Development of Noncontact Displacement Sensor at IRICEN

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Synopsis

Non contact type sensors do not interfere with the normal operation of the train movement. Displacement measurement of bridge bearing with respect to temperature is long pending item, so it necessary to have one. The current practice of measurement is intermittent manual recording which is too less data and also inaccurate. The ultrasonic sensor developed at IRICEN can also record temperature. It is being developed to record continuously for several months. It can also be used to capture track displacement due to train movement. In this paper aspects related to Electronics behind the sensor, its validation and some sample recordings are shown.

1. Introduction

Many sensors are available in the market along with the data acquisition system. Most are very costly and are of contact type. At IRICEN many students are coming for summer/ industrial training. To utilize the technical recourse in meaningful way and also to develop their technical skill this year IRICEN put them on a project to develop a noncontact type sensor which can measure displacement. This sensor is cost effective and indigenously built.

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This sensor is based on ultrasonic waves and corrected for temperature and humidity. Range and accuracy of this sensor are approximately 3 m and is 0.035 mm/mm respectively.

2. Working Principle of Sensor

This sensor is based on generating, transmitting and receiving ultrasonic waves similar to a 'Bat' able to locate the object in pitch dark night while flying. The schematic diagram is shown in Fig. 1. Accordingly, this sensor is provided with an ultrasonic transmitter and ultrasonic receiver. Operation of transmitter and receiver is controlled by micro controller unit. This sensor is also provided with a programmable chip upon which set of instructions can be written and executed.

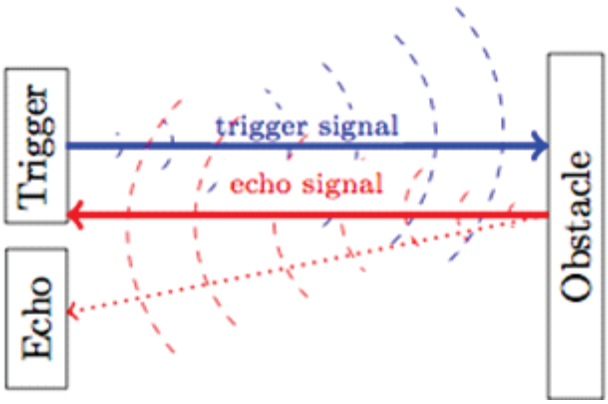


Fig. 1: Schematic principle

When the supply to the circuit is switched ON, the on board modules (Temperature, Humidity, RTC, Ultrasonic sensor) will be initialised. The code loaded on microcontroller unit will direct the ultrasonic sensor to dispatch 10 micro second pulse and raise the voltage of TRIG to High Voltage. The transmitter will then send 8 bursts of 40KHz frequency of ultrasonic waves and simultaneously the Echo Pin will be turned HIGH. When the bursts wave will encounter an obstruction or object on its path it will be reflected back to the receiver. As soon as the receiver captures this wave the Echo Pin will be turned LOW. The time taken by the Echo Pin to go LOW from HIGH is calculated. Half of this time is the actual time taken by the wave to travel from transmitter to the object. The above

operation is shown in Fig. 2.Simultaneously the Temperature, Humidity and the Time is also noted.

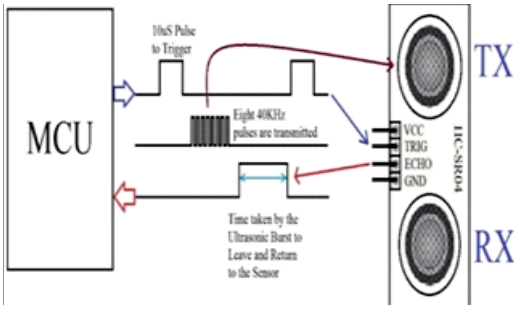


Fig. 2: Timing diagram of Hc-sr04 working with controller

Time elapsed between the trigger event and echo event is total time taken by the ultrasonic waves to travel from source to object and back to source. Therefore, the total time required by ultrasonic waves to reach to source to object is half of this time, say t. Therefore, the distance between source and object is the product of velocity of ultrasonic wave and time Δt The velocity of ultra-sonic wave in air is depends upon the ambient temperature (T°C) and the relative humidity (H). Therefore, two more sensors (i) DHT 11 - to measure ambient temperature (T°C) and (ii)DS18B20 - to measure relative humidity(H) are also provided on board. The corrected speed of ultra-sonic wave is given as follows;

$$V = V_0 + 0.606 \times T + 0.0124 \times H$$

Where, V_0=331.39m/s, speed of ultra-sonic wave in dry air at 0°C

Depending, the range of distance measured, the sensor is preprogrammed to maintain uniform time delay between successive bursts of ultra-sonic wave. For 50 cm range (suitable for bridge bearing)the sampling frequency will be 660 Hz; and for 20 cm range (suitable for track deflection) the sampling frequency will be 850 Hz.This step is necessary to prevent the trigger signal to affect the eco signal and the high voltage of echo to reduce to low voltage. In other words there will not be any overlap of transmitter will send signal after the reflected waves plus some delay, so that there is no overlap between transmitted and received signal.

Salient features of prototype Sensor

The present module is based on Arduino environment. Arduino is an open source electronics platform based on easy to use hardware and software. It consists of both physical and programmable circuit board and a piece of software. Integrated Development Environment (IDE) is used to write and upload computer code to the physical board. Salient features of this sensor are given in Table 1.

Table 1: Salient features of sensor

Sl. No.	Component	Description
1	HC-SR04	Ultrasonic sensor for measuring displacement from initial measured position.
2	RTC	Real Time Clock for keeping track of successive date, day and time of each reading.
3	DHT 11	On board temperature sensor.
4	DS18B20	On board humidity sensor.
5	SD card	16 GB SD card for high storing capacity.
6	Casing	Rigid casing for safety and long life.

Fig 3 corresponds to microcontroller used which is a single integrated circuit containing a processor core, memory, and programmable input/output peripherals. Further, table 2 highlights the specifications of HC-sr04 ultrasonic sensor

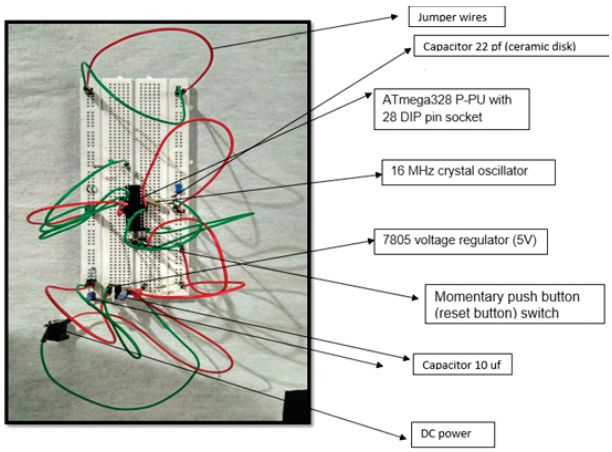


Fig. 3: Microcontroller AT-MEGA328P

Table 2: Specification of HC-SR04 sensor

Sl. No.	Properties	Values
1	FOV (full cone)	Horizontal ~21° Vertical ~4°
2	Spatial resolution (full cone)	0.6-1.4°
3	Range	2 to 300 cm
4	Accuracy	absolute error ~ 0.035 cm/cm
5	Precision (for 200 cm range)	standard deviation ~ 0.1-0.5 cm

Ref: https://app.box.com/s/sj7du1n32in2777rcoi2

Micro controller is instructed by boot loader to perform a specific task. Boot manger (loader) is a device where set of instructions are uploaded. It is then synced with micro controller so as to transmit and inform the micro controller regarding the set of instructions to be simulated. The circuit of boot manager is shown in Fig. 4.

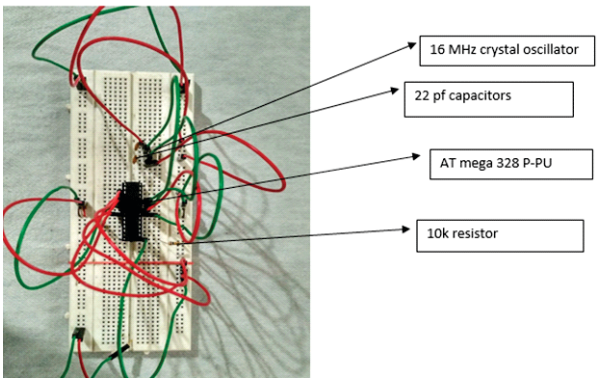


Fig. 4: Circuit of boot loader

Advantages and limitations of prototype sensor

Advantages

i. This sensor is indigenous and cost effective.

ii. This sensor is accurate, compact and easy to use.

iii. This sensor measures displacement of the object, ambient temperature and humidity.

iv. The speed of sound is corrected on real time basis w.r.t. ambient temperature and humidity.
v. This sensor records the Real Time Clock (RTC) for each successive displacement.
vi. Memory is enough for six months.

Limitations

i. The range of the device is 3m.
ii. Fixed frequency (40 KHz) of ultrasonic sound wave.
iii. Least count is 0.1 mm.
iv. Requirement of power supply is the main constraint, the power supply is provided with available battery which may last for seven days.

Calibration of Sensor

Static Calibration-This sensor was first calibrated for static object placed at different distance and calibration chart between actual distance and observed distance is plotted to estimate the error. It was observed that the initial error is mainly due to the projection of transmitter and receiver units. The static calibration graph, between the observed distances and the actual distance, is shown in Fig. 5.

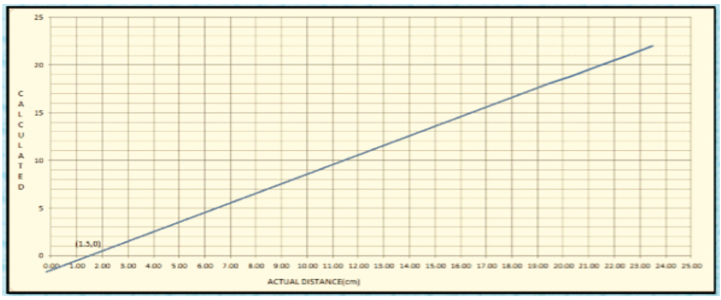


Fig. 5: Static calibration graph

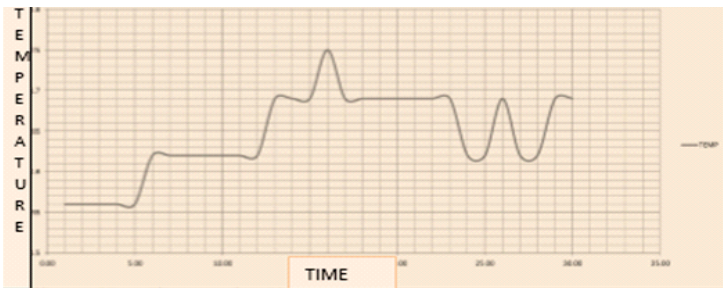


Fig. 6: Graph showing temperature variation with time

Variations in laboratory temperature (in mille degree) with time is shown in Fig. 6.

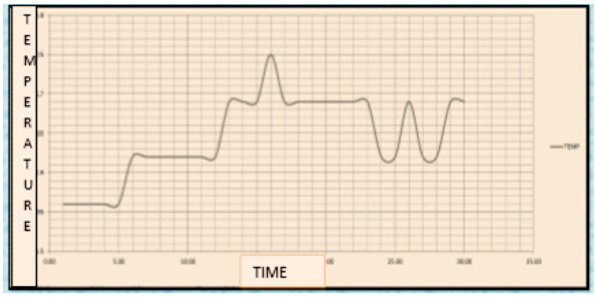
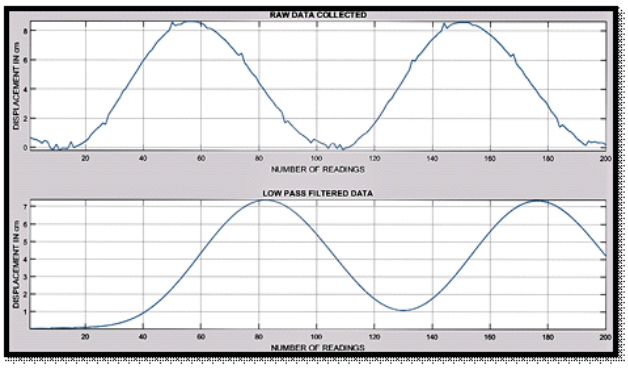


Fig. 6: Graph showing temperature variation with time

Dynamic Calibration - To calibrate for dynamic displacement, the sensor was placed to measure the movement of milling machine. The milling machine was programmed to move backward and forward so as to oscillate with the fixed frequency and known amplitude. The captured data is plotted and the amplitude and



frequency was verified. The raw and filtered plot for amplitude is shown in Fig. 7 (a) and (b). From the plot it can be seen that the measured amplitude of raw and filtered data are slightly different. The filtered amplitude matches with the actual amplitude.

Fig. 7 (a) and (b): Raw and filtered response

The FFT of raw and filtered data is shown in Fig. 8. From the plot one can see that the frequency correspond to largest response is 1 Hz for filtered data while in the raw plot frequency due actual movement (1 Hz) and also due to noise (3Hz) are available.

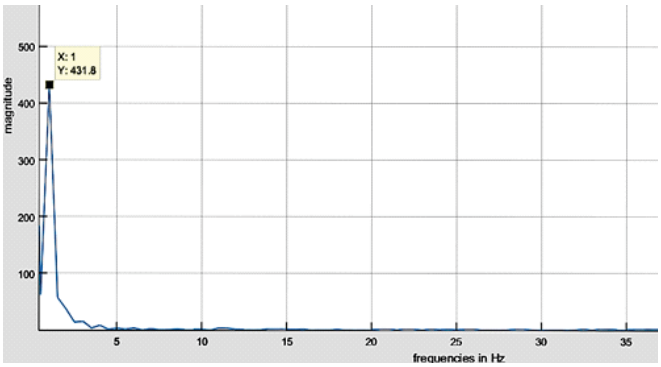


Fig. 8: FFT plot of filtered data

Application of Sensor

Measurement of bearing movement- This sensor is yet to be placed on a bridge to record the movement of bearing. However, for the demonstration purpose a model of roller and rocker bearing used to show the usability of this sensor. Which is shown in Fig. 9.

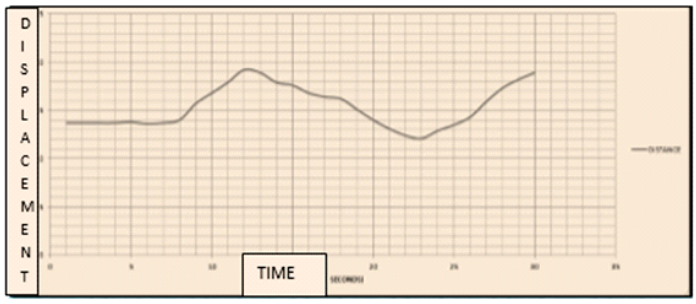


Fig. 9: Manual displacement (cm) of Rocker Roller bearing with respect to time (sec.)in laboratory

Measurement of track deflection due to moving train-The second application of this sensor could be measurement of vertical deflection of Railway track due to passage of traffic and if the weight of rolling stock is known. The track modular can be easily worked out under static as well as dynamic conditions. Fig. 10 shows placing of sensor in track.

Fig. 10: Sensor protected by black wooden box is placed in track

A box enclosing the sensor can be seen in above picture, it is provided to protect the sensor from falling of ballast and blocking path of ultrasonic waves. Above setup is made to record the displacement of the track due to moving passenger train. Fig. 11

(a) and (b) shows plots of the raw data and filtered displacement of track recorded during passage of a passenger train.

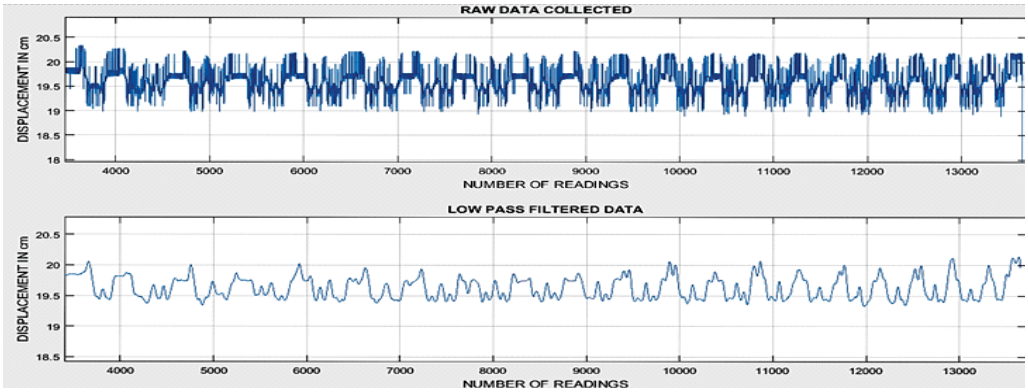


Fig. 11 (a) and (b): Displacement of track under passenger train passage

Cost of Development of Sensor

The approximate cost of development of sensor excluding power source and memory card is approximately 4,500/- which can be further reduced upon mass production and further R&D on indigenous circuit development.

Conclusion

The sensor developed at IRICEN performs well and precision is also good. It is matter of appreciation that student of engineering are able to demonstrate their technical capability through development of such cost effective sensor which can be of great use in Railway. It can also be noted that IRICEN may also contribute in the R&D if the environment is conducive.

Acknowledgements

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