axis of the rotor. Vertical-axis rotor meters are known as cup-type meters. Whereas, horizontal-axis rotor meters are referred to as propeller-type current meters. The vertical-axis rotor meters require more maintenance and tedious compare to horizontal-axis current meters. The advantage of Horizontal-axis current meters is not easily to become tangled in debris and grass of flowing river. Mechanical current meter performance depends on the inertia of the rotor and friction in the bearings. It measures velocity by translating linear motion into angular motion. On the other hand, electromagnetic current meters manipulate Faraday's Law. However, its performance for electromagnetic current meters depends on the location of the electrodes on the probe, and the construction of the meter electronics.

Thus, propeller type current meter with mechanical performance is reliability and stability in measurement (Khozaei, 2016b). The current meter was chosen compared among the tools using Velocity-area method. Calibrations are performed in a circulating water tank and a propeller type current meter measurement device. The circulating water tank is a hydrodynamic experimental device that allows water to flow and the current meter is placed in flowing water. In the circulating water tank, the water circulates at a certain speed, and the working section can be tested for a long time, which is convenient for velocity measurement recording both the displacement velocity and its rotation velocity (Takeda, 2018). Ultimately, the calibration coefficient is obtained through linear regression analysis (Staubli, 2016).

IMPLEMENTATION OF PROPELLER TYPE CURRENT METER

CONSTRUCTION OF THE MECHANICAL COMPONENTS

Current meter determines the water velocity using mechanical means. The velocity of the water forces the rotor to revolve at the same speed of the flowing water. Linear equation is used to estimate water velocity by relating it to the rotation frequency or the number of revolutions produce by the rotor. The number of revolutions produce by rotor is then count in each period of time (Montañés, 2006).

Current meters are available with different size and pitch of the rotor to suit a variety of conditions. The pitch of the impeller blades is responsible for the constant C which determines the linear relationship of flow velocity and rotational speed of the current meter $v \approx C \times n$. Protractor is used to measure the angle between rotor plane and blade tip chord or also known as the pitch angle. The following equation is used to calculate the velocity.

$$v = Cn + \Delta \quad (1)$$

Where v is velocity, C is hydraulic pitch of the propeller, n is number of pulses counted and Δ is a constant determined by rating tests (Camnasio & Orsi, 2011). Fig. 1 shows the process of making the prototype of propeller type water current meter; (a) the lathe machine was used to craft a chunk of wood 2cm × 3cm into dome shape or known as spinner nose cone, (b) sand paper was used to smooth the spinner all out after shaping so that it fitted over the propeller hub and (c) the worm screw shaft was screwed into the spinner that attached together with propeller hub. The spinner makes the water current meter more streamlined. It reduces aerodynamic drag and smooth the water flow so that propellers enter the water intakes more efficiently. The design of the propeller or blade must be symmetrical with respect to their chord. For time and cost reduction, computer's fan propeller was used as a propeller.

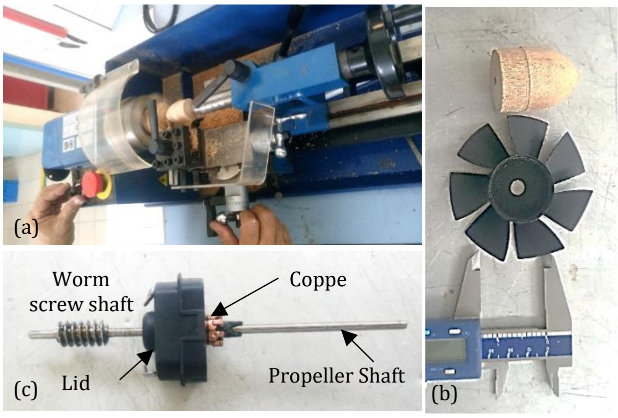

Figure 1. (a) The process of shaping the spinner nose cone, (b) the spinner fitted over a propeller hub and (c) the copper attached on top of the propeller shaft

CONSTRUCTION OF THE METER ELECTRONICS

The meter electronics manipulate ATmega2560 microcontroller board because it is easy to adapt any design and low in cost (Khozaei, 2016a). The board have 14 digital input or output pins, 6 analogues input with an Analogue Digital converter (ADC). On the 5V pin of microcontroller board, the output signal of any transduce must be less than 40mA on each of these pins. The board also support different bus protocol such as I2C, SPI and TTL (Last, 2017). This makes the microcontroller board capable to manage the RTC, SD and transducers module correspondingly by using these bus protocols.

The specifications of the transducer used in the meter is depicted in the Table 1. The Inductive Proximity Sensor is used to separate various metallic materials on the basis of the amount of current produced due to the change in the magnetic field of the sensor.

The variation in current is directly proportional to the distance of the metallic material from the sensor. Proximity sensors provide medium or low-resolution sensing, depending on the number of pulses measured per revolution. The copper rotates with the impeller and at every full rotation it induces a pulse by using electromagnetic in the waterproof coil proportional to water current speed. These pulses were counted by the microcontroller. The proximity sensor required at least 10V of power source. Hence, conditional circuit is needed in the proximity sensor in order to be compatible with the TTL protocol of the microcontroller. The conditional circuit used 1kΩ and 510Ω resistors that are placed as a voltage divider. The pulse signal was then converted into an electrical digital form for the microcontroller to understand the data and proses it. The output from 0 - 5V signal conditioning circuit is converted to digital signal from 0 – 1024, by a build in a 10-bit ADC that is embed in microcontroller board.

Table 1. The proximity sensor specification

M8 Inductive Proximity Sensor	
Sensing Distance(mm)	6mm
Operating voltage	10-30V
Switching frequency	0.5KHz
Response time	0.5ms/0.5ms
Protection category	IP67
Operating temperature	-25°C to 70°C

The DS3231 and SD card module was used as a time stamping and recorder or data storage respectively. The DS3232 from Dallas Semiconductor is an RTC that able to maintain an accurate time and date for the main controller board. DS3232 was selected to avoid losing the time base in case of measuring system power supply fails. The module uses the I2C Communication Protocol to communicate with analogue pin 21 and 20 of the microcontroller board. 2GB of SDHC/microSDHC card was used because it able to store a large volume of data. The card module is communicated through an SPI bus protocol in order to match it with the microcontroller. Pin 53, 52 and 50 are respectively connected with SS (Slave Select) to select the chip if there are multiple slave devices, SCK (Clock Signal) is for clock signal and MISO (Master in Slave Out) is for data in the opposite direction. A multi-channel power supply with DC/DC converter was used to power up all the transducers, RTC, SD module and transceivers from 7000 mAh Li-Po batteries.

PROGRAMMING

The control algorithms were coded using the Arduino IDE. The main program was divided into four procedures; the initialization, measurement, recording and transmission shown in Fig. 2 (a). Meanwhile Fig. 2 (b) shows the process of counting pulses performed by the microcontroller. The line TCCR5A was set as 0; in setup clears the register TCCR5A so that it was ready to start counting. Calling getCount() returns the current count, resets the count, and starts counting again. The current count is printed once per second. If no pulses are detected on pin 47, the values will be 0. The count is reset until button stop pressed.

TESTING

Proximity sensors provide medium or low-resolution sensing, depending on the number of pulses measured per revolution. Fig.3 (a) shows that the copper rotates with the impeller and e very full rotation it induces a pulse by using electromagnetic in the waterproof coil proportional to water current speed. The conditional circuit used 1kΩ and 510Ω resistors that are placed as a voltage divider. This output pulse produces a low signal at 0.1V and 4.98V for a typically high signal shown in (b), whereas (c) shows for every 1 second, these pulses were counted by the microcontroller which is proportional to the water velocity in m/s.

The Flow Channel was used to perform calibration of the current meter. It is a self-contained open channel designed for studying flow phenomena. The channel usually performs typical experiment such as flow measurement and open channel flow which provided a good solution for the prototype calibration. The channel is of rectangular cross section supported by rectangular steel frame with side walls are transparent to allow full visual observation. A head tank with a stilling baffle provides a smooth flow and water is returned to the storage tank via an end tank. The channel size is around 100 mm wide, 300 mm high and 8 m long. The current meter is fixed in a particular place or spot in the channel and let the flowing water move the propeller. Pulses produce by the meter are count and records its rotation velocity.

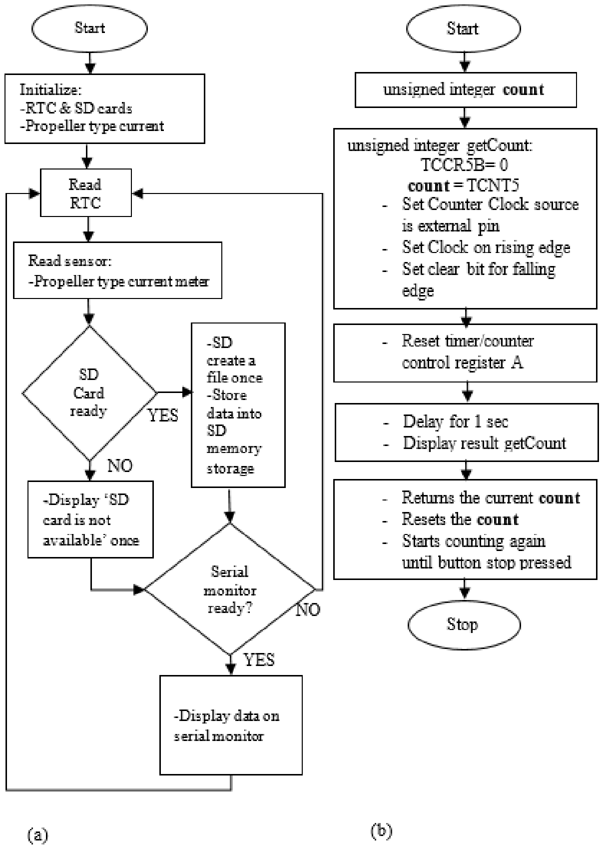

Figure 2. (a) The main program and (b) the flow chart of prototype's counter

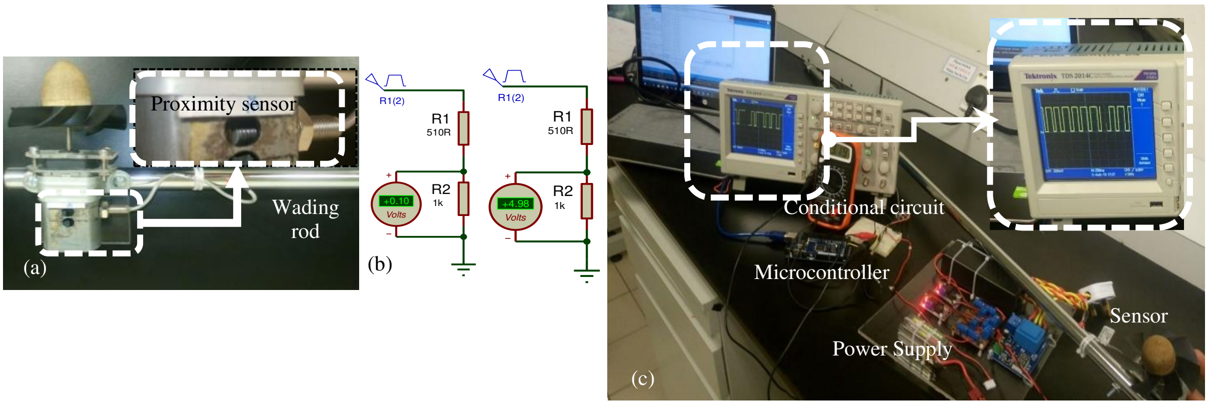

Figure 3. (a) The proximity sensor, (b) the conditioner circuit simulation of propeller type current meter and (c) Pulses produced by the sensor

CALIBRATION

Based on the standard United States Geological Survey (USGS) protocols, one-minute sampling duration is used to collect velocity data. However, in selecting an appropriate instrument, the amount of time required to conduct the measurements between current meter and Acoustic Doppler Current Profiler (ADCP) are at least 2 and 20 minutes respectively. The accuracy of the measurement is to compare with a known standard meter. Accuracy is often reported quantitatively by using relative error:

$$\text{Relative Error} = \frac{\text{measured value} - \text{expected value}}{\text{expected value}} \quad (2)$$

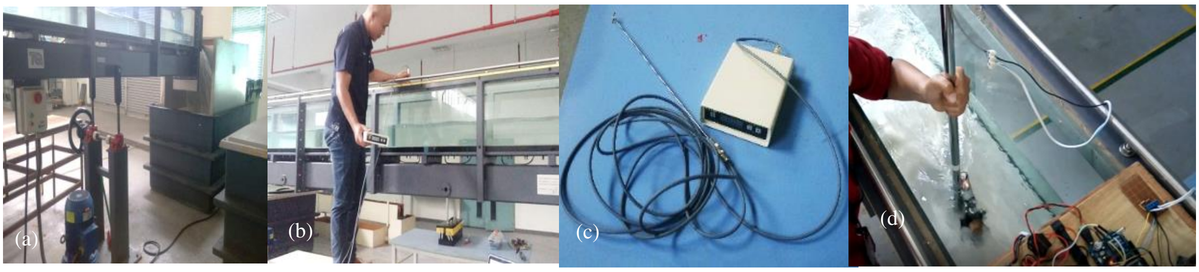

Figure 4. (a) The structure of 8m long Flow Channel, (b) the standard propeller type current meter was calibrated before the experiment started, (c) the standard propeller type current meter used in the experiment and (d) the prototype was calibrated at the Flow Channel.

The calibration of the prototype with the standard propeller type current meter was performed in an 8-meter-long Flow Channel shown in Fig. 4: (a) The Flow Channel is a straight open channel with flowing water. The flowing speed were varied from 0.3 m/s to 0.6 m/s, (b) shows the experimental uncertainty of the standard flow velocity measurements was around ± 0.1 m/s and (c) shows the standard meter used in the calibration process was a commercial and well establish current meter, Nixon Streamflo 430 Flowmeters. The standard meter required its calibration chart to convert the generated frequency to cm/s. Fig. 4: (c) shows the prototype current meter, the same amount of velocities is applied to it and the standard current meter. During the process, the magnitude of velocities is not important. However, the flow velocities supplying by the Flow Channel to both meters were in stability stable. Thus, the value display in test meter is compared with the standard meter and shown in Table 2 and 3. The sensitivity of the prototype is obtained by multiplying the determined ratio of the two output by the known sensitivity of the standard current meter shown in Fig. 5.

RESULTS AND DISCUSSIONS

The cost of the proposed propeller type current meter is summarized in Table 2. It shows an economical cost compared to a well establish current meter. Currently, Nixon Streamflo 430 selling price is around RM 2080.83. If the selling price of Nixon Streamflo 430 meter is three time from its total cost, then the proposed current meter is expected to be 44.95% lower than the commercial current meter.

The accuracy was determined by comparing the standard meter to the velocity measured by the prototype meter. Table 3 shows the analysis details between standard and test meter of Propeller type current meter, when the indicator reading was 44 Hz, the percentage error was 7.5% error. This indicate that the prototype meter cannot measured water velocity less than 0.43 m/s. The percentage errors were reduced and more precise with higher velocity of flowing water. The graph was plotted and shown in Figure 5. The linearity or R2 is about 0.9625 for the standard propeller type meter's values and the test meter, which indicate measured value produced by test meter agrees with the reference water velocity measured by the standard instrument. Relative error of the prototype current meter can be reduced by inserting 1.0094 correction factor at the programming stage shown in Figure 2. If the correction factor was applied, the systematic errors of the tests demonstrated should be less than ±1% of inaccuracy shown in Table 4.

Table 2. Bill of materials

Components	Quantity	Cost (RM)
M8 Inductive Proximity sensor	1	100.50
RTC module	1	4.90
SD card module	1	5.90
Li-Po battery	2	150.00
DC/DC converter	2	6.70
Microcontroller board	1	75.00
Propeller hub, shaft & copper ring	1 each	9.80
Wading rod & wood 2cm × 3cm	1 each	12.90
Printed Circuit Board (PCB)	1	2.00
Resistors	2	0.10
Encloser, casing	1	8.20
Miscellaneous (screw, nut, washer, wires, electricity etc.)		13.50
Total cost		381.30

Table 3. Analysis details between standard and test meter of propeller type current meter

Standard propeller type current meter			**Test meter (the prototype)**			
Indicator Reading (Hz)	Linear Velocity (cm/s)	Standard Value (m/s)	1st Trial (m/s)	2nd Trial (m/s)	Average (m/s)	Error (%)
44	34.0	0.340	0.36	0.37	0.365	7.5
57	42.5	0.425	0.42	0.43	0.425	0.1
66	46.0	0.460	0.46	0.45	0.455	-1.0
70	50.0	0.500	0.48	0.51	0.495	-0.9
75	53.5	0.535	0.54	0.55	0.545	1.9

Table 4. Expected systematic errors if 1.0094 correction factor was applied

Average (m/s)	Average with correction factor (m/s)	Error (%)
0.365	0.362	-0.9
0.425	0.421	-0.9
0.455	0.451	-0.9
0.495	0.491	-0.9
0.545	0.540	-0.9

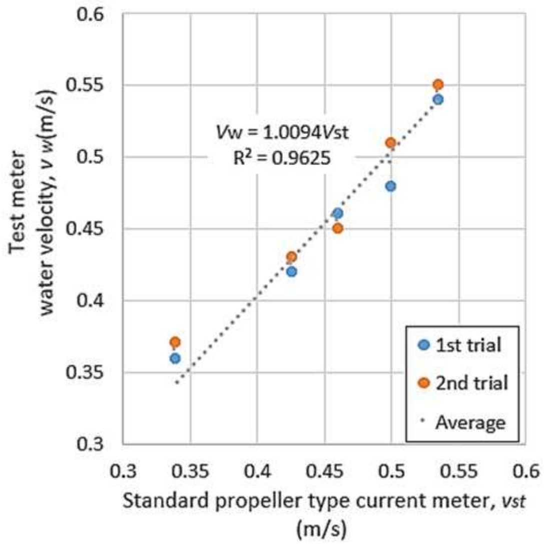

Figure 5. Vw vs Vst Linearity Graph

CONCLUSION

The prototype current meter with electromagnetic measuring technique was a practical solution for flow velocity measurement in open channel. The prototype was calibrated in an 8-meter-long Flow Channel that varied from 0.3 m/s to 0.6 m/s. The propeller type current meter responds instantly and consistently to any changes in water velocity shown in Fig. 5. The desired velocity component was accurately register with average error of 1.0% which was an acceptable error. Additionally, the cost of the meter was 44.95% lower than the commercial current meter i.e. Nixon Streamflo 430. A suggested future improvement is that the propeller type current meter should be operated for a longer period of time to detect the occurrences of any system failure. The meter should also be tested for durability in the body material. The data logger's body must be able to receive a 20 Mpa minimum of tensile strength. It is necessary to identify the robustness of the meter when operating for a long period of time.

REFERENCES

Adeogun, A. G., & Mohammed, A. A. (2012). Review of methods of measuring streamflow using hydraulic structures. In *Hydraulic Structures*, 1-12.

Camnasio, E., & Orsi, E. (2011). Calibration method of current meters. *Journal of Hydraulic Engineering*, *137*(3), 386–392.

Fowles, G., & Boyes, W. (2009). Mechanical measurements. In W. Boyes (Ed.), *Instrumentation reference book*. Butterworth-Heinemann.

Herschy, R. (2011). *Streamflow Measurement* (2nd ed.). Taylor and Francis.

Khozaei, M. H. (2016a). Numerical and experimental study of effects of geometrical parameters on propeller type current meter. (Unpublished master dissertation). University of Tehran. https://doi.org/10.13140/RG.2.1.2043.2402

Khozaei, M. H. (2016b). The influence of the geometrical parameters of propeller-type current- meter on its performance. *Proceedings of 50th The IIER International Conference*, Switzerland. https://doi.org/10.13140/RG.2.1.1528.9363

Last, B. E. (2017). *Adafruit data logger shield*. Adafruit Industries.

Montañés, J. L. (2006). Hydraulic canals: design, construction, regulation and maintenance (J. L. Montañés (ed.)). Taylor & Francis.

Shaw, E. M., Beven, K. J., Chappell, N. A., & Lamb, R. (2010). *Hydrology in practice* (4th ed.). Spon Press.

Staubli, T. (2016). Propeller-type current meters. Discharge and velocity measurement, 95–100.

Takeda, R. (2018). A design method on propeller current meters. *Journal of Fluids Engineering*, *100*, 83–90.

Tumanski, S. (2006). *Principles of Electrical Measurement*. Taylor and Francis Group.