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Development of an Intelligent Sensor Based Inspection Robot for Closed Environment

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***Abstract*— The Inspection of the closed environment may be relevant for improving security and efficiency in industrial plants, These specific operation as inspection, maintenance, cleaning etc. are expensive, thus the application of the robots appears to be one of the most attractive solutions.**

Recently, in industry duct and ventilation becomes old and many inspection robots were developed in the past. Wired robots put to practical use, but they required heavy power supply. Therefore, a new inspection robot using a wireless communication system is considered useful for inspection of complex and long distance closed environment. A lot of trouble caused by air duct and ventilation like crack, leak and mechanical damage.

This Paper describes the development and implementation of inspection robot mounted with an intelligent sensor. In a closed environment, human cannot enter for inspection. So, the main goal was to develop a small inspection robot which can autonomously navigation inside closed environment and measure defect like cracks, leak, mechanical damage and places of the defects inside closed environment. It provides useful information through wireless Zigbee for maintenance. At user end another Zigbee has been received these information and use this information for displayed on GUI.

Keywords*— *Crack Detection, Intelligent Sensor, LabVIEW

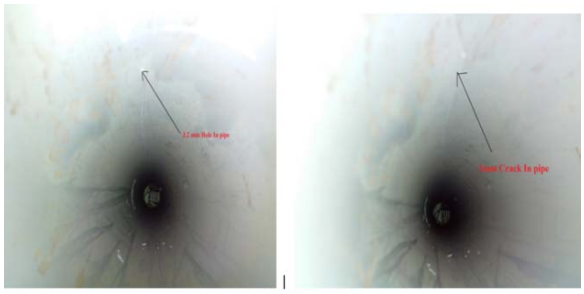
I. INTRODUCTION

Air duct, ventilation and cooling system is a closed environment and play very important role in an industry. A lot of problems occur inside the close environment due to the Earth's population grows and the global climate is changing so, after few years damage and defects are occurring inside closed environment. If the defect is caused by rust and calamity, it is difficult to find out the defect and the place of the defects, Therefore scheduled inspection must be done. If someone decides to do this inspection manually, then a large amount of time, effort and labor are well trained to inspection the small environment. There is some closed environment where human cannot enter for inspection, which is shown in Figure 1.

Figure 1 Inspection in Closed Environment by Human

II. INSPECTION OF CLOSED ENVIRONMENT

(a) Closed Environment Inside the Air Duct



(b) Close Environment of Ventilation

Figure 2 The Problem that can Occurs Inside Closed Environment

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Figure 2(a) shows closed environment, the height is around 30cm to 35 cm. These closed environment have various type of the joint like T, Y. while Figure 2(b) shows a problem that may occur inside of the closed environment that require the intervention of mobile robot.

III. Development of Robot System

A. Necessary Function

Maneuverability: The robot must go inside the closed environment and also pass through the various joints.

***Hazardousness**:* The robot must work under dusty conditions, with obstacles and possible leakage.

Compactness: The size of the robot must be smaller than the size of the inspection environment.

Location and crack width measurement: The system can provide accurate width of crack and also measure the location and position of the crack inside the environment.

Easy operability: The user of this system may not be an engineer. It is necessary that a field inspector can operate the system easily.

B. System Design

To meet with the condition mentioned above, we designed the system as follow. The design of the inspection robot is shown in Figure 3.

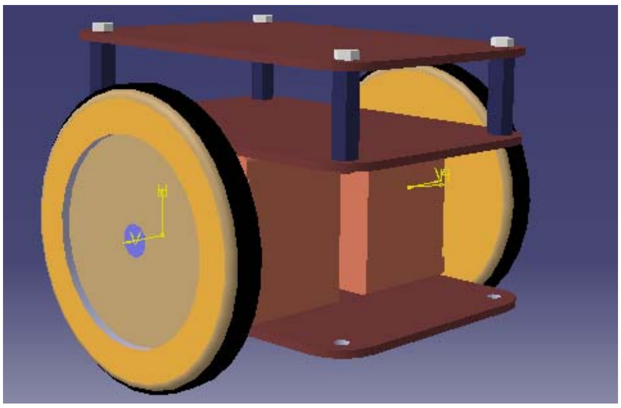


Figure 3 Design of the inspection robot

The robot is fully autonomous inside the closed environment. The mobile platform's design is based on the robot developed for the rescue purpose [1]. It has two main wheel(left and right) and two caster wheel are used to move on dirty and closed environment.

A Six Pair of IR Sensor is mounted on the robot for obstacle and path finding inside the environment. The Ultrasonic sensor are also mounted on the robot for crack width measurement while ArduIMU sensor are used to locate the current position and location of the robot inside the environment. The wireless camera are used for the vision and current look inside the environment.

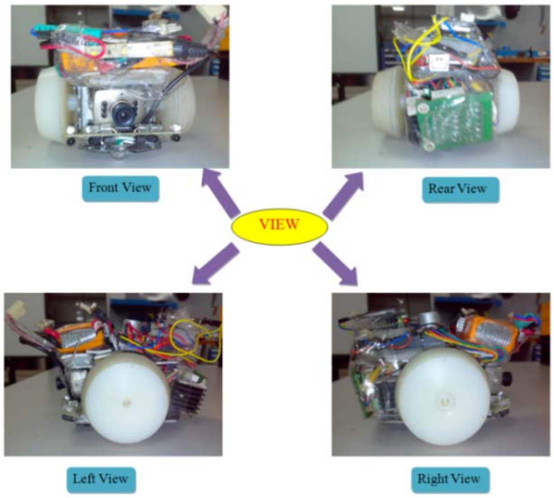


Figure 4 Integrated Inspection Robot

The size of the robot is 110mm (Length) X 110mm (Width) X 90 mm (Height). The weight of the robot is 1.1 Kg. The maximum speed is 13cm/s. One Li-Po Battery (11.1V, 1300 mAh) are mounted in the body of the robot. This is enough for 37min. working time. The integrated robot is shown in Figure 4.

The robot has a small size on board controller. The measured data like width of the crack and current location of robot are transmitted to user end.

C Sensors

1) IR Sensor

IR Sensor which is shown in Figure 5, is mounted on robot because it offer the faster response time compare to Ultrasonic sensor[2-3]. IR sensor measures the distance between the obstacle and robot, based on the sensor data robot is travelled inside environment. Range of IR sensor is 1cm to 12 cm.

Figure 5 IR Sensor used for Obstacle avoidance

2) Ultrasonic Sensor

Ultrasonic Non Destructive Techniques is widely used for crack detection[4-7]. In an ultrasonic Non Destructive method short pulse of ultrasound is transmitted and measure the reflected back wave, based on reflected back wave sensor detect the width of the crack. An Ultrasonic Sensor is mounted on top of the robot as shown in Figure 6. It measure the crack width inside the closed environment based on the pulse duration.

Figure 6 Ultrasonic Sensor for Crack width Measurement

3) ArduIMU

ArduIMU has two IC and Controller. MPU6000 consists of a 3-axis Gyroscope and a 3-axis Accelerometer in it. Inertial Measurement Unit is an electronic device which measure vehicle state like attitude, orientation, velocity and position[8-10]. Main Purpose of ArduIMU sensor is to measure the accurate heading angle among the rotation axis based on that angle current location of the robot has been measured. For Measuring the heading angle ArduIMU sensor is mounted on top of the robot which is shown in Figure 7.

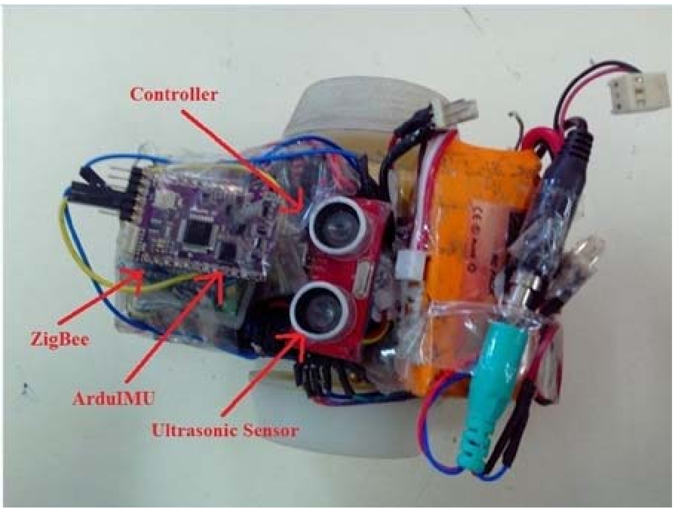


Figure 7 ArduIMU sensor for Measuring the heading angle

4) GUI for Inspection

The Graphics User Interface is designed so that a beginner operator can use it intuitively. Figure 8 shows the GUI of the system which display the measured date by robot and wirelessly transmitted to host PC. Measured data by the inspection robot are display on the GUI. The Measured crack, distance of crack from starting point and X and Y location the crack and robot are display on the respectively in an array.

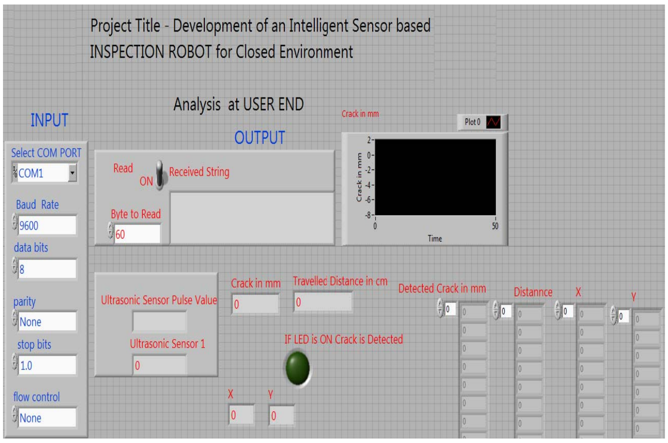


Figure 8 GUI for Inspection System

IV. Methodology and Algorithms

The operation of the whole system can be represented using the flow chart. Figure 9 shows an overall flow diagram of the system. When power supply is applied to robot first few second all sensors are initialized and set threshold as per environment. Sequentially different function IR Sensor, Ultrasonic Sensor, Locomotion for robot movement, crack measurement and position measurement respectively. All Measured data are transmitted to user end through Zigbee. At the user end another Zigbee module received these transmitted data and separate collected data into a different sensor function. Separated data like crack depth, distance traveled by the robot and current position of the robot display in the GUI for visualization.

On a block of IR Sensor, Microcontroller takes the data from IR sensor and based on this data, microcontroller decides which way to move. In sub block of the IR sensor check and compare values of threshold values, if all sensor data are less than threshold value then robot going in a forward direction. In these works always left turn algorithm is used, means when it has two choices for turning then first it will take left turn.

The Ultrasonic NDT method is used to detect the crack inside a closed environment. In NDT method transmit sound waves whose frequency range is 0.2MHz to 800MHz in metallic, nonmetallic, magnetic or nonmagnetic. Ultrasonic NDT method operated on the principle of 'transmitted' and 'reflected' sound wave. sound has a constant velocity in a substance, so if there is any defect or change in material then acoustical impedance of material is changed and sound velocity is also changed. It will produced an echo at point. The change in velocity and time taken for the sound to reach and return from substance depth and size of crack is measured.

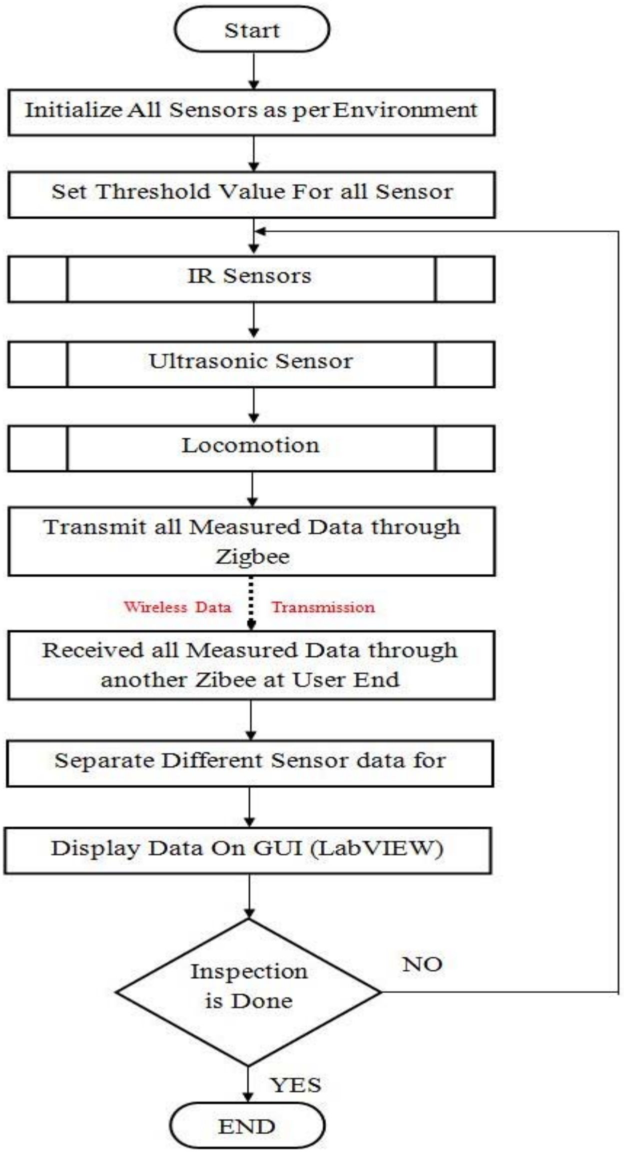


FIGURE 9. System Flow Chat

For Mobile Robot Navigation Dead reckoning algorithm[11] is used, this algorithm measure current position by using a previously determined position. Dead reckoning calculate a relative position from the initial starting point information, Generally it uses an Inertial Measurement Unit (IMU) which is consist of Internal sensor, such as accelerometers and gyroscopes. Internal Navigation system updates the orientation and position automatically without external signal. IMU provide the position and orientation of inspection robot at high rate [12-14]. In the initial information of robot is known, orientation and position is calculated by the integration of angular rates and the acceleration.

V. FIELD TEST

To test the performance of the developed robot system, full size closed environment as a test field was constructed. It has 6m X 6m size and all turn and joints shown in the left of Figure 10(a). It is almost the same as air duct or ventilation in industry and commercial building. It has been covered by a closed environment as shown in the right of the Figure 10(b).

(a) Test Field Before Covered

(b) Test Field After Covered

Figure 10. Test Field for Experiment

First, the IR Sensor calibration was done and check the robot travelled in a environment without touch of the side wall. To seen inside the environment LED mounted on the robot. Figure 11 shows that scene of the environment Lighted by LED and IR sensor on the robot. It can seen that the LED gives enough good light and robot travelled in the maneuverability environment without touch of the side wall.

Figure 11 Scene of robot travelled in an Environment

Next, Ultrasonic sensor calibrated and tested for crack measurement. Ultrasonic sensor sent the pulse and received the pulse, if there is no crack zero pulse width detected, based on the pulse width, width of the crack is measured. Figure 12 shows the calibration of the ultrasonic sensor.

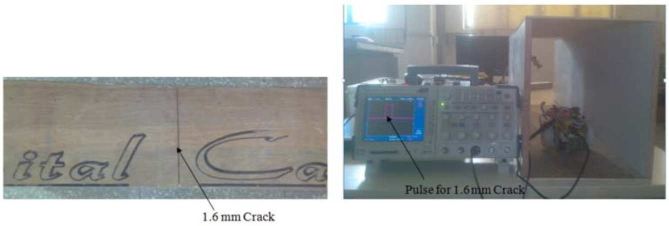
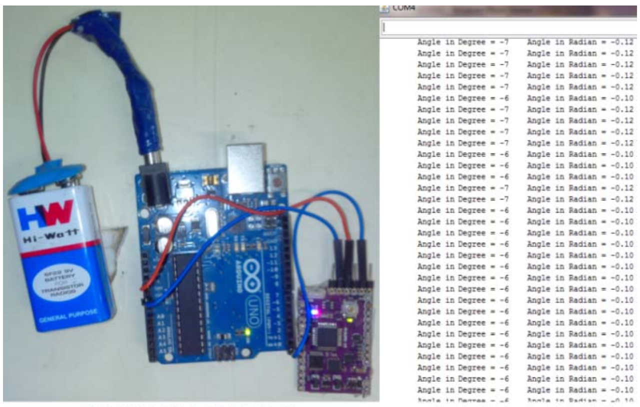


Figure 12 Scene of the calibration of the Ultrasonic sensor for crack measurement

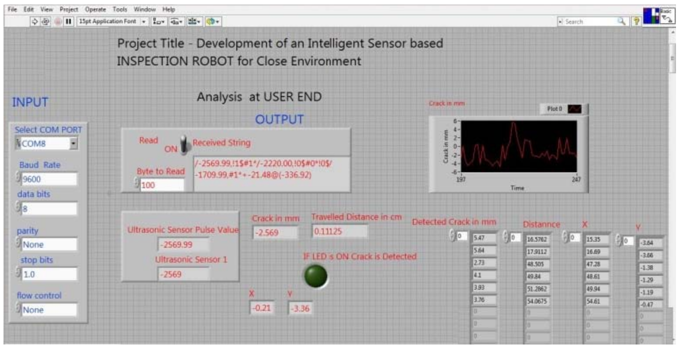
Finally, ArduIMU sensor calibrated and tested to current heading angle of the robot. Current position of the robot is estimated only by the ArduIMU sensor. The relative relationship between the current position and the potion where a reference data was obtained is estimated by sensor. Current position of the robot was measured from the current heading angle and step travelled by the robot. Figure 13 shows the Calibration of the ArduIMU sensor.



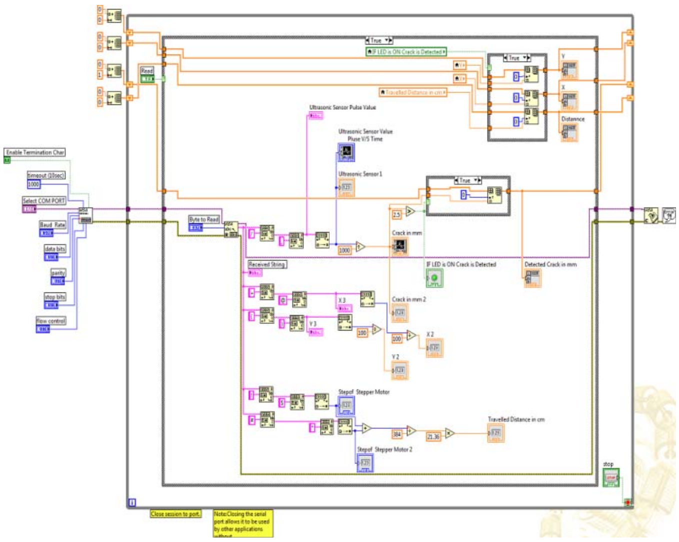
(a) ArduIMU Interfacing with Arduino UNO (b) Serial Data Received at COM Port

Figure 13Scene of the calibration of the ArduIMU sensor

For Inspection these all data were wirelessly transmitted to the host PC. Figure 14 shows the scene of the LabVIEW based GUI and block diagram of inspection robot which provide value of the depth of the crack, place of the crack and X-Y coordinate of detected crack.



(a) GUI for the Inspection at Host PC



(b) Block diagram of the Inspection robot

(c) Visual feedback from the inspection environment

Figure 14 Inspection at User End (Host PC)

CONCLUSION

In this Paper, developing robots for inspection for the closed environment. The field test has been done at a full size mock up of the closed environment for this paper work. The performance of the developed system has been tested and good results were obtained.

This paper work presents a novel approach for intelligent sensor based inspection robot for closed environment . The inspection robot has been tried and tested to measure surface crack and leak using intelligent ultrasonic sensor with accuracy of +/- 3% and it measure minimum 1 mm crack. Developed robot travelled autonomously in the inspection field and measured the distance travel by robot and place of crack. For inspection purpose, GUI has been developed in LabVIEW platform which enable viewing of wireless data transmitted by the robot from the inspection area.

TABLE I. SUMMARY OF RESULTS

Sr. No	Actual crack (mm)	Measured Crack (mm)	Deviation (mm)	Error (%)
1.	1.6	1.6430	+/- 0.4	2.68 %
2.	1.8	1.821	+/- 0.4	1.16 %
3.	2.1	2.1619	+/- 0.3	2.947 %
4.	3.1	3.1405	+/- 0.3	1.303%
5.	4.95	5.053	+/- 0.3	2.082%

REFERENCES

[1] K. Ohno, S. Morimura, S. Tadokoro, E. Koyanagi and T. Yoshida, “Semi-autonomous Control System of Rescue Crawler Robot Having Flippers for Getting Over Unknown-Steps,” Proceedings of the 2007 IEEE/RSJ International Conference on Intelligent Robots and Systems, pp.3012-3018, 2007.

[2] G. Benet, F. Blanes, J.E. Simó, P. Perez, " Using infrared sensors for distance measurement in mobile robots", Robotics and Autonomous System, No. 40 (2002), pp. 255-266.

[3] Baharuddin Mustapha, Aladin Zayegh, Rezaul K. Begg, "Ultrasonic and Infrared Sensors Performance in a Wireless Obstacle Detection System" First International Conference on Artificial Intelligence, Modelling & Simulation p.p.439-444, 2013

[4] Z. Chen, M. Temitayo, and P. D. Isa, "Pipe Flaws Detection by Using the Mindstorm Robot", vol. 2, no. 6, pp. 569-574, 2012.

[5] S. Bhowmick, "Ultrasonic Inspection for Wall Thickness Measurement at Thermal Power Stations", International Journal of Engineering Research and Technology. ISSN 0974-3154 Volume 4, Number 1 (2011), pp. 89-107 [Online].Available: http://www.irphouse.com

[6] S.-N. Yu, J.-H. Jang, and C.-S. Han, “Auto inspection system using a mobile robot for detecting concrete cracks in a tunnel,” Automation in Construction,vol.16,no.3,pp.255–261,2007.

[7] a. Ohya et al.,"Development of inspection robot for under oor of house", 2009 IEEE International Conference on Robotics and Automation, pp. 1429-1434, May 2009.

[8] Lu Lou, Xin Xu, “An Approach to Improving Attitude Estimation Using Sensor Fusion for Robot Navigation”, Procedia Engineering, vol. 15, pp. 5601–5605,2011.[Online].Available: http://dx.doi.org/10.1016/j.proeng.2011.08.1040.

[9] Norhafizan Ahmad, Raja Ariffin Raja Ghazilla, and Nazirah M. Khairi, "Reviews on Various Inertial Measurement Unit (IMU) Sensor Applications", International Journal of Signal Processing Systems Vol. 1, No. 2 December 2013

[10] Stelian Persa, Pieter P. Jonker, "Multisensor robot navigation system", Proc. SPIE 4573, Mobile Robots XVI, 187 (February 20, 2002)

[11] Bong-Su Cho, Woo-sung Moon, Woo-Jin Seo and Kwang-Ryul Baek, "A dead reckoning localization system for mobile robots using inertial sensors and wheel revolution encoding", Journal of Mechanical Science and Technology 25, 2907 - 2917
Online publication date : 1 - Nov - 2011
DOI 10.1007/s12206-011-0805-1

[12] D. H. Titterton and J. L. Weston, Strapdown inertial navigation technology, Second Ed. The Institute of Electrical Engineers, United Kingdom (2004).

[13] P. G. Savage, Strapdown inertial navigation integration algorithm design part 1: Attitude algorithm, Journal of Guidance, Control, and Dynamics, 21 (1) (1998) 19-28.

[14] P. G. Savage, Strapdown inertial navigation integration algorithm design part 2: Velocity and position algorithms, Journal of Guidance, Control, and Dynamics, 21 (2) (1998) 208-221.