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Non-Contact Rail Track Parameter Measurement

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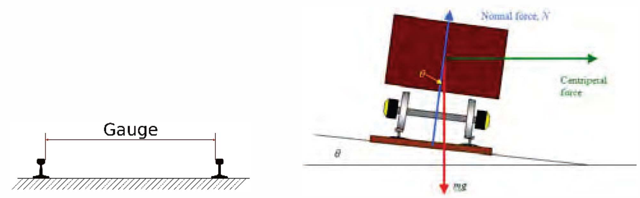
***Abstract*—This paper presents an approach to measure the rail gauge and tilt angle of the railway track using non contact measurement techniques.The objective of this study is to improve the present manual measurement techniques and replace it with advanced digital techniques.In order to achieve non contact measurement of gauge low frequency ultrasonic distance measurement method is presented.In this study non contact measurement methods are presented because use of contact type sensors may increase the possibility of errors and frequent calibration is required.Since earlier times the conventional gauge level measurement tool is being used in Indian Railways, and the amount of work required to measure and rectify the rail tracks are very time consuming and tremendous man power is required.This project aims to improve the conventional measurement techniques in to digital methods which uses ultrasonic sensors and accelerometers to obtain the rail track parameters.**

Keywords:Ultrasonic,Accelerometer,Raspberry Pi,Embedded System

I. INTRODUCTION

India is one of the world's largest railway networks comprising 115,000 km of track over a route of 65,436 km and 7,172 stations.In 2013/14, Indian Railways carried 8.425 billion passengers annually or more than 23 million passengers daily and 1050.18 million tons of freight in the year.So the importance of keeping the rail lines accurate is of higher priority.Indian railways uses four gauges, the 1,676 mm broad gauge which is wider than the 1,435 mm standard gauge; the 1,000 mm metre gauge; and two narrow gauges, 762 mm and 610 mm. Track sections are rated for speeds ranging from 75 to 160 km/h.Since the earlier times conventional manual gauge measurement tool is being used by Indian railways.Even though IR have ultra modern gauge measurement and rectification systems,since the rail network is very wide it becomes almost impossible to reach every corner of the country which makes the study of implementing portable track parameter measurement tool relevant.A non-contact testing method proposed by Scalea [1] and others studies cross sectional inspection of rail tracks.A study conducted by Irigoyen[2] describes the case study of low cost embedded system in which raspberry pi has a wide community support so we decided to choose raspberry pi as our central system and there is a good scope for future expansion of modules for dynamic measurement experiments.Ultrasonic sensors[1] are widely been used for distance measurement and in our study we are using an ultrasonic ranging[3] sensor with a range from 2cm up to 4m.Human ear can hear sound frequency ranging from 20Hz to 20KHz.Ultrasonic sound waves are beyond human ability which is above 20KHz.The ultrasonic



(a) Track gauge (b) Cant level

Fig. 1: Rail Track Parameters (a)Track gauge (b) Cant level

module which we are using have a transmitter and a receiver[4] which will send sound waves from one rail track and hits the parallel track edge and returns back which will be received by the receiver.The time required to travel is being calculated and from that distance[5] is calculated.The secondary study was to measure the tilt angle.Westeon[6] and others implemented vertical track irregularity monitoring using accelerometers.But our design requirement is to measure the inclination,for that we used 3-axis accelerometer[7] which is mounted exactly at the centroid of the conventional track measurement tool.The accelerometer[8] returns acceleration values when interfaced with an embedded system from its 3-axises and we can measure the inclination.

II. ULTRASONIC MODULE

The ultrasonic[9] ranging module we used for the study is HC-SR04 which is having a range from 2cm to 4m.The modules transmitter[10]automatically starts sending sound waves continuously in one direction and when it encounter an obstacle, in our case the rail track, it will return back and receiver will capture the sound waves.The ultrasonic spreading velocity in air is 340m/sec [9].The module uses 10us high level signal.

A. Timing Diagram

The timing diagram is shown in fig:2.Here we are supplying a 10us pulse to trigger the input to start ranging and the module sends 8 cycle burst of ultrasound at 40kHz and raise its eco.We can calculate the distance by using the equation(1).

$$L = CX \quad (1)$$

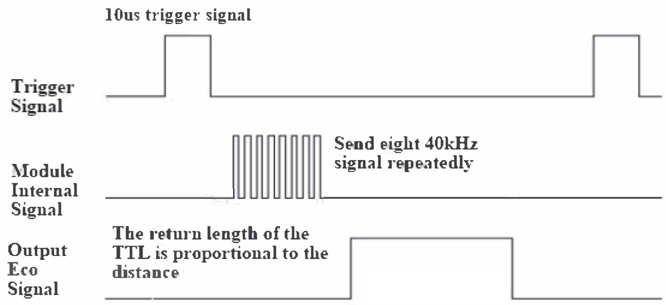


Fig. 2: Timing Diagram of Ultrasound

L=measured distance
C=ultrasonic spreading velocity
X=half the time value from transmitting to receiving

III. ACCELEROMETER MODULE

Accelerometers are low powered micro electro mechanical devices capable of sensing quick motions and condition monitoring[11][12].Studies conducted by Pearson and others [8] shows the usefulness of tilt sensors in rail vehicles orientation.Another study by Veltink[7] used a uni axial accelerometer for angular measurement which are susceptible to measurement errors here we are using 3-axis accelerometer for static tilt measurement.In our study we use MMA-7455 3-axis accelerometer which is capable of measuring 2g,4g and 8g acceleration values.The acceleration forces acting on x and y axises are used for finding the angle between the a and b vectors.Simple vector algebra provides a means to calculate the angle change 'alpha' of the apparent gravity vector between any two accelerometer readings.The scalar product a.b between any two vectors a and b gives the angle 'alpha' between the two vectors. This result is easily proved by applying the triangle cosine theorem to the triangle with sides comprised of the vectors a, b and a-b.Fig.3 shows the vector diagram from which the inclination 'alpha' can be derived in terms of scalar products and vector products as shown in equation (3)and (5).The inclination algorithm is programmed under python environment and I2C protocol is used to interface accelerometer with raspberry pi.

$$\mathbf{a.b} = \begin{pmatrix} a_x \\ a_y \\ a_z \end{pmatrix} \cdot \begin{pmatrix} b_x \\ b_y \\ b_z \end{pmatrix} = a_x b_x + a_y b_y + a_z b_z = |a|\,|b|\,cos\alpha \quad (2)$$

$$\Rightarrow cos\alpha = \frac{a_x b_x + a_y b_y + a_z b_z}{\sqrt{a_x^2 + a_y^2 + a_z^2}\sqrt{b_x^2 + b_y^2 + b_z^2}} \quad (3)$$

$$\Rightarrow a \times b = \begin{pmatrix} a_x \\ a_y \\ a_z \end{pmatrix} \times \begin{pmatrix} b_x \\ b_y \\ b_z \end{pmatrix}$$

$$\Rightarrow \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ a_x & a_y & a_z \\ b_x & b_y & b_z \end{vmatrix} \times \begin{pmatrix} a_y b_z & -a_z b_y \\ a_z b_x & -a_x b_z \\ a_x b_y & -a_y b_x \end{pmatrix} = |a|\,|b|\,\hat{n} sin\alpha \quad (4)$$

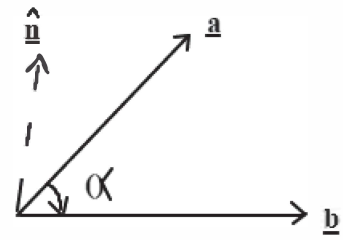


Fig. 3: Vector Diagram

$$\Rightarrow \hat{n} sin\alpha$$

$$\Rightarrow \left(\frac{1}{\sqrt{a_x^2 + a_y^2 + a_z^2}}\right)\left(\frac{1}{\sqrt{b_x^2 + b_y^2 + b_z^2}}\right)\begin{pmatrix} a_y b_z & -a_z b_y \\ a_z b_x & -a_x b_z \\ a_x b_y & -a_y b_x \end{pmatrix} \quad (5)$$

IV. DESIGN OF EMBEDDED MEASUREMENT SYSTEM

Our system runs on a Raspberry Pi[13] model B+ which is a 3.5W, USD 35 Linux based computer with a 700 MHz ARM1176JZF-S architecture and we used a light weight Linux distribution Raspian Wheezy as the operating system.The accelerometer module is interfaced with the general purpose input out put (GPIO) pins and I2C protocol which is commonly used for communication with low powered devices.The accelerometer module is a low voltage operated devices, from 2.4 V-3.6 V and it has a programmable threshold interrupt output.In case of ultrasound we used HC-SR04 module and interfaced it with the GPIO pins of raspberry pi the working voltage of the module is 5V which is drawn from the pi's extra available power pin and the working current is 15mA.The measuring angle is 15 degree.The whole system is integrated with the measurement tool the accelerometer is mounted exactly at the centroid of the tool as shown in fig.6(a).And the ultrasonic module is attached with the adjustable spring arrangement as shown in fig.6(b) so that it could move on its own according to the change in measurement.The whole equipment is lightweight and can hold easily and can be fixed anywhere on the track for corresponding measurement at that particular point.For experimental purposes we used a 5V, 2.1A cell phone power adapter.The system will easily run on a rechargeable battery.

V. TRACK MEASUREMENT SYSTEM IMPLEMENTATION

The system is designed in such a way that it can be used both as conventional measurement tool as well as automatic digital non contact[14] measurement tool.The decision of implementing and experimenting portable system was made according to the survey we took from the track measurement

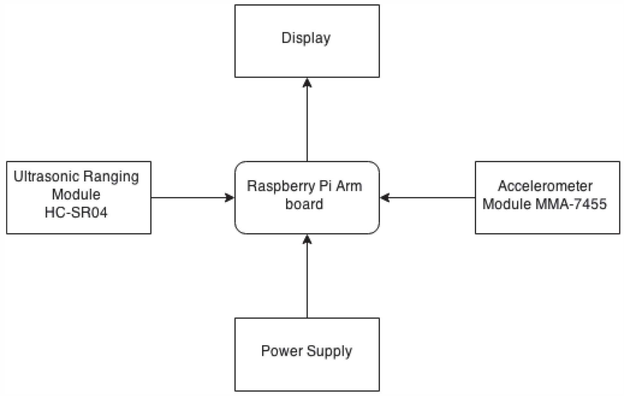
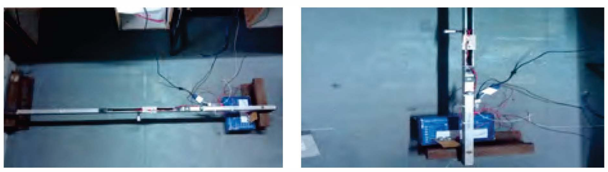


Fig. 4: System Block Diagram



(a) System Setup (b) Track Setup

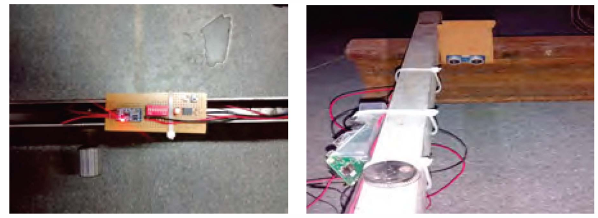
Fig. 5: Experimental Design (a)System Setup (b) Track Setup

and rectification employees,section engineers and Indian railway officers from Pune area.Virtual measurement sometimes may lead to minute errors and causes disastrous derailing.As shown in fig:5(a),(b) we made an experimental setup using the real specimen of 60kg rail track.The Linux computer raspberry pi powered system is the central processor,the whole project is done under open source environment for static measurement only.The ultrasonic and accelerometer working algorithms are programmed in python programming language.

Since the system components are very portable the integration with the measurement tool was easily done.The measurement tool has one edge holder which is fixed and the other edge holder which is spring adjustable so that according to the error when we place the tool between the tracks perpendicular to each other it will show the reading through a scale attached with the spring internally.In conventional tool we have to manually notice the reading.Here we are attaching the ultrasonic module on the adjustable spring holder so that it can change the position according to the measurement difference and can transmits the signals right from there which acts as a self adjustable positioning system.The system automatically registers the distance in to the display.The accelerometer is attached at the centroid of the tool so that when ever there is an inclination difference, mostly inclinations are noticed in turnouts and turns it will return the angle in degrees the resolution of the accelerometer is 1 degree and the ultrasonic module is from 1mm-2mm.

VI. Results

The table:I shows the ultrasonic measured distances corresponding to the standard broad gauge 1676mm.The actual distance is compared with the measured distance manually



(a) Accelerometer Module (b) Ultrasonic Module

Fig. 6: System Implementation (a)Accelerometer Module (b) Ultrasonic Module

and we are obtaining a tolerance of +/- 2mm through the ultrasound measurement.The system is tested continuously and the average accuracy obtained is 99.3 percent.

Broad Gauge(cm)	Measured Gauge(cm)	Error(mm)
167.6	167.5	1
167.6	167.6	0
167.6	167.6	0
167.6	167.5	1
167.6	167.5	1
167.6	167.5	1
167.6	167.5	1
167.6	167.4	2
167.6	167.4	2
167.6	167.4	2
167.6	167.5	1
167.6	167.5	1
167.6	167.6	0
167.6	167.6	0
167.6	167.6	0
167.6	167.5	1
167.6	167.5	1
167.6	167.4	2
167.6	167.4	2
167.6	167.5	1
167.6	167.4	2
167.6	167.6	0
167.6	167.6	0
167.6	167.6	0
167.6	167.6	0
167.6	167.4	2
167.6	167.3	3
167.6	167.4	2
167.6	167.4	2
167.6	167.6	0
167.6	167.6	0
167.6	167.3	3

TABLE I: Ultrasonic measurement results

The table-II shows the accelerometer output corresponding to the angle we measured.For each degree of measurement starting from 0-25 is measured by using a calibrated angle measurement tool.The accelerometer output is compared with the actual manual angular measurement and we are obtaining a tolerance of +/- 1 degree.The fig:7 shows the performance graph of the accelerometer.

VII. Conclusion and Future Scope

The measurement system which is capable of measuring track gauge and cant level on a system on chip based ARM board is proposed and the corresponding measurement is

Tilt angle(Deg)	Accelerometer out put(Deg)	Error(Deg)
0	1	1
1	2	1
2	3	1
3	3	0
4	4	0
5	6	1
6	6	0
7	8	1
8	10	2
9	10	1
10	10	0
11	10	-1
12	11	-1
13	12	-1
14	15	1
15	15	0
16	15	-1
17	16	-1
18	20	2
19	22	2
20	21	1
21	22	1
22	23	1
23	26	3
24	26	2
25	27	2

TABLE II: Accelerometer measurement results

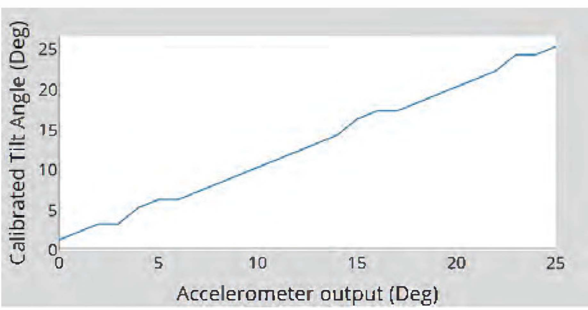


Fig. 7: Accelerometer Performance Graph

tested on rail tracks.The primary objective of the study was to implement and test a non contact tool integrated with manual measurement.The system is under development and is returning a good accuracy in real time.The future scope of the study is to expand the operations from static to dynamic which can be achieved by adding gyroscope and compass module with the accelerometer and extending mobility to the system using rollers and handle arrangement so that work men can easily access the measurement for an extended distance comparatively.

VIII. ACKNOWLEDGMENT

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