International Journal of Advanced Information in Engineering and Technology (IJAIET)
Vol.1, No.1, September 2014

AUTONOMOUS SYSTEM FOR NON DESTRUCTIVE EVALUATION

R.Shimila
Assistant Professor
ECE
RMKCET
Chennai, India
Shimisweety@Gmail.Com

M.Chithrarth
Student
ECE
RMKCET
Chennai, India
Chithrarth2006@Live.In

Abstract— **Inspection robots are gaining attention for non-destructive evaluation (NDE) of engineering structures, especially for monitoring structures which are inaccessible and hazardous for human interventions. The project aims at designing and developing an autonomous inspection robot which can perform ultrasonic testing for ferromagnetic structures. An on-board storage device is used to store the data received from the transducer during the process of inspection to avoid communication through radio frequency. The exact positioning of the robot is achieved by the data derived from optical wheel encoders. A compact Pulse -receiver is used for activating the pulse echo transducer at the desired frequency. The power required by the entire system is reduced and optimized also by autonomously switching off the Pulse-receiver through an optocoupler switch while the robot is translating from one position to another. The entire system is governed by a microcontroller board located on the main circuit board of the robot.**
Keywords- Analog to Digital Conversion [ADC], Center for Non Destructive Evaluation [CNDE], Counts per Rotation [CPR],Integrated Circuit[IC],Light Emitting Diode[LED],Metal oxide semi-conductor Field effect transistor[MOSFET],Non DestructiveEvaluation[NDE],PulseWidthModulation[PWM], RotationsperMinute[RPM],RemoteSensingAgents[RSA], StructuralHealthMonitoring[SHM].

1.INTRODUCTION

One of the extraordinary creations of mankind is robots. In the present world, these robots find a wide range of applications. This project deals about one such fascinating robot. The main theme is to design and develop an automated crawler robot which can easily sense and detect splits and even small hair line cracks in horizontal as well as vertical ferromagnetic structures by performing non-destructive evaluation technique. It is a versatile robot which can support a wide range of fields from Nuclear reactors to Railway tracks, Bridges, Towers and any ferromagnetic structures. Although a lot of research has already been done in the existing field, the existing systems face a problem with power consumption, accurate positioning, data communication and miniaturization. Moreover these testing equipment are very costly. Conventional method involves use of Pulse-Receivers which are not suited for integration in SHM.

1.1. DESCRIPTION OF EXISTING SYSTEM

The existing system includes visual inspection and Eddy current inspection. It uses manual survey. They are specialized in a particular structure. Existing systems uses water as a couplant between robot and the structure which inhibits the accuracy since it checks only the surface, leaving out the cracks in the core. In eddy current inspection surface of the rail or component must first be cleaned of all coatings, rust and so on. To get a sensitive reading, contrast paint must first be applied to the rail, followed by the magnetic particle coating. The same inspection must then be carried out in two different directions at a very slow overall speed. The existing system has the following disadvantages it is expensive, use of couplant reduces accuracy, the same inspection must then be carried out in two different directions at a very slow overall speed, it involves high power consumption, accurate positioning cannot be made, suffers from data communication and miniaturization among others.

1.2. DESCRIPTION OF PROPOSED SYSTEM

This project has been designed in such a way to overcome all the possible drawbacks that were encountered in the existing system. The crawler robot uses a high power transducer and prohibits the use of couplant in any form between the robot and the ferromagnetic structure thereby enhancing its accuracy[1]. It is highly versatile in the manner in which it can be used in a wide range of applications like-Railway tracks, Towers and Bridges and Nuclear reactors etc. It perform surface to core level testing, thus detecting even hair line cracks. It stores the data which are transmitted from the robot in a SD card, so that the precise location of the cracks can be calculated. Accurate positioning can be made. At the same time, it greatly reduces the cost and increases efficiency.

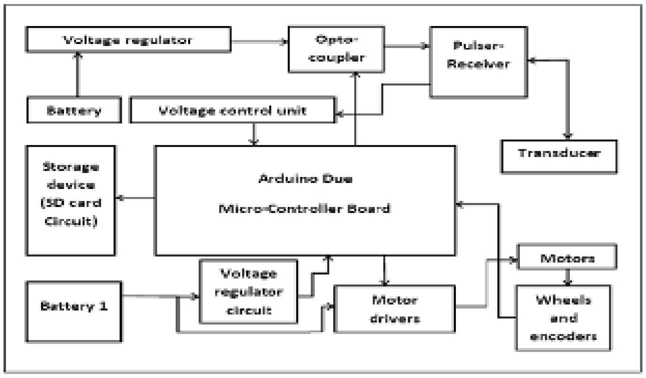

Fig 1.2.1Schematic of Entire project

2. ACCURATE POSITIONING AND PRECISE MOTION

The robot developed in this design Module has the ability to achieve accurate positioning and precise motion with precision up to 2 mm. Also to determine the location and characteristics of the defect, it is essential to locate the position and orientation of the robot accurately, which was another objective of this design Module. All the equipment including the power supply for the robot, pulse-receiver, couplant, oscilloscopes (for analyzing the data) were external to the robot developed. The distance moved by each wheel can be precisely determined from the number of interrupts made by the optical rotary encoders. We fix a reference point as origin which generally is the starting point of the robot. The distance moved by both the wheels and the difference in distance moved by both the wheels is used to determine the exact location and orientation of the robot.It describes the principle of working of optical rotary encoders. The opaque plated of the set of encoders obtained are attached with the flange that carries the wheel and the light source and detector are attached to a fixed base on the robot chassis such that the opaque plate can freely rotate between the source and detector. Every time the wheel moves the opaque plate also moves. This causes an interrupt. The number of rotations by the shaft can be determined from the number of interrupts caused and vice versa. This means that the number of interrupts can determine the number of shaft turns and in turn the number of rotations by the wheels. So we drive the motor as per the number of interrupt. The signal from micro controller governs the number of interrupts for which a motor would be powered which will determine the number of rotation by the wheel. The number of rotations by the wheel will determine the distance moved by the robot. Thus the input from micro controller is used to move the robot precisely.
The precision of the robot depends on two major factors
Resolution of the encoders used and Wheel diameter. Using a right combination for the two a precision of 2mm was achieved. Fig 2.1.1 Shows mounting of optical encoders on the robot.

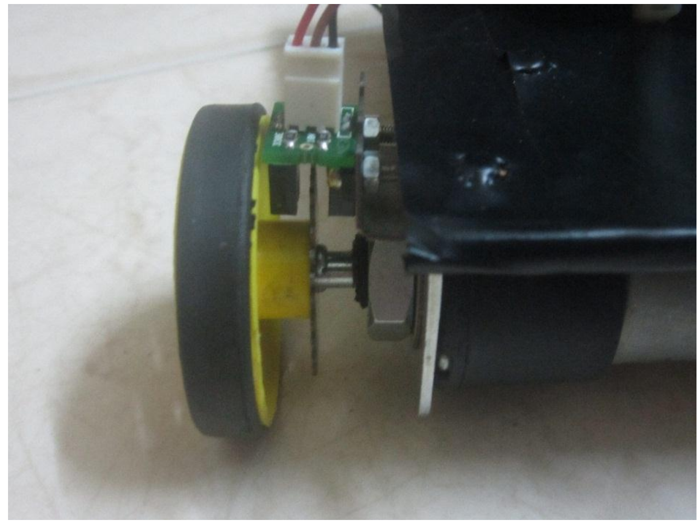

Fig 2.1.1 Mounting of optical encoders

3. MATHEMATICAL MODEL

To develop a robot that can move on vertical ferromagnetic structures. The normal reaction on any wheel was a component of the pulling force generated by the magnet. The friction force in dynamic condition must balance the force of gravity acting on the robot. The force of friction must be equal to the weight of the robot.

$$f = mg$$

The frictional force between two bodies is given by

$$f = \mu N$$

$$F_p = N$$

and hence,

$$mg = f = F_p \mu$$

$$F_p = mg/\mu$$

For most of the ferromagnetic structures the value of coefficient of friction ranges from 0.23 to 0.4. Taking into consideration the worst case scenario the value of pulling force of magnet required to pull a robot of 5Kg on iron wall is equal to 213.4N.
The pull force of a permanent magnet is given by

$$Fp = AB^2/(2\mu_0\mu_r)$$

For air $\mu_r = 1.00000037 \times 4\pi \times 10^{-7}$

$$\mu_0 = 4 * \pi * 10^{-7}$$

the value for B^2A for the given force was calculated. Based on which it was decided to use two magnets of industrial grade N35 places at a distance of maximum 5mm from the surface of the structure to be inspected.

4. VEHICLE ARCHITECTURE

A DC source is used for powering the robot. As most of the commonly available motors require a power supply of 12V or 24V a Lithium Polymer battery which can supply 12V was used for this purpose. The torque requirement for the motors required for this Module was not very high. In order to achieve precise motion it is essential to use motors with lesser speed (RPM) and which respond very fast and accurately to Pulse Width Modulation (PWM). The robot developed in this Module uses motors with 10 RPM and 5Kg-cm torque. The first prototype for this Module was built using two magnetic wheels to generate pulling force for the robot on any ferromagnetic structure. This system had several drawbacks and so the magnetic wheels were replaced by rubber wheels. In the final design two magnets each of dimension 50mm*50mm*12mm were used to generate the pull force. These were placed at the bottom of the robot maintaining a distance of 4mm from the base of the robot.

The magnets used in this rover are high grade neodymium magnets of grade N35. Two sets of magnets are used for providing the required traction force between the wheels and the surface

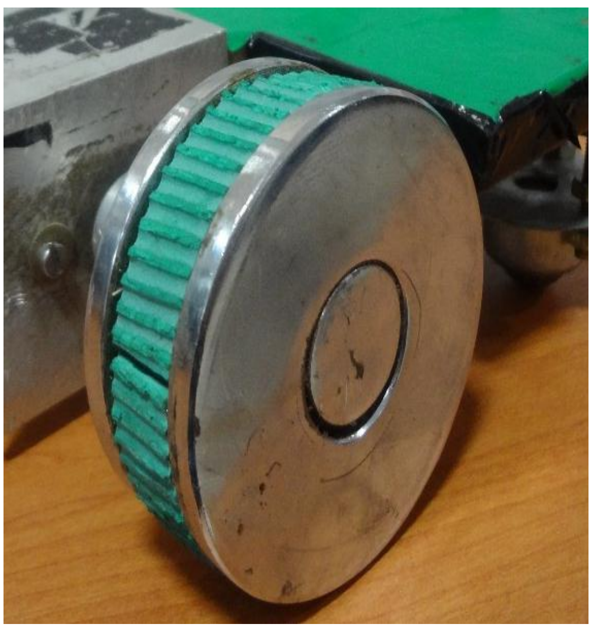

Fig 4.1(a) Magnetic wheels used in the initial prototype of the robot

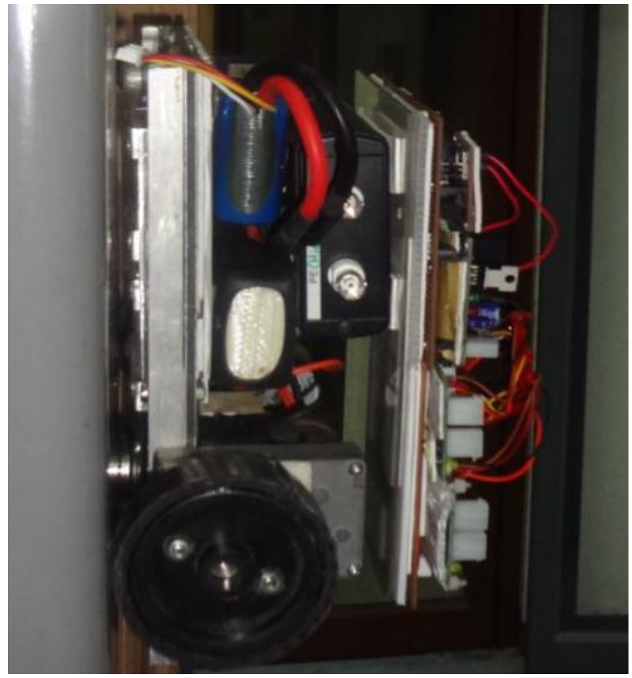

Fig 4.1(b) final prototype of this design Module

5. CLIMBING OF ROBOT

The vertical climbing is achieved by a combination of frictional force and magnetic pull force. For the robot to climb vertically it is essential that the magnets generate enough pull force which in turn generates enough frictional force to hold the robot in any position on the structure to be monitored[2],[5],[6]. Magnetic wheels facilitate the climbing of the robot even in corners which is difficult to achieve otherwise. On the other hand the use of magnetic wheels drastically reduces the frictional force between the wheels and the surface as the coefficient of friction is very low for magnets.

Fig. 5.1 robot while climbing vertically

5.1 WHEEL DISTANCE AND COMPACTNESS

For robot to access inaccessible places it was essential that the robot must be compact. In order to reduce the distance between the wheels, we tried to place both the wheels non-coaxially. When magnetic wheels were the only source of pull force this design provided uniform force distributed evenly over the entire body of the robot [3]. A more compact system could be designed. Increased skidding between the wheel and the robot while making a turn, which made accurate positionin*g* very difficult. Considering the above mentioned advantages and disadvantages it was decided to place the wheels co-axially. The magnetic field affects the working of many electronic components including ICs. For this reason a magnetic shield iron plate is placed on the rare side of the magnets.

6. NDE PAYLOAD

Table 6.1 shows the specifications of the pulse receiver used. This pulse receiver was chosen for its compact size and relatively less power consumption as it was essential for the robot to have an on-board pulse receiver. The Pulse receiver operates at constant power supply of 12V and 0.5amp. In order to avoid over voltage protection LM 2576-12 and 0.5 amps fuse is used for over current protection. This pulse receiver activates the transducer at the desired frequency which in our case is 500 KHz.

Parameter	Value
Supply voltage	9V to 12V DC
Power	Max 3.5W
Size	200*110*43[mm]
Input channels	2
Input range	275mVpp
Input Impedance	50 Ohms
Bandwidth [-3db]	40Khz to 22 Mhz
Output range	1.125Vpp

Table 6.1 Specifications of the Pulse receiver.

The output received from the op-box can vary from -8V to +8V. Sometimes even spikes up to 25 V are received. The maximum allowable input voltage for the Analog pin of the Arduino Due is 3.3V. In order to bring the output signal within the range of the arduino input the voltage control unit has been developed and implemented. It consists of a clipper circuit and a voltage divider. Also, the micro-controller cannot allow negative voltages so in order to offset the output signal from negative to positive; a voltage offset circuit has been implemented.

A clipper circuit consists of 2 Zener diodes in series which are connected in parallel to the input signal and ground. For our purpose we had to clip the input signal from +3.3V to -3.3V. For this we have used 2 Zener diode of 3.3V each. Fig.6.2 (a) shows the circuit diagram of a clipper circuit. A resistor of 1KΩ is connected in series with the Zener diodes. This serves the purpose of power dissipation. The microcontroller cannot withstand negative voltages. In order to offset the signal from -3.3 to above 0V, it was essential that both the modules are powered separately. This ensured that the ground voltage of arduino was different from the ground voltage of the Pulse receiver.

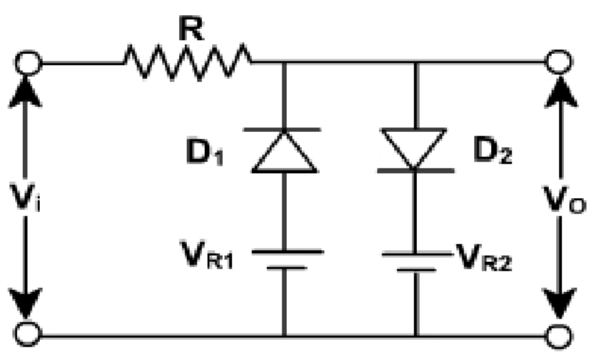

Fig.6.2 (a) clipper circuit.

Even after clipping and offsetting the extra voltage, it could range from 0 to 6.6V which is unacceptable for the Adruino. So a voltage divider is used to scale down the signal from a maximum of 6.6V to a maximum of 3.3V.

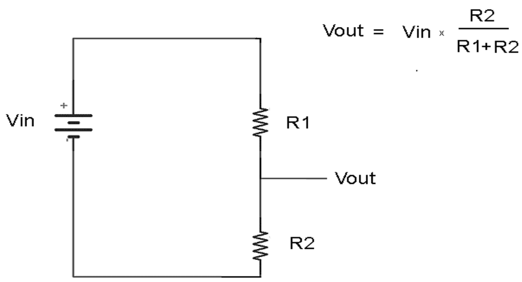

Fig. 6.2 (b) voltage divider.

This scaled the voltage proportionally in the ratio 2:1. The voltage divider consists of 2 resistances of equal value.

7. SMART DATA TRANSFER

The conventional approach followed for data transfer from, micro controller to SD card has been modified in this project. This enabled us to write data on storage device using controllers with relatively less clock frequency, which indirectly helped in overcoming the problem faced due to limited writing speed of Arduino. Unlike other inspection robots which continuously transfer data from the robot while performing SHM, the current system transfers data in packets which requires testing to be performed in stages. We perform SHM in stages[4],[7]. Every time the robot monitors a structure it records data up to 96KB which is the flash memory of Arduino Due. It then stops monitoring, and transfers the data to SD card. Once this is done it automatically navigates to the next position and repeats the same procedure. This process uses Flash memory of the controller to write data, and speed of writing data on the flash memory is relatively high. This allows storing the packet of data on SD card at a very high speed, which is in the order of 106 samples per second. Thus we store data in packets, where each packet stores data which is sufficient to determine the characteristics of the structure at that position.

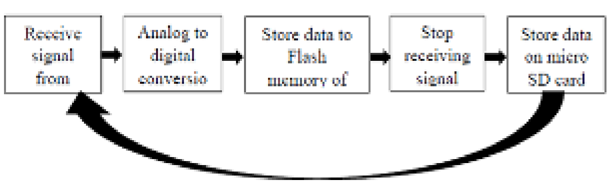

Fig. 7.1 Transfer of data from transducer to SD card

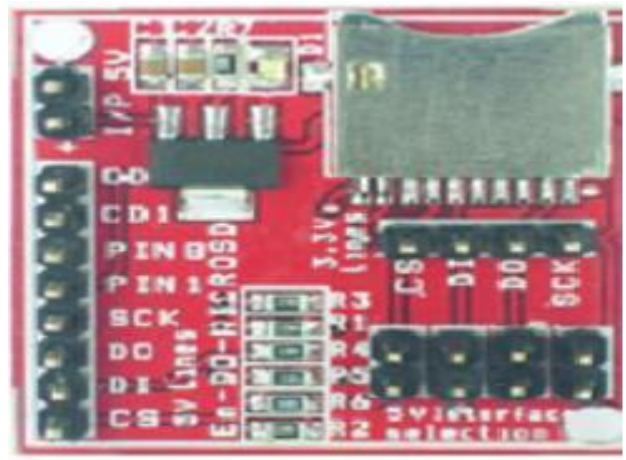

Fig. 7.2 SD card adapter

8. RESULTS AND DISCUSSION

8.1. Sample test 1:

This test was performed to check the ability of the robot to perform inspection over a flat plate. The set up includes final design of the robot, oscilloscope. During this test the data was not transferred to SD card but was analyzed using an oscilloscope.

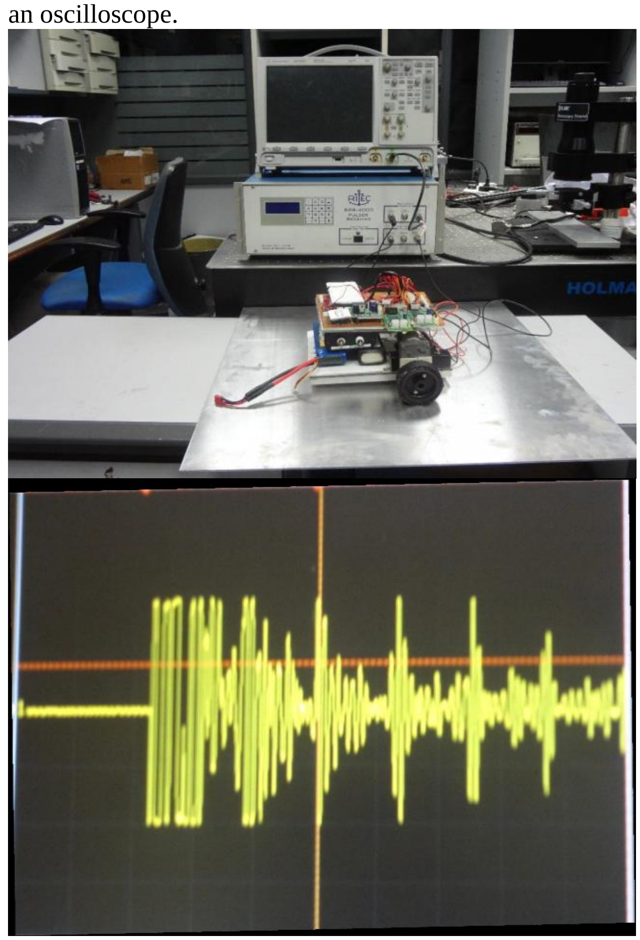

Fig.8.1 rover evaluating the structure

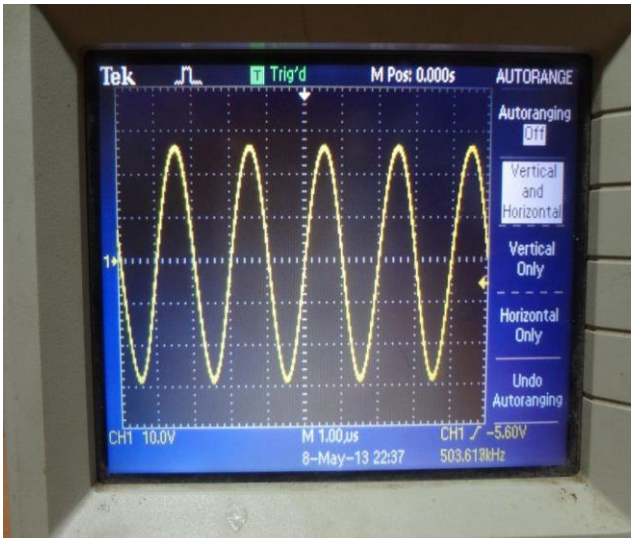

Fig.8.2 signal as received on the oscilloscope.

8.2. Sample test 2:

The area marked when plotted as per the data obtained from the SD card is presented in Fig. 8.3 The noise reduction done in an oscilloscope reduces the fluctuations which are visible in between two peak values. Also the sampling rate of the arduino is one of the limiting factor which results in an inaccurate wave on SD card.

The robot developed could successfully climb on vertical ferromagnetic structures. It can perform SHM for flat horizontal and flat ferromagnetic vertical structures. The modified mode of data transfer improved the data collected on the SD card and yielded fairly accurate results when a wave of 500 KHz was plotted. The sampling rate of the arduino is the limiting factor which needs to be improved using an external ADC.

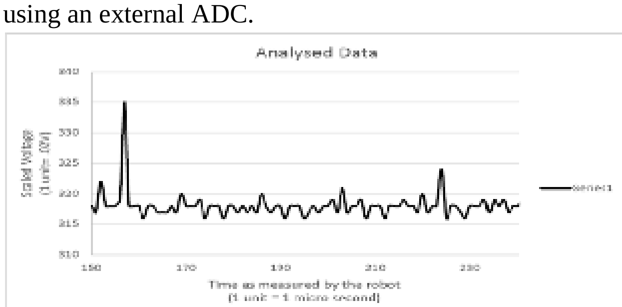

Fig. 8.3 Signal generated from the data stored on SD card.

9. CONCLUSIONS

This project developed a robotic system to address the challenges involved in SHM of inaccessible structures. These include power consumption, rate of data transfer, cost effectiveness, accurate positioning, and data storage. It has achieved the power consumed in the entire process through efficiently allocating the power consumed in entire process among various components of the robot. Also the power consumed by the pulse receiver which is a major component of the power consumed is reduced by switching it off while the robot is translating from one position to another. This is done by controlling the power input to the pulse receiver by an optocoupler. This project improved the quality of data collected on the SD card which was initially affected drastically by the rate of data transfer from Arduino Due to SD Card. This is done by storing the data on the Flash memory of the Arduino Due and then transferring the data to the SD card while the robot is translating. Also the robot went through many structural changes in order to improve on its ability to climb on vertical ferromagnetic structures. The final design thus obtained is very robust and can carry a payload of 5Kg during climbing on vertical ferromagnetic structures.

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