

DESIGN AND CONSTRUCTION OF A LIGHTWEIGHT DIGITAL SURVEYORS WHEEL

A. Alkasim*, T.N. Ibrahim and A.B. Dikko

Department of Physics Modibbo Adama University of Technology, P.M.B. 2076, Yola

*Corresponding Email Address: alkasimabbat@gmail.com

ABSTRACT

The surveyor's wheel is a device used to measure distances. It's made up of a single wheel attached to a handle pushed or pulled along by a person walking with an iron rim to provide strength and a device to read the distance travelled mounted either near the hub of the wheel or at the top of the handle. In this paper, a Digital Surveyors wheel was designed and constructed using a light-weight material (plastic), a 9V Battery as power source, transistors, CMOS ICs and other components. The selection of these components has resulted in the generation of a reliable Pulse Width Modulated wave that is been decoded by a Decade counter into a Seven segment common cathode display. The Wheel will be used in earmarking an area for surveys of number of household, number of refuse dumpsites or number of solar panels within a specified area where tape measurement will be difficult. Test results showing the performance of major components indicates a good level of efficiency, also test results comparing measurements between Measuring Tape and Digital Surveyors wheel shows a high level of accuracy with percentage Errors of less than 2 % for long distance measurements (≥ 5 m), and up to 10% for short distances (< 5 m); caused by design limitations.

Key words: Surveyors wheel, Digital counter, seven segment displays, Construction, design

1 INTRODUCTION

Over time, surveyors, builders, map makers and scientists have created special tools to help them measure distances, height of buildings and other tall structures very accurately. Some of the tools used to achieve such measurement are measuring wheel, theodolite, among others which have their units in yard, meter or half-rod, but for these project work, meter is the unit used. Hence, meter is defined as the distance traveled by light in a vacuum in a time interval of $1/299792458$ second [1]. In principle, the meter can be realized by observing the distance that light travels in an accurately timed period in a vacuum (or strictly in a region of space where gravitational effect are minimized). However, a more effective and non-difficult way of realization is by measuring the absolute frequency of a particular kind of light, relative to Cesium atomic clock and converting this to a wavelength value, hence using equation (1).

$$c = f\lambda \quad \text{or} \quad \lambda = \frac{c}{f} \quad (1)$$

where f is the Frequency, λ is the wavelength and c is the speed of light.

From this relationship, the wavelength of light is then known precisely and forms an extremely high resolution "ruler". Displacements to a few tens of meters can be directly measured in terms of this wavelength by means of laser Interferometry [2].

In the 17th century, the surveyor's wheel was introduced and used to measure distance. A single wheel is attached to a handle and the device can be pushed or pulled along by a person walking. Early devices were made of wood and may have an iron rim to provide strength and the device to read the distance travelled would be mounted either near the hub of the wheel or at the top of the handle [3].

The device is used for measuring distance covered by taking revolution of a rotating wheel, it is rolled over the distance to be measured and readings are taken or displayed via a seven-segment read out. The system consists of four functional blocks as shown in figure 1. Power supply is derived from

a DC source (direct current source) for the reason of portability; the encoder is formed by a sensor incorporated on a rotating wheel. The coded output of this block is sent to the decade or divided by ten counters (there are six of such IC's which are cascaded). The output of these block are displayed via a seven-segment display.

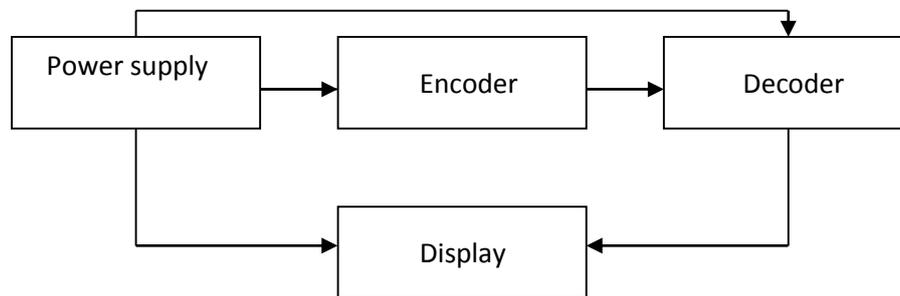


Figure 1. Block diagram of the surveyor's wheel: a distance measuring device

2 OPTICAL ROTARY ENCODERS

An optical rotary encoder is a device that produces angular position data directly in digital form, eliminating any need for the ADC converter [4]. A light source and photocell arrangement are mounted so that the slots pass the light beam as the disk rotates. The angle of the shaft is deduced from the output of the photocell. There are two types of optical rotary encoders: the absolute encoder and the incremental encoder [5]. The concept used in this work is, incremental optical encoder using one sensor and the direction of the disk is achieved using a mechanical approach so that it will rotate in one direction.

3 DESIGN OF THE SYSTEM

3.1 Power Supply Unit

Electronic circuit generally required direct current (DC) to power components. However, dc voltage can be obtained from batteries or by alternating current (AC) voltage rectification. For the purpose of this project a Battery source was used to provide DC voltage for the reason of mobility. A 9-volt layer- type of Le'clanche cell was chosen, because it is within the range of operation of 4026b IC and can be regulated to power both photo-transistor and infra-red diode [6].

3.2 The Encoding Unit

This forms the backbone of the work, and it is based on optical rotary encoder which produces a series of pulses that represent positions on the rotating disk [5]. The concept is illustrated in Figure 4, which shows a slotted disk attached to a shaft. A light source (IR diode) and photocell (phototransistor) arrangement are mounted so that the slots pass the light beam as the disk rotates, the entire arrangement is referred to as an optical rotary encoder [7]. The circuit of the Infra-red diode and phototransistor is shown in Figure 2,

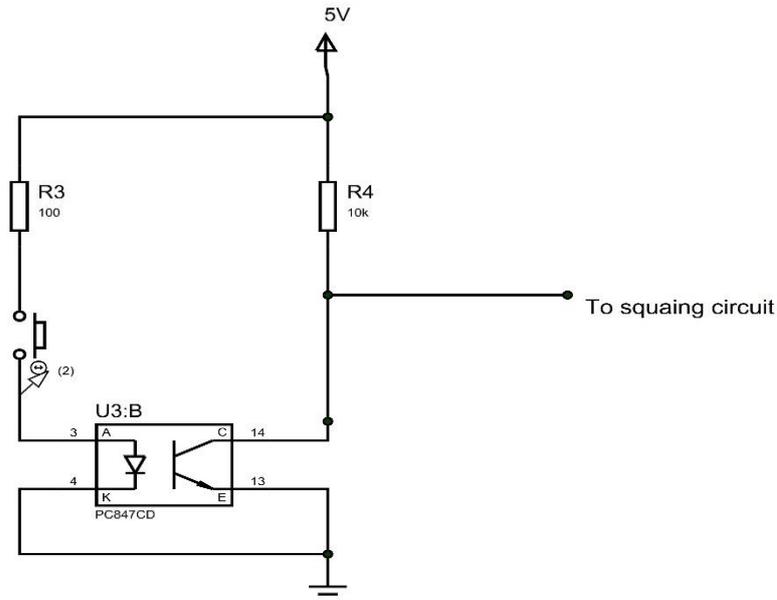


Figure 2. Opto coupler (IR diode, Phototransistor and resistors)

The Wheel (disk)

The wheel is designed to measure a distance of 1metre/revolution as adopted by [8], in other to achieve this the wheel was graduated with 10 slots to give a reading of 10 cm/slot. The circumference of a circle, S of radius, R is given by

$$S = 2\pi R \tag{2}$$

A choice of 100 cm circumference was made since it is equivalent to 1m. Hence the radius of the wheel is $\frac{100}{2\pi} = 15.915 \text{ cm} \approx 16 \text{ cm}$

On the wheel, it is required that 10 slots are made available which is equivalent to 10 cm each. Since the angle of a circle at a point equals 360 degrees. That is, $\theta = 360^\circ$ and X = 10 (numbers of slots)

Therefore, the angle between the slots, Y is given as

$$Y = Y = \frac{\theta}{X} = \frac{360}{10} = 36^\circ \tag{3}$$

Infra-red diode

The infra-red diode or light source was used to supply light to the coded disk. Infra-red of OPE5585 value was chosen and as presented in Table 1

Table 1. The chosen values for the infra-red diode used

S/N	Component	Specification
1	Continuous DC forward current, I_F	100mA
2	Frequency spectrum, F	100THz to 400THz
3	Power dissipation	200 mW
4	View color	invisible
5	Forward voltage drop, V_F	2 mV

Hence from fig.1, the equation is given by

$$V_{CC} - I_F R - V_F = 0 \tag{4}$$

Therefore, the limiting resistor R can be calculated as

$$R = \frac{V_{CC} - V_F}{I_F} \tag{5}$$

$$= \frac{5-2}{100} \times 1000 = 30 \Omega$$

But a 100 Ω resistor was used for complete protection of the infra-red diode

Photo-transistor (photocell)

This is a light sensitive transistor and is similar to an ordinary bipolar junction transistor (BJT) except that it has no connection to the base. Its operation is based on the photodiode that exists at the common base (CB) junction instead of the base current, the input to the transistor is provided in the form of light. A collector resistor (resistance) of 1k Ω was used at the collector and no base resistance. The photo-transistor switches 'NO' when light falls on its base surface, giving rise to a collector current. At this stage it is said to be a low level '0', while in the dark light region, it is said to be a high level '1' [9, 10]. Hence, this alteration of level only sent high to the IC which tends to count as well as decodes the data counted via a 7-segment display

3.3 Decoding /Display Unit

This is the section where all the necessary logic takes place. The unit consists of CMOS 4026b IC, seven segment display and resistors.

Complementary Metal Oxide Semiconductor, CMOS 4026b IC

It is a Decade counter/Divider which consist of a 5-stage Johnson decade counter and an output decoder which converts the Johnson code to a 7 segment decoded output for driving one stage in a numerical display. These devices a particularly advantageous in display applications where low power dissipation and/or low package count are important. It has inputs on CLOCK, RESET, CLOCK INHIBIT, CARRYOUT and seven segment decoded outputs (a,b,c,d,e,f,g) and additional inputs available are DISPLAY ENABLE INPUT, DISPLAY ENABLE and UNGATED "C" SEGMENT [11, 12].

Seven segment display

A common cathode (Red) 7-segment display is used, this display has high efficiency. The parameters for common cathode 7-segment display are: Static forward voltage $V_F = 2.8 \text{ V}$ and Static reverse current $I_R = 30 \text{ mA}$. The disply section is further divided into two parts, the centimeter measurement and the meter measurement sections.

The Centimeter section

In the design of this section (as well as that of meter section) a careful consideration was made on the type of logic component to be used for proper operation. Hence complementary metal oxide semiconductor (CMOS) family was chosen base on the following consideration;

- Operating voltage: It is between the ranges of 3 V to 18 V.
- Logic level: this varies between input and output for CMOS; it can be assumed that the value for logic zero is close to ground and the logic one is close to supply voltage. Thus
Logic high = V_{CC}
Logic low = 0 V
- Propagation delay: this dependent on supply voltage, with faster response for higher values of supply voltage.
- Power dissipation: the power consumption depends mainly on the rate at which it changes state. At low frequency the power dissipation is very low.
- Cost / availability: they are relatively affordable and readily available.

This synchronous decade or divider by ten counter (4026b) does the counting of sequence of pulses that comes from the output of the photo-transistor via the clock pin (pin 1) of the 4026b IC. The outputs a-g goes high to light the appropriate segments of a common- cathode 7-segment display as the clock advances. Figure 3 shows the design of the centimeter section in which a 4026b IC's is cascaded.

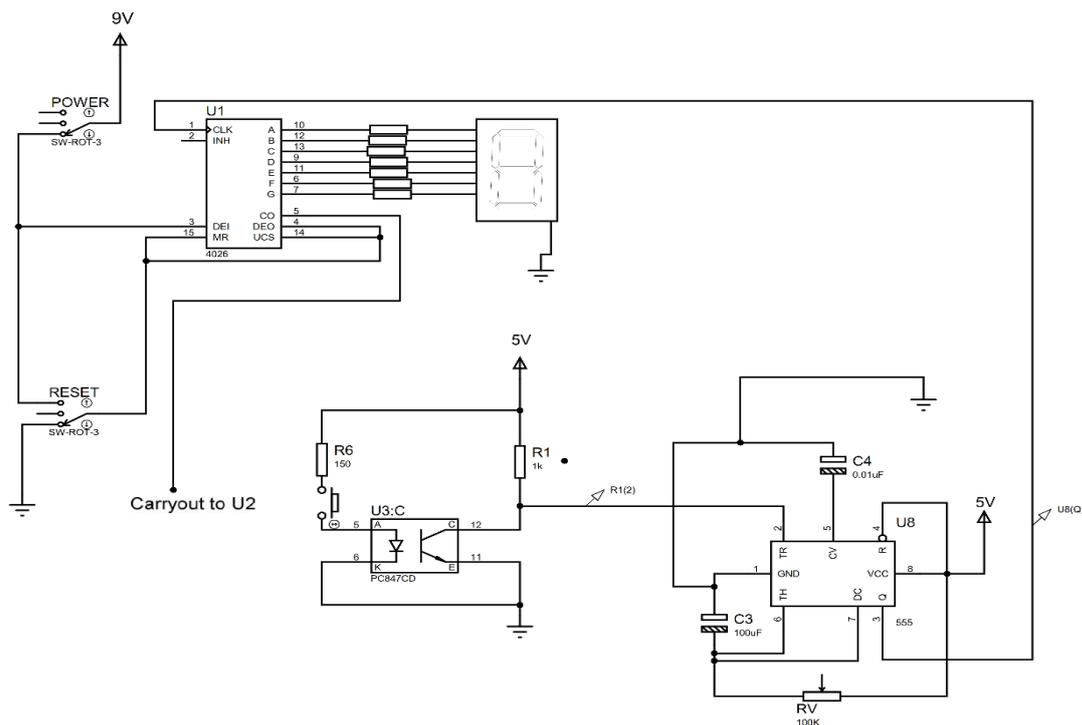


Figure 3. Centimeter Section Design

The limiting resistor R can be obtained using equation (5). Therefore, using the Parameters for 4026b IC thus:

At 4.5 V supply, the maximum output current is 1mA

At 9.0 V supply, the maximum output current is 4mA

The parameter for common cathode 7-segment display;

Static forward voltage V_F is 3.8 V

Static reverse current I_R is 30 mA

Therefore, $R = 126.66 \Omega$

A 330 Ω resistor was used for complete protection of the seven-segment display, by connecting the resistors between the outputs of 4026b IC and inputs to 7-segment display. Note that the first IC (list significant bit) counts the pulse from 1 to 9, the counts number 10, is carried out to the next IC. This continues till 90 cm before moving to the meter section.

Squaring circuit using mono stable multi vibrator (555timer)

Mono stable Multi vibrator is also known as One Short Multi vibrator [13, 14]. As its name indicates it has one stable state and it switches to unstable state for a predetermined time period T when it is triggered. The time period T is determined by the RC time constant in the circuit.

In this circuit, the 555 Timer is wired in Mono-stable mode. The 8th pin and 1st pin of the 555 timer are used to give power V_{CC} and Ground respectively. 4th pin is the Reset pin of 555 Timer, which is active low so it is connected to V_{CC} to avoid accidental resets. 5th pin is the Control Voltage pin used to provide external reference voltage to internal comparators. Since it is not used here, it is grounded via a capacitor C' (0.01 μ F) to avoid high frequency noises. When a negative trigger is applied on the Trigger input of 555, output goes high and capacitor C3 starts charging through resistor RV1. When the capacitor voltage becomes greater than 2/3 V_{CC} , output goes low and capacitor starts discharging through the Discharge pin of 555 Timer. The Time period of the unstable state is given the by expression [6, 14].

$$T = 1.1RC \tag{6}$$

Instead of putting fixed values for R and C, to obtain a constant T, we decided to make the value of the capacitor constant 100 uF and install a variable resistor of value 100 kΩ so as to obtain a range of time, T between 0.11s and 11s.

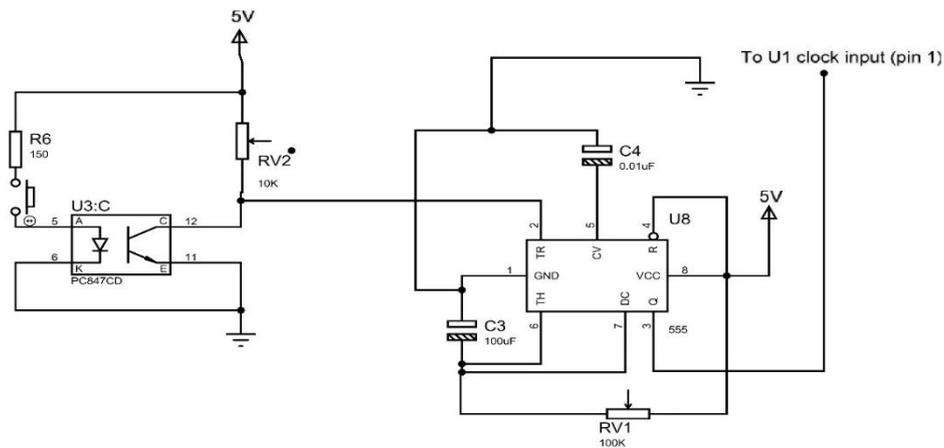
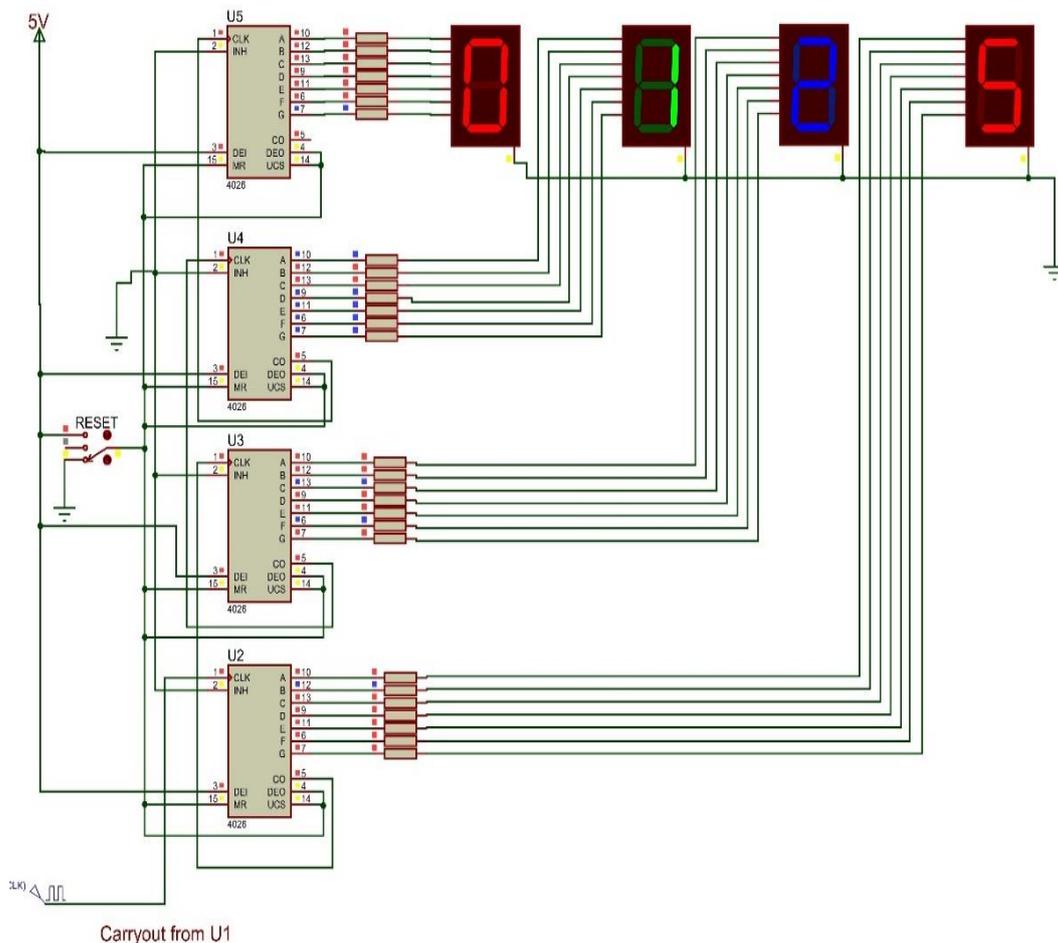


Figure 4. Squaring circuit using a mono-stable multi-vibrator

The Meter section

It is made up of 4 numbers of 4026b IC which are cascaded. Each IC drives a 7-segment display. The same calculation is employed as that in the centimeter section. Figure 5 shows the complete circuit unit comprising the centimeter section and the meter section.



Caryout from U1

Figure 5. The complete circuit including the Meter and Centimeter sections

3.4 Operation of the Complete Unit

Pulses been generated from the wheel in conjunction with photo-transistor, infra-red diode is sent to trigger pin of the 555 timer which read a logic high at the output pin (Q pin) the Mono stable multi vibrator circuit generates a Pulse Width Modulated wave, sent to the centimeter section via pin 1, for normal operation the clock enable (pin 1). Reset pin (pin 15) is taken low, while the display pin (pin 3) is taken high [6, 12]. On the positive edge of the clock pulse, the counter can be incremented by one count if the clock input is taken high. The CO (pin 5) carries the count to the next IC when the count on the previous IC exceeds 9 and so the procedure is repeated for the meter section until the device reads to its limit of 9999.9 meters where the last carryout on the last Decade counter is grounded. The outputs from above is sent to a digital readout that displays the number, decimal counts based on the revolution of the disk made by the decade counter. The 7-segment lettered a to g comes 'NO' based on the BCD state output.

3.5 Coupling/Assembling

It involves inserting, connecting or joining the various components on a Vero board in accordance with the design specification skillfully. The Vero board consist of two faces, a free face and a face with copper coatings in form of parallels lines or dots. It contains many perforated holes that facilitate the insertion of component. The photograph of the coupled work is presented in Figure 6.



Figure 6. The constructed Digital Surveyors wheel

3.5.1 Test

The performance of all the components, based on their theoretical formula were tested. The major tests were done on (i) Simulation (Proteus Simulation) (ii) software used (iii) Bread board (iv) Vero board and (v) Digital multi –meters. This is as desired in [15].

3.5.2 Conformance Analysis

This was carried out by splitting the circuit in to three sections, which are; centimeter, meter, and both joint together. Each IC counts from 0 to 9 before sending a pulse to the next IC which shows that the design is accurate since each section counts appropriately and hence the circuit was realized.

3.5.3 Voltage Tests for both Bread Board and Vero Board

The Bread Board and the Vero Board testing are presented in the Table 2. The test was conducted by measuring the output of 4026 IC and the input to the seven segments, the pulse magnitude in volts (that is output of the photo transistor which sent the pulse signal to the trigger pin of the Mono-stable Multi-vibrator). From the Table, it is observed that there are variations in the values obtained which may be as a result of soldering method or improper continuity.

4 RESULTS AND DISCUSSION

Table 2 shows the test result of the output voltages the input voltages to the 7-segment and the pulse magnitude on both the Bread board, and Vero board.

Table 2. Variation in voltages for both bread board, Vero board and the pulse magnitude (voltage) test for both boards

Bread Board			Vero Board		
Output of 4024 IC	Input to 7-segment	Pulse Magnitude	Output of 4026 IC	Input to 7-segment	Pulse Magnitude
2.7V	1.58V	3.07V	2.5V	1.56V	2.97V

A comparison of measured values obtained for a length of distance measured with the coupled device as against a tape rule measurement as well as the Percentage error of the device based on the tape measurement as given by equation (7) was computed and presented as in Table 3

$$\% \text{ Error} = \frac{\text{tape measured value} - \text{Digital wheel measured value}}{\text{tape measured value}} \times 100 \quad (7)$$

Table 3. Comparison of measured distance between the measuring tape and the Digital wheel

S/N	Tape measurement (m)	Digital wheel measurement (m)	Error (%)
1	0.50	0.40	20.0
2	1.00	0.90	10.0
3	2.00	1.90	5.00
4	5.00	4.90	2.00
5	10.00	9.90	1.00
6	15.00	14.90	0.67
7	20.00	19.90	0.50
8	25.00	24.90	0.40
9	30.00	29.90	0.30

The reduction of the percentage error with long distances of about 100 m was as presented in Figure 7.

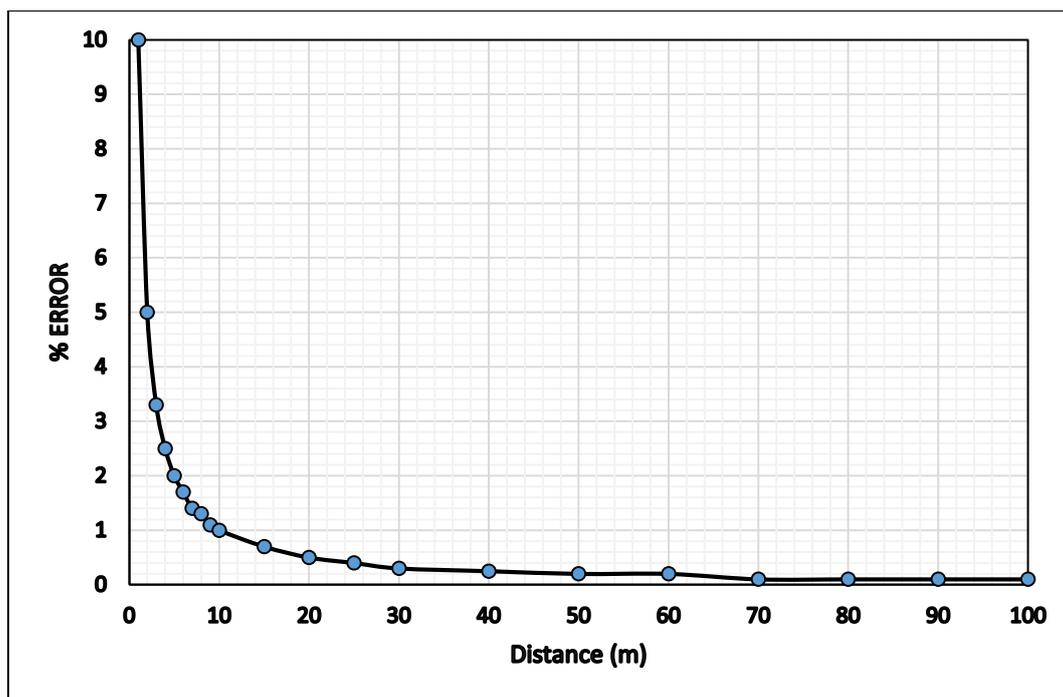


Figure 7. Graphical representation of Error over distance measured

The result indicates that the instrument can be used to Estimates, Evaluates and Mapped, areas with an error of 10% at small distances to 0.1% at longer distances as seen from Fig 7. Therefore, the error reduces with increase in length. So for more accuracy of measurement using the device, it is tagged ± 10 cm. The level of accuracy the device has is large enough for large distance measurement (>100 m). Also, the need to consider cost implication in any system design cannot be overruled. The commercial success of a system would depend on its availability to the consumers in terms of cost, maintainability and reliability, for this reason necessary attention was paid on the type of component used, cost and reliability. Furthermore, the test performed shows or rather agrees with the theoretical calculations and design. The device could be used in determining the number of refused dumpsite, house hold or Solar panels within a specified area.

5 CONCLUSION

A final coupling of the individual stages (Power, Encoding and decoding/Display unit) resulting in realizing the Digital Surveyors wheel, able to measure distance from one meter to Hundreds of meters was achieved with an accuracy of up to 99% accuracy. Based on the results obtained from different tests performed, there is a good conformity with the expected output. The various units worked satisfactorily and the whole unit has performance accuracy of not less than 90%. The accuracy decreases with time duration, that is the power consumed is a function of time. However, the decrement of accuracy with time could be overcome by using a Two 9 V battery sources, one for encoding unit and the other for the rest of the circuit. Also, a microprocessor may be included to facilitate better operation and reduced volume or weight.

REFERENCES

1. Yerima, J.B., Alkasim, A., Pascal, T and Zakari, S.B. (2008). A method of measuring Acceleration due to Gravity Using RC Circuit, *Technology and Development (A Journal of Scientific and Technological Research)*, vol. 10, pp. 41 - 46.
2. Baba, M.T and Haruna I.U. (2018) *Basic Applied Mechanics: Dynamics with Comprehensive Work Examples*, Paraclete publishers (Educational services) Yola-Nigeria.
3. Gerard L'E. Turner, (1983). *Nineteenth Century Scientific Instruments*, Sotheby Publications, ISBN 0-85667-170-3.
4. Kilian (2004); *Modern Control Technology: Components and System* 2nd Ed, Denman.

5. Eitel, E. (2014), *Basics of Rotary Encoders: Overview and New Technologies*, Machine Design Magazine, Accessed: 30 June 2014.
6. Forrest M. M. (1984). *Getting Started in Electronics*, Printed in the United States.
7. James H.H. and Paul Y. L. (1982). *Essentials of Electric Circuits*. Reston Publishing Company, 1982 ISBN 0-8359-1767-3, pp. 96–97.
8. Usman A. B. (2005). *Distance Measuring Device*, An Undergraduate B.Tech Project submitted to the Department of Elect/Elect Faculty of Engineering, Abubakar Tafawa Balewa University, unpublished.
9. Thomas E. K. (2000). *Industrial Electronics 2nd Edition*, Prentice Hall, USA.
10. Willy M. C. (2006). *Analog Design Essentials*, 1st Edition, New York; Berlin: Springer.
11. Boylestad, E.A. (1996). *Electronic Devices and Circuit Theory*, Prentice Hall, London.
12. Thomas L. F. (1997). *Digital Fundamentals*, 2nd Edition, Hall International, USA.
13. Green D. C. (1982). *Digital Electronics Technology*. Pitman Publishing Ltd. New Zealand.
14. Dyer, S. A. (2004). *Wiley Survey of Instrumentation and Measurement*. John Wiley & Sons. ISBN 9780471221654. Retrieved 2013-03-17.
15. McMillan, G. K. Considine, D.M. (1999). (ed.) *Process Instruments and Controls Handbook 5th Edition*. McGraw Hill, ISBN 978-0-07-012582-7.