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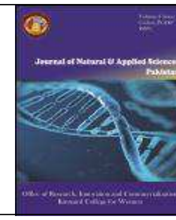

IMPLEMENTATION OF WIRE RESISTANCE COMPENSATION TECHNIQUE ON DIRECT SENSOR TO ATMEL 89C51 MICROCONTROLLER INTERFACE

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Abstract

A direct sensor to Atmel 89c51 micro controller interfacing with large wire resistance compensation method is implemented. A capacitor is allowed to discharge through four different paths, one at a time. The specific discharging time is then converted into digital number using coding and then the counts ratio for different discharging paths is used to compensate the effect of wire resistance.
The experimental data is taken for Atmel 89c51 for two different cases. In the first case the sensor resistance is varied from 1kΩ to 1.1kΩ(1% tolerance) in the regular steps of 10Ω and then the counts ratio corresponding to the discharging time is calculated and plotted. The second case is to vary the wire resistance from 1Ω to 20Ω in the steps of 1Ω and the counts ratio corresponding to its discharging time is calculated and plotted.
The results and analysis show that the counts increases as increase in the resistance whether it is sensor resistance or wire resistance i.e. number of counts is directly proportional to the increase in resistance. However, the increase is not linear and also there is relatively small difference between the counts ratio with NLRC and with LRC. Hence the implementation of a modified scheme of wire resistance compensation works well even if the sensor is placed at some distance and connected through long connecting wires.
The results of wire resistance variation show that the counts oscillate about the value 1 i.e. ± 0.001 (up to 3 decimal places) with the wire resistance compensation method. The counts with no wire resistance compensation method increases from the value 1 and go on increasing with the increment in wire resistance. The noise factor produces a minimum limit on the accuracy achieved with this technique; hence it needs to be minimized.

I. INTRODUCTION

Sensors are such devices through which we can be able to sense different physical quantities or parameters of our environment and can get information about them. But in this step the information cannot be understand by us properly because it is in the form of signals so we need to interface the sensor with such device through which we can extract the required information and these devices can be micro processor or micro controller. The sensors can be resistive, capacitive and bridge. Resistive sensors can be of single element or differential or in bridge form whose resistance changes according to the change in the physical quantity that is to be measured. The factors that we can measure can be temperature, humidity, pressure, speed, light, gas etc. The interfacing of sensor with micro controller consists of two methods now:

A. Conventional Measurement schemes

In this scheme the sensor is interfaced with micro controller through signal conditioning cascaded with ADC (Analog to Digital Convertor) which is shown in fig 1

Fig.1 Conventional Measurement Scheme

This scheme consists of a sensor which actually senses the physical quantity and changes it into electrical signal which is then send for signal conditioning. Here signal conditioning means to increase signal to noise ratio, sampling, to make it in a format that could be in digital (after analog to digital conversion) so that it can be synchronized with the micro controller and there we can programmed it according to the requirement to get the desired result [1].

B. Proposed scheme

The proposed scheme is basically a direct interfacing of sensor with a micro controller without using any ADC or signal conditioning as shown in Fig.2. In this scheme, the resistive/capacitive sensors are excited by microcontroller and then their time based output signal is measured corresponding to which digital output comes in result on the pins of micro controller. This digital output is basically the counts of discharging time period of capacitor which is used in RC circuit. Here, the time taken should be five times the RC time constant.

- **For Resistive Sensor**

In resistive sensor, RC circuit is used in which the capacitor is charged up to threshold voltage V_{TH} and when the discharging starts through resistor the controller starts taking the counts corresponding to discharging time until it discharges to V_{TL}. Larger the resistor value greater will be the counts.

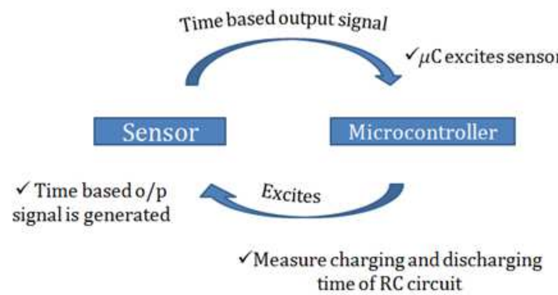

Fig. 2 Proposed Sche

Here, it is illustrated by the Fig.3

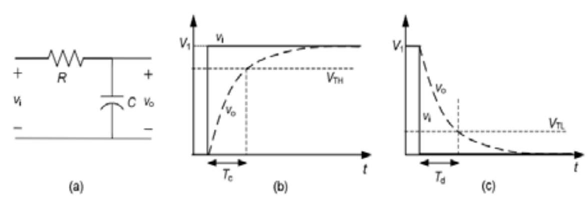

Fig.3 (a) RC circuit. (b) Charging stage of the RC circuit. (c) Discharging stage of the RC circuit

The output voltage is calculated as

$$v_{\circ}(t) = V_1\left(1 - e^{-\frac{t}{Rc}}\right) \quad (1)$$

The required time to charge capacitor from zero to specified high threshold voltage (V_{TH}) is calculated from

$$T_c = RCln\left(\frac{V_1}{V_1 - V_{th}}\right) \quad (2)$$

which shows that the required time is directly proportional to R and C. If capacitor is already at V_1 and a step of zero voltage is provided at input, the voltage at output is given as

$$v_{\circ}(t) = V_1 e^{-\frac{t}{Rc}} \quad (3)$$

The time required to discharge capacitor from V_1 to low threshold voltage (V_{TL}) is

$$T_d = RCln\left(\frac{V_1}{V_{TL}}\right) \quad (4)$$

that is also proportional to R and C [2].

Procedure steps for resistive sensor:

The first category of non-ADC interface uses the passive sensors[3]. This technique of analog to digital conversion involves multi-steps in its performance. As shown in fig below

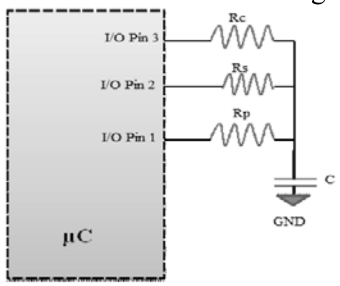

Fig.4 Passive sensor technique

- Pin 1 is set as output pin, giving high or 1. Other two pins are set as input (high-Z). The capacitor C is charged through I/O pin 1.
- Now Pin 1 is set as input (high-Z) and pin 2 is set as output to give low or 0, the capacitor will discharge via sensor resistance R_s until it touches the point of low threshold (V_{IL}) of pin 3.
- The counter is incremented during the discharging of capacitor to measure the discharging time.
- The discharging produces an integer N_s which is proportional to the R_s.
- All the steps are repeated for calibration resistance R_c, to get a integer N_c, proportional to R_c.

By using the measured integer values and the formula given below, one can find out the sensor resistance by not taking into account the value of capacitor.

$$R_S = \left(\frac{T_S}{T_C}\right) R_C = \left(\frac{N_S}{N_C}\right) R_C \qquad (5)$$

Related techniques of this category have been used for capacitive sensors[4-8], differential capacitive sensors[9] and resistive bridge sensors[10-12].

Charging –discharging stage of the capacitor working as passive sensor is shown in the form of graph below. The charging stage is starting from V_{ss} to V_{DD} of the positive supply voltage to the I/O pin. After some steady state the internal timer of the microcontroller starts to count. Then the discharging stage begins from V_{DD}, as the discharging approaches to $V_{TL,}$ the timer stops to count and show the binary output.

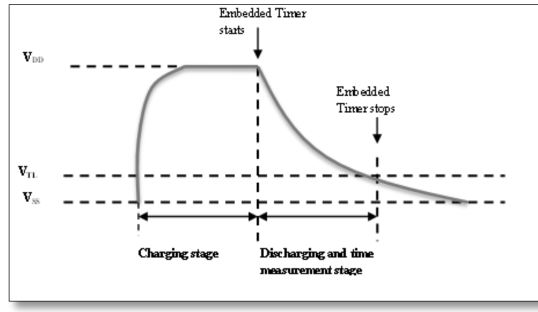

Fig.5 Waveform of voltage across the capacitor (Vc) in fig during charge-discharge stages

C. Distant Sensor:

All the prior techniques are favorable for the sensors placed near the micro controller but for the sensors placed at some distance there comes a factor of lead resistance and if the low valued resistive sensor possessing low sensitivity is placed at very large distance then the effect of large lead resistance comes into account and introduces appreciable errors in the output.

Error introduced by the lead resistance R_{LD} in the operation of a sensor resistance R_x depends on the ratio of R_{LD}/R_x. Here, R_x is the resistance of sensor element. The change in the operating temperature also leads to the change in the resistance of the Lead wires so even a few meters of connecting wire can introduce a large errors due to not only lead resistance but also due to the variation in the lead resistance as a result of change in the temperature.

Typical value of lead resistance of a wire (copper wire, 30 SWG) at 25 °C is 344mΩ/m and the temperature coefficient of copper is 0.00385 Ω/Ω/°C and for a 10 °C change in the operating temperature the change in the resistance of lead wires will be 13 mΩ/m[13].

This system consists of three modules:

- Measuring unit
- Wiring
- Sensor

Fig.6 Block diagram

II. MICROCONTROLLER BASED SENSOR INTERFACE WITH WIRE RESISTANCE

In this method the direct interfacing of microcontroller Atmel 89c51 with sensor using large lead resistance compensation method is implemented. Four paths are used in this method and are operated by micro controller.

The first path includes the sensor and the lead resistance while the second path is independent of sensor and just includes lead resistance. The third path is used to correct the offset error which is contributed by the micro controller in the measurement of resistance and the final discharging operation is intended to measure time corresponding to the reference resistor.

The diode in this method is basically used just for unidirectional current that is when it is forward biased it allows the current to flow from that path but in reverse biased it does not allow that current to flow. Similarly the switches are basically used just for selection of path that which path should be used. So the measurement process involves charging and discharging of the capacitor alternatively for four times [1]. The capacitor is charged through pin3.1 of the micro controller when it is set at digital HIGH and the remaining pins are at high impedance state. The required path is used w h en its corresponding pin is made output pin by setting at digital LOW. Pin 0.2 is used as a detection pin.

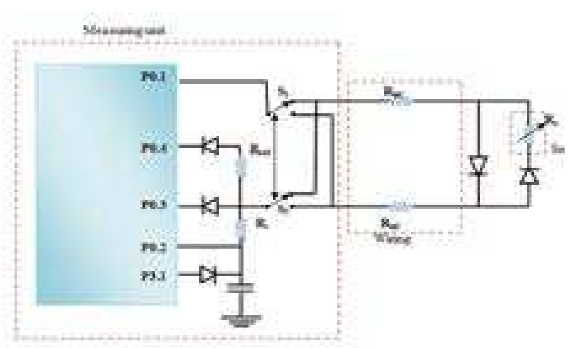

Fig. 7Circuit Diagram

A. Charging requisites:

For this condition, a capacitor C charge towards VDD through P3.1 and diode is used here for unidirectional current.

B. Discharging Requisites:

During discharging, the time taken to reach certain voltage (V_{TL}) is measured.

Following are the different discharging paths in the proposed system:

- **Path1**

When we allow the capacitor to discharge through path1 i.e. including sensor resistance R_x then the discharging path will become now

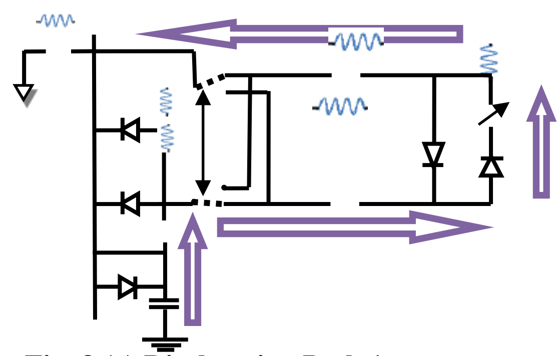

Fig. 8 (a) Discharging Path 1

So the total resistance offered by this path is

$$\mathbf{R_{T1} = R_x + (R_s + R_{ON1} + R_{LD1} + R_{LD2} + R_{ON2} + R_{pin})} \quad \textbf{(6)}$$

Here, R_s is an additional resistor connected to ensure that the discharging current is smaller than the maximum output current (I_{max}). R_{ON1} and R_{ON2} are the ON state resistances of the switches S1 and S2 and R_{pin} is the internal pin resistance offered by the microcontroller.

Diode D_1 will be forward biased and D_2 will be reverse biased and the current $i_1(t)$ flowing through R_{T1} will be

$$\boldsymbol{i_1(t)} = \frac{(\boldsymbol{V_{DD}} - \boldsymbol{V_{DON}})}{\boldsymbol{R_{T1}}} \boldsymbol{e^{-t/R_{T1}C}} \quad \textbf{(7)}$$

where $\boldsymbol{V_{DON}}$ is the ON state forward voltage drop of the diode D_1.

and the capacitor voltage $\boldsymbol{v_c(t)}$ can be expressed as

$$\boldsymbol{v_c(t)} = \boldsymbol{V_{DON}} + \boldsymbol{v_{R_{T1}}(t)} \quad \textbf{(8)}$$

The capacitor voltage $\boldsymbol{v_c(t)}$ at the time of the start of discharge (t=0) will be

$$\boldsymbol{v_c(t)} = \boldsymbol{V_{DD}} \quad \textbf{(9)}$$

The discharging process is continued till the capacitor voltage drops down to a threshold voltage , $\boldsymbol{V_{TL}}$ and let $\boldsymbol{T1}$ be the time taken to discharge the capacitor. At t= $\boldsymbol{T1}$,$\boldsymbol{v_c(T_1)} =$ $\boldsymbol{V_{TL}}$ and $\boldsymbol{V_{TL}}$ can be written as

$$\boldsymbol{V_{TL} = V_{DON} + (V_{DD} - V_{DON})e^{-T1/R_{T1}C}} \quad \textbf{(10)}$$

and the time taken to discharge the capacitor will be calculated as

$$\boldsymbol{T_1 = R_{T1}C \ \ln \frac{(V_{DD}-V_{DON})}{(V_{TL}-V_{DON})}} \quad \textbf{(11)}$$

Here, values of C, V_{DD} , V_{TL} and V_{DON} are constants and the T_1 totally depends on R_{T1} i.e. time to discharge the capacitor is proportional to the total resistance offered by the discharging path. The timer of the micro controller will be started when the capacitor starts to discharge and will be stopped when $\boldsymbol{v_c(t) = V_{TL}}$. So the discharging time is now available in terms of counts, a digital number say N_1. The equations from (7) to (11) are same for all discharging paths except the total resistance, R_T involved in different paths. The Fig. 8 shows that the charging time of capacitor for all paths remains same but discharging time changes due to the change in the total resistance of different paths.

- **Path2**

When we allow the capacitor to discharge through path2 (given below in Fig.8 (b)) i.e. excluding sensor resistance R_x and just lead resistance is involved then the discharging path will be:

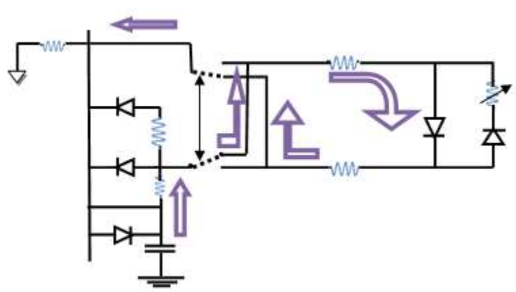

Fig. 8(b) Discharging Path 2

So the total resistance offered by this path is

$$\mathbf{R_{T2} = (R_s + R_{ON1} + R_{LD1} + R_{LD2} + R_{ON2} + R_{pin})} \quad \textbf{(12)}$$

The count obtained from the counter corresponding to this discharging time T_2 is N_2.

- **Path3**

The offset error of internal pin resistance of micro controller comes into account while taking the measurement so to compensate this offset error we allow the capacitor to discharge through path3

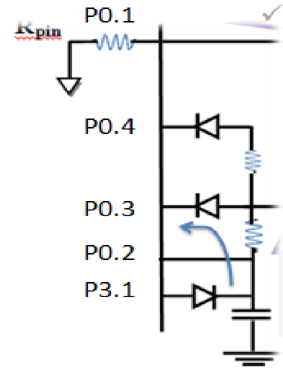

Fig. 8(c) Discharging path 3

then the total resistance offered by this path is

$$\mathbf{R_{T3} = R_s + R_{pin}} \quad \textbf{(13)}$$

The count obtained from the counter corresponding to this discharging time T_3 is N_3.

- **Path4**

The final discharging operation is intended when we allow the capacitor to discharge through reference resistor R_{ref} i.e. path4

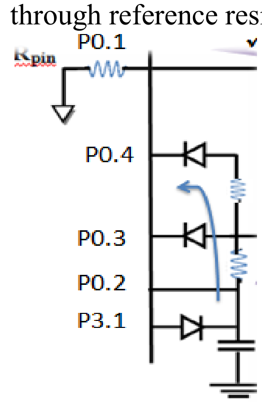

Fig.8 (d) Discharging path 4

So the total resistance offered by this path is

$$\mathbf{R_{T4} = R_{ref} + (R_s + R_{pin})} \quad \textbf{(14)}$$

The count obtained from the counter corresponding to this discharging time T_4 is N_4. Now if we perform the ratio-metric operation of the four discharging time periods of capacitor i.e. T_1, T_2, T_3 and T_4, we get the output as the ratio of sensor resistance to reference resistance as $\mathbf{R_x/R_{ref}}$ which is independent of lead resistances.

$$\boldsymbol{\frac{(T_1-T_2)}{(T_4-T_3)} = \frac{(R_{T1}-R_{T2})}{(R_{T4}-R_{T3})} = \frac{R_x}{R_{ref}}} \quad \textbf{(15)}$$

Since the counts corresponding to the discharging time periods are now available so the equation (15) can be rewritten in terms of counts as

$$\frac{R_x}{R_{ref}} = \frac{(N_1 - N_2)}{(N_4 - N_3)} \quad (16)$$

This equation (16) is not affected by the lead resistance. If this compensation method is not considered then the calculated ratio will become [1]:

$$\frac{(T_1 - T_3)}{(T_4 - T_3)} = \frac{(N_1 - N_3)}{(N_4 - N_3)} = \frac{R_x}{R_{ref}} \quad (17)$$

III. SIMULATION STUDIES

The proposed system was implemented and has been verified by simulating the circuit on the software Proteus ISIS (Intelligent Schematic Input System) and the firmware was written in C-code by using the compiler Keil µvision4 for the microcontroller ATMEL89C51 according to the following tables.

- **Charging requisites:**

For all paths charging conditions are same as follow:

Pins	State
Pin0.1	HZ
Pin0.2	High or 1
Pin0.3	HZ
Pin0.4	HZ
Pin3.1	High or 1

Table1 Error! Use the Home tab to apply 0 to the text that you want to appear here. **Charging requisites for pins**

- **Discharging requisites:**

There are different states of microcontroller pins for four different discharging paths of capacitor.

Pins	State
Pin0.1	Low or 0
Pin0.2	HZ
Pin0.3	HZ
Pin0.4	HZ
Pin3.1	Low or 0
S1,S2	0

Table 2 Pin Requisites for path 1

Pins	State
Pin0.1	Low or 0
Pin0.2	HZ
Pin0.3	HZ
Pin0.4	HZ
Pin3.1	Low or 0
S1,S2	1

Table 3 Pin Requisites for path 2

Pins	State
Pin0.1	HZ
Pin0.2	HZ
Pin0.3	Low or 0
Pin0.4	HZ
Pin3.1	Low or 0
S1,S2	No effect

Table 4 Pin Requisites for path 3

Pins	State
Pin0.1	HZ
Pin0.2	HZ
Pin0.3	HZ
Pin0.4	Low or 0
Pin3.1	Low or 0
S1,S2	No effect

Table 5 Pin Requisites for path 4

IV. EXPERIMENTAL RESULTS

There are two different cases in the experimental portion that are implemented on hardware as well as on software.

A. Case 1 (Variation in sensor resistance R_x):

In this case the lead resistances R_{LD1} and R_{LD2} were fixed and set as 10ohm, the nominal resistance R_o of the sensor was set as 1kohm and the sensor resistance R_x was incremented from 1kohm to 1.1kohm in the steps of 10ohm and capacitor is of 2.2µF. The ratio R_x to R_{ref} is then calculated using (16) (Lead Resistance Compensation- LRC) and (17) (No Lead Resistance Compensation-NLRC).
Fig.9 shows the theoretical estimation of the variation of discharging time ratio and counts with

the ratio of sensor resistance and reference resistance (Rx/Rref). The result shows that the discharging time ratio increases linearly with (Rx/Rref). The ratio of no. of counts is theoretically equal to the discharging time ratio with Lead Resistance Compensation as explained in equation 15 and their graph overlaps. It is evident from the graph in fig.9 that without lead resistance compensation the counts are greater than the lead resistance compensation method because in NLRC the lead resistance is included which increases the net resistance of that path and hence the count increases.

The system shows experimentally a similar behavior predicted theoretically i.e. increase in count ratio with the (R_x/R_{ref}). However, the increase is not linear and also there is relatively small difference between the counts ratio with NLRC and with LRC. Moreover, there is an anomaly of decreasing count ratio for (R_x/R_{ref} = 1.1)

There could be a number of reasons for this deviation from theoretical behavior. These include:

- Tolerance of the resistances used in the hardware. The resistances of 1% tolerance are used in the hardware circuit so there comes the possibility that if the resistance of 1kΩ is used in the circuit than it may not offer the actual 1kΩ but offers with ± 10Ω.

  - The internal resistance of the pins of the microcontroller. Two effects are involved regarding internal pin resistance.
    - the internal resistance of one pin can vary while taking several readings
    - the internal resistance is different for different pins of the microcontroller
  - For the regular increment of resistances, combinations of resistances are employed to get the desired resistance value. This increases the number of contacts points and introduces the noise factor in the circuit hence changes the counts.

B. Case 2 (Variation in Lead resistance R_{LD}):

In this case the sensor resistance R_x was fixed and set as 1kohm **(**the nominal resistance R_o) and the lead resistances R_{LD1} and R_{LD2} was

Experimental

incremented from 0ohm to 20ohm in the steps of 1ohm. The ratio R_x to R_{ref} is then calculated using (16) (Lead Resistance Compensation- LRC) and (17) (No Lead Resistance Compensation-NLRC).

In the second part of the experiment, the sensor resistance is set to 1kΩ and the lead resistance is allowed to vary from 0Ω to 20Ω in the regular step of 1Ω. The theoretical estimation of the system behavior based on calculated values is plotted in the Fig.10. The results shows that with the increase in the wire resistance the counts corresponding to that fix value of resistance also increases linearly but when lead resistance compensation method is applied the counts become independent of lead resistance.

The experimental results from experimental values are plotted in Fig.10 The results shows that the counts oscillate about the value 1 i.e. ± 0.001 (up to 3 decimal places) when we apply the lead resistance compensation method and the counts with no lead resistance compensation method are increased from the value 1 and go on increasing with the increment in wire resistance.

This shows that effectiveness of the lead resistance compensation technique for the sensors placed at distance from the microcontroller. The small oscillatory behavior of ± 0.001 around the value 1 in the count ratio can be due to the presence of noise factor. The experimental setup and connections made on bread board instead of Printed circuit board (PCB), the variation in the internal pin resistances due to internal power dissipation and/or the variation in ambient temperature contributes to the noise factor.

V. CONCLUSION

The lead resistance compensation method is implemented for direct interfacing of sensor with micro controller Atmel 89c51. Simulation as well as hardware implementation reveals that the lead resistance compensation method produces more accurate results for the distant sensors having large wire resistance. The noise factor produces a minimum limit on the accuracy achieved with this technique; hence it needs to be minimized.

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Figures

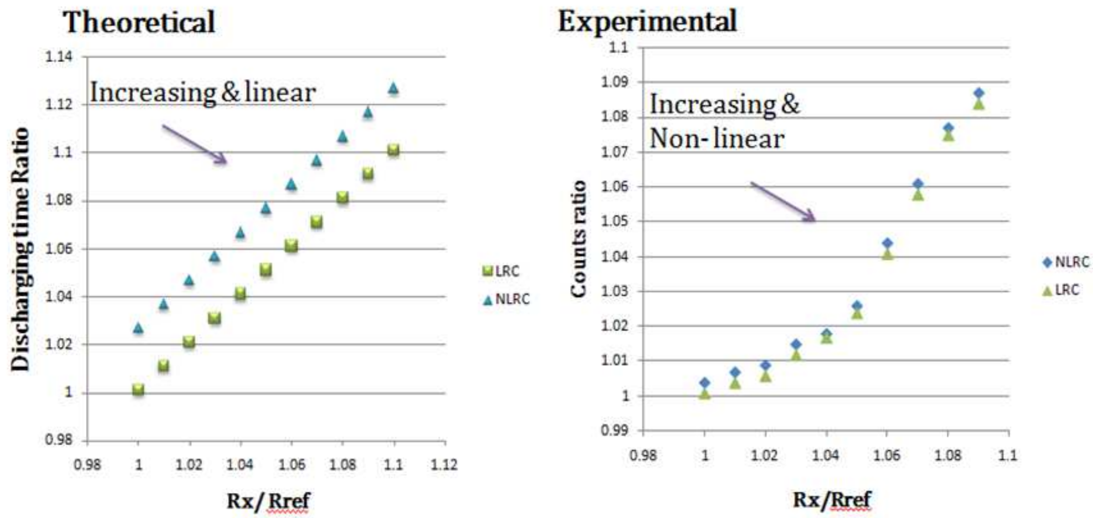

Fig.9 Graph between sensor to reference resistance ratio and its counts ratio with fixed R_{LD} and variation in Rx

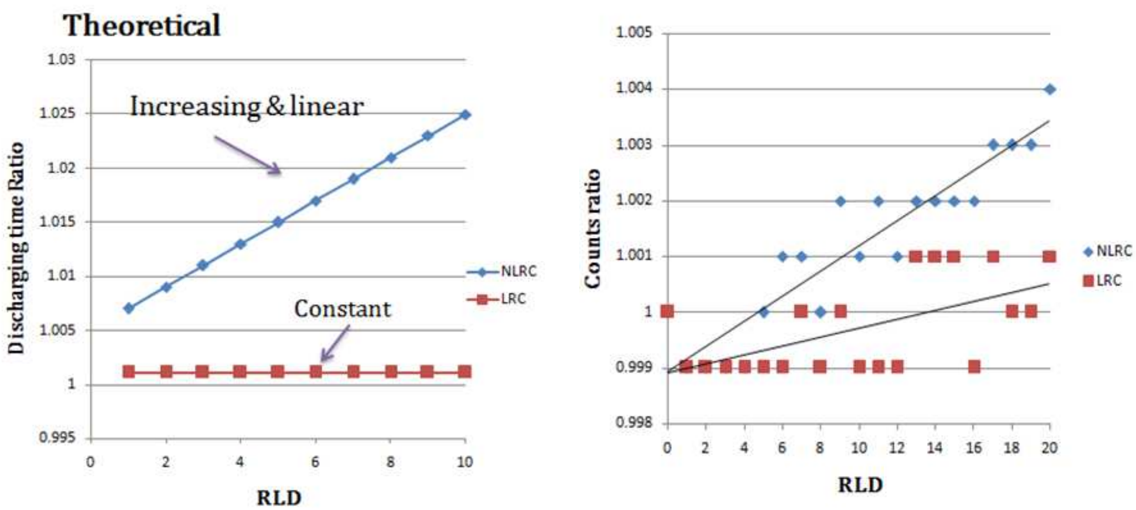

Fig.10 Graph between Lead resistance and its discharging time ratio with fixed Rx and variation in R_{LD}