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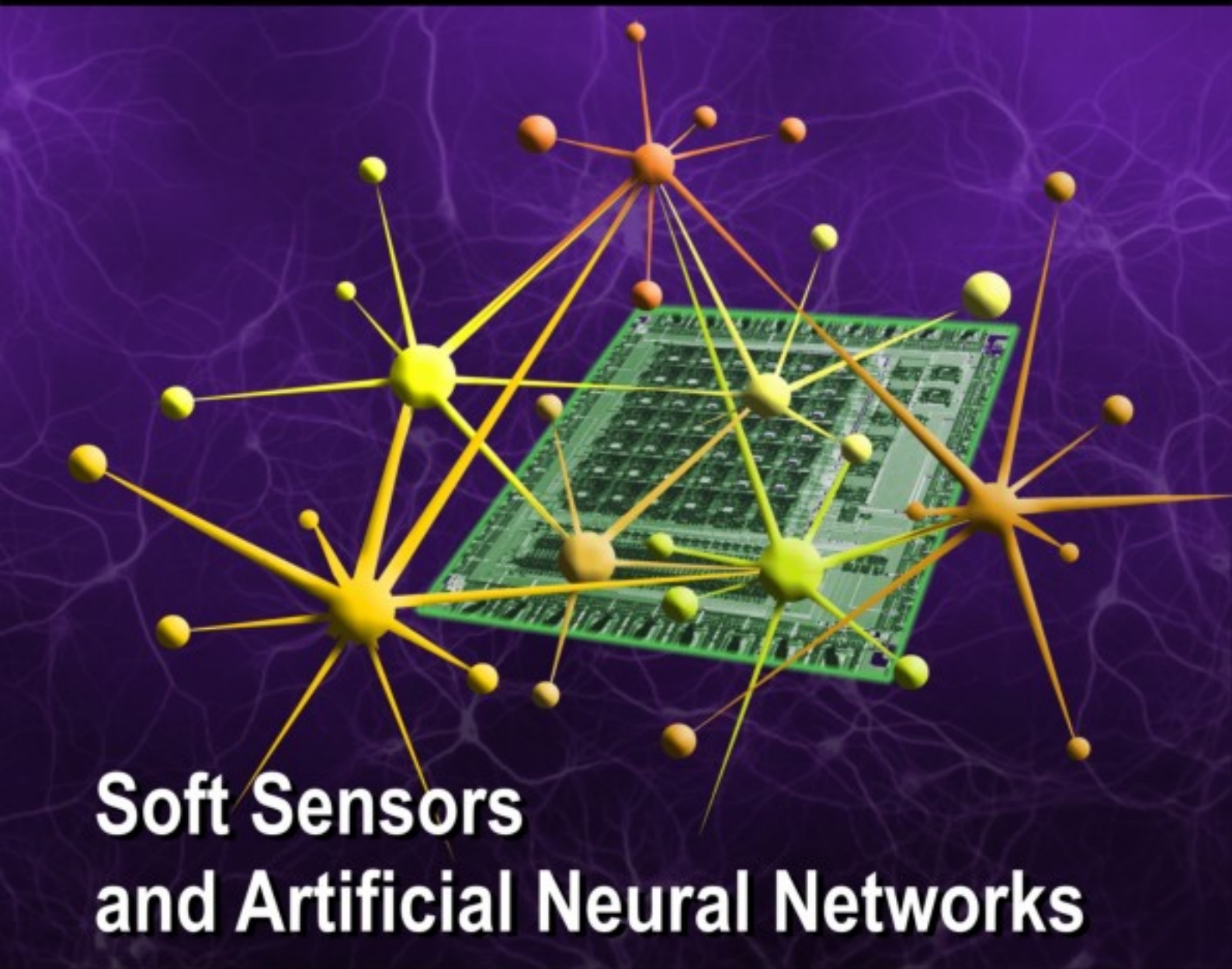

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Editor-in-Chief: professor Sergey Y. Yurish, phone: +34 696067716, fax: +34 93 4011989,
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Programmable Solution for Solving Non-linearity Characteristics of Smart Sensor Applications

S. Khan, *I. Adam, Zahirul Alam, *K. F. Mohd Suhut and *N. Yusof
International Islamic University, Malaysia, PO Box 10, Kuala Lumpur 50728
* University Kuala Lumpur- British Malaysia Institute, Malaysia
E-mail: sheroz@iiu.edu.my, ismail_adam@yahoo.com, kamal@bmi.edu.my, nhayati@bmi.edu.my

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Abstract: This paper presents a simple but programmable technique to solve the problem of non-linear characteristics of sensors used in more sensitive applications. The nonlinearity of the output response becomes a very sensitive issue in cases where a proportional increase in the physical quantity fails to bring about a proportional increase in the signal measured. The nonlinearity is addressed by using the interpolation method on the characteristics of a given sensor, approximating it to a set of tangent lines, the tangent points of which are recognized in the code of the processor by IF-THEN code. The method suggested here eliminates the use of external circuits for interfacing, and eases the programming burden on the processor at the cost of proportionally reduced memory requirements. The mathematically worked out results are compared with the simulation and experimental results for an IR sensor selected for the purpose and used for level measurement. This work will be of paramount importance and significance in applications where the controlled signal is required to follow the input signal precisely particularly in sensitive robotic applications. *Copyright © 2007 IFSA.*

Keywords: Nonlinearity, Interpolation, Smart Sensors

1. Introduction

Sensing transducers work on the principle to give an output signal in response to changes in a physical input that is to be measured. A physical input may include things such as humidity, moisture content or pressure which are being monitored or used for controlling plants [1-3]. However, the output signal obtained suffers from the nonlinearity characteristics of sensors, making the designer to use additional circuits external to the main transducer for eliminating nonlinearities by one of the sensor

characterization methods. The nonlinearity will be of quite concerns in some applications, for example, any error in controlling the temperature of a boiler will obviously be disastrous, so is the case of robotic applications where wrongly made decisions for taking an onward step by a robot could become disaster in sensors measuring separation between objects or liquid levels. For separation and level measurement there are a number of sensors that are in use such as potential metric devices, capacitance, conductivity probes and ultrasonic devices. All such sensors besides having their own advantages are associated with the concerns of more careful design requirements and the requirement of complicated signal conditioning circuitry to combat the concerns of sensor nonlinearity [4-5]. In some other solutions digital signal processing techniques and other compensation methods are used [6-7]. The technique suggested here in this work is shown for two sensors, the digital output sensor (GP2D15) and the analogue output sensor (GP2D12) [8] with their responses shown in Fig. 1 and Fig. 2 respectively. In many applications, the capability of the analogue output infra red sensor (GP2D12) is not fully exploited. The capability of analogue output infra red sensor (GP2D12) to sense the gradual change of distance is overlooked, and hence is less commonly used compared to its sibling digital output infra red sensor (GP2D15), which gained comparatively more popularity for applications in industry. The inappropriate justification on choosing between these two different sensors is mainly due to two factors--- the designer is only looking for a sensor whose output can be varied within the specified range such in robotic applications, and secondly due to the failure of GP2D12 on dealing with the nonlinearity issue which limits its range of applications.

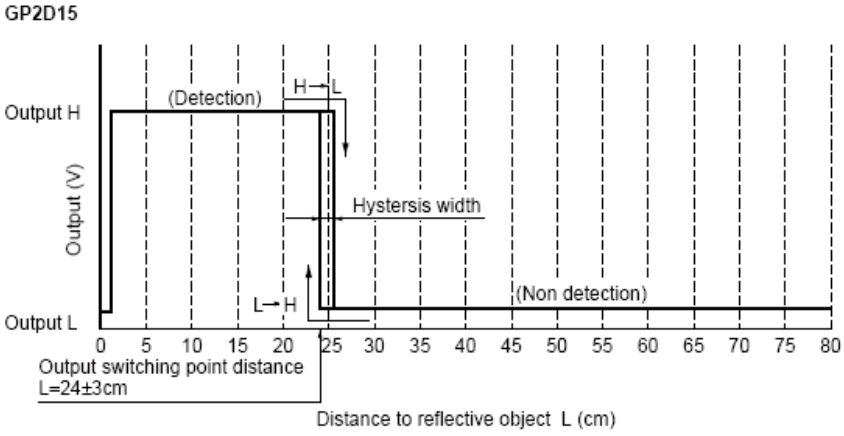

Fig. 1. GP2D15 Output Response by SHARP.

The linearity problem is solved by representing the given response curve through a set of lines drawn manually and tangent to the curve at selected points. The microcontroller in use is programmed for making exclusive jumps among the equations for choosing one of the tangents that closely fits to the voltage input sensed at one of the analogue pins. Hence choosing an equation is equivalent to choosing the corresponding proportional output value. The results of manually calculated distances are compared with a simulation results obtained through using PIC IDE Simulator. The effect of increasing the number of equations is studied to have a favourable effect on the output without sacrificing speed and memory compromises.

Most of the data acquisition systems are microcontrollers-based with input connected to built-in Analog-to-Digital converter (ADC) and pulse width modulated (PWM) outputs. Our work in this suggestion is based on its comparison with the one which is already suggested in [9] which requires additional circuit requirements external to the microcontroller-based transducer for programming the microcontroller in order to make the external circuit help in linearization of the sensor output response. This method is causing two major concerns -- space and cost requirement. Further it comes with the

sacrifice of time and memory requirement in the form of code for making the initial checks on the input in the light of comparisons made by the resistor divider. The work suggested here is program the microcontroller with C language in the light of some manual calculations done manually to the response curve of the infra red distance sensor thus lending itself to many robotic and other related applications where precision in distance measurements is of critical importance.

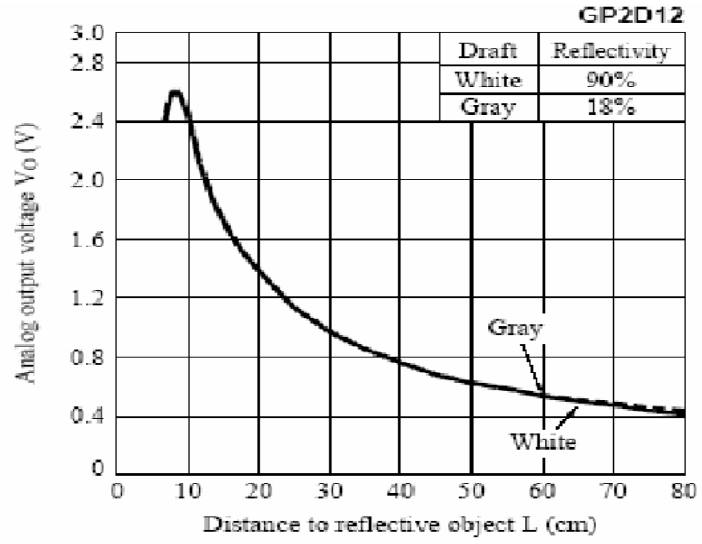

Fig. 2. GP2D12 Output Response – Provided by SHARP.

2. Popular Technique in Solving the Non-linearity Issue

Fig. 3 shows the output response of a GP2D12 analogue output sensor with respect to the distance of an object from its shutter. Tangent lines are drawn manually at selected points as shown in Fig. 3 to represent the given graph as a set of straight tangent lines with each line given by $y = mx + c$, with 'm' being the gradient and 'c' as the y intercept 'x' of the tangent line respectively.

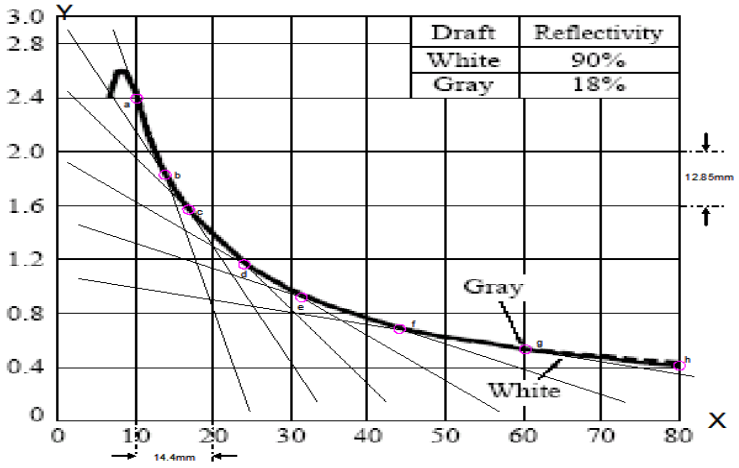

Fig. 3. Number of Tangent Lines Drawn on the Response Graph.

This technique yields distance 'x' given by $x=(y-c)/m$ for a sensed input value of 'y' volts. Though the theory is quite simple, its practical implementation is a challenging task due to a number of 'c' values

that must be measured from the nonlinear response graph given which leads to multiplication of final system errors. For this reason, a lot of designers used the table look up method to solve such problem by pre-programming the output data of distance *x* stored in ROM. However, the method in this work significantly differs in that a simple program is developed to getting in order by a given pointer data of the sensed voltage *'y'* that is being read by sensor from the memory. This is where this programming saves memory space which seems to be comfortably practical and economical in many applications.

3. Solving the Non-linearity Response by Interpolation

In Fig. 2 shows tangent lines are drawn on the output response of GP2D12. They are arranged in a manner that all points on non-linear graph, important from sensitivity view point, are covered by these tangent lines. The coordinates of the points at which tangent lines touch the curve are found by measuring their vertical from the x-axis and horizontal distance form the y-axis. The coordinates so calculated are tabulated in Table 1. For example, at point (e) the distance of the coordinate in horizontal to y axis is 45mm. If it is divided by 14.4 mm and multiplied by 10 cm, resolved 31.25cm; and the distance of the coordinate to x axis is 29.6mm. By dividing 29.6 mm with 12.85mm and multiplying it with 0.4 volt, the result if 0.92 volt is archived. All the calculated coordinates were tabulated in Table 1.

Table 1. Table of Coordinates derived from Fig. 3.

Point	**a**	**b**	**c**	**d**	**e**	**f**	**g**	**h**
X	10.00	13.89	16.67	23.94	31.25	43.82	60.00	80.00
Y	02.40	01.83	01.57	01.17	00.92	00.68	00.53	00.41

The interpolation technique is used to estimate the unknown point between the given two known points. The function is formed by the two known points, and simpler to be solved in such linear problem as only two points are required to perform the exact calculation. For two known points (x_0, y_0) and (x_1, y_1), the equation of interpolation for calculating the x-coordinate of an unknown point in terms of its corresponding y-coordinate is given by $x_b = x_0 + \frac{[y_b - y_0]}{[y_1 - y_0]} \times [x_1 - x_0]$. By putting into this equation the coordinates provided in Table 1, the corresponding equations are as listed in Table 2 for using in the programming code of the microcontroller.

Table 2. Equations Deduced from Coordinate listed in Table 1.

Range of y_b	**Distance measured by the sensor (x_b)**	**Equation**
1.83-2.40	26.37895 - y_b x 6.82456	1
1.57-1.83	33.4569 - y_b x 10.6923	2
1.17-1.57	45.20475 - y_b x 18.175	3
0.92-1.17	58.1508 - y_b x 29.24	4
0.68-0.92	79.435 - y_b x 52.375	5
0.53-0.68	117.16933 - y_b x 107.867	6
0.41– 0.53	148.3333 - y_b x166.667	7

4. Source Code Development

The microcontroller (MICROCHIP PIC16F877A) with a built-in analogue to digital converter is used along with a (2 x 16) Liquid Crystal Display (LCD) for the practical implementation of the technique mentioned above [10]. The Embedded C compiler from Custom Computer Services (CCS) is used for developing the implementation source code for the system. The program is simpler and easy to be developed compared to the tedious assembly language. The flow-chart for developing the source is shown in Fig. 4.

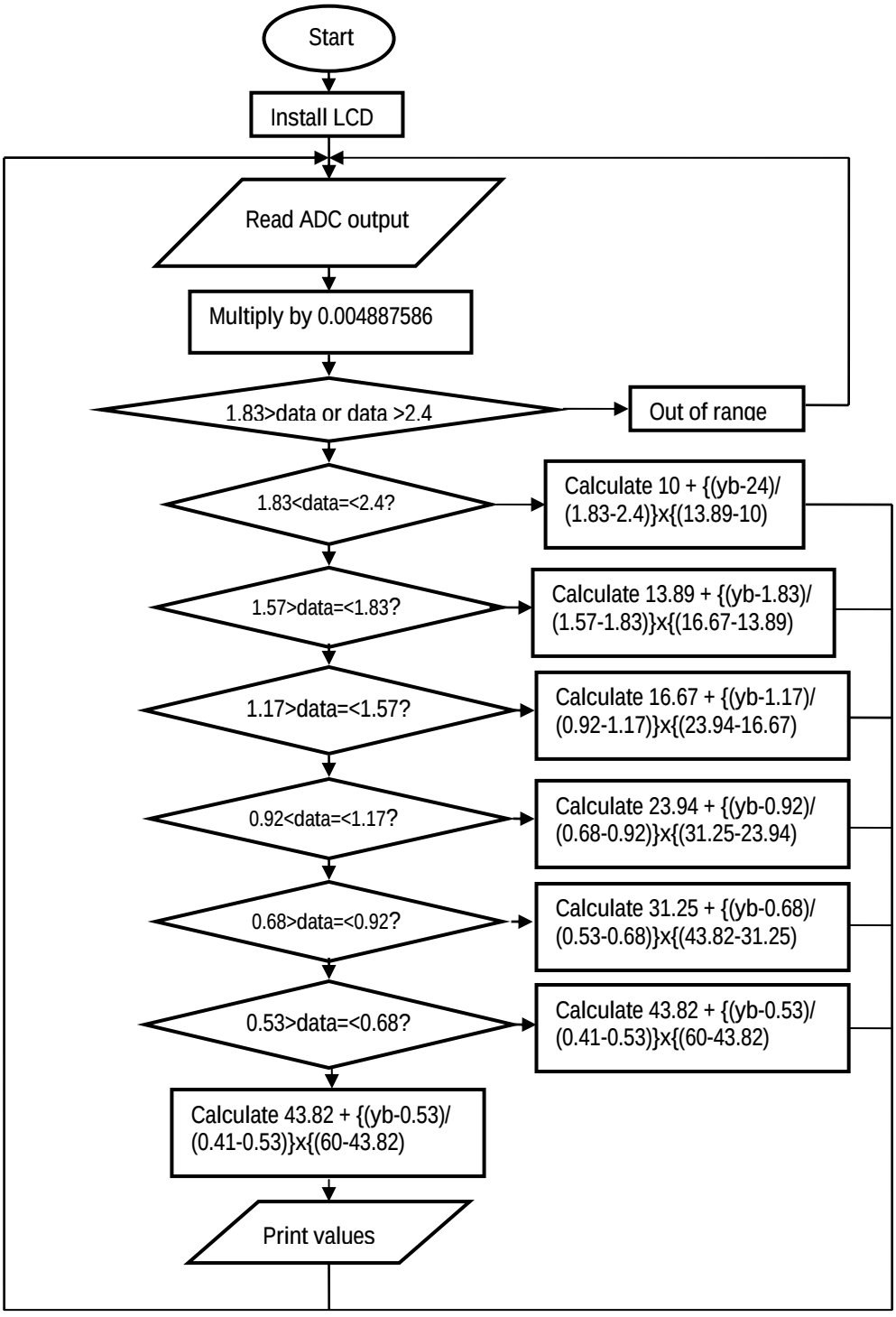

Fig. 4. Source code flow-chart.

The program starts by initializing all the input/output ports, the intended registers and the LCD. Then the processor reads the sensed voltage through the ADC channel 0 (PIN 1). The digital voltage is furthered converted to analogue voltage by using $volt\ (ana) = volt\ (dig) \times 5/1023$.

The result of the conversion is tested using IF-ELSE statements in the code to decide on which of the seven equations will be relevant to be used depending on what is given in Table 2. For input voltage falling out of the available range (0.41 to 2.4 V), the system prompts back to the user a message such as, while for an input voltage '*Out of Range'*, while the system displays the permissible range for a maximum distance of 10 cm.

5. Simulation and Verification

In order to verify the equations discussed in the previous section, the manual calculation are done for all the seven test points. For that purpose, the value inserted y_b is ensured to fall in the range covered by each equation selected. The results were compared to the results generated by the PIC IDE Simulator from Oshon Software. The simulation is done by converting the analogue input to digital and feed the value into the PIC IDE Simulator and the simulation window is shown in Fig. 5.

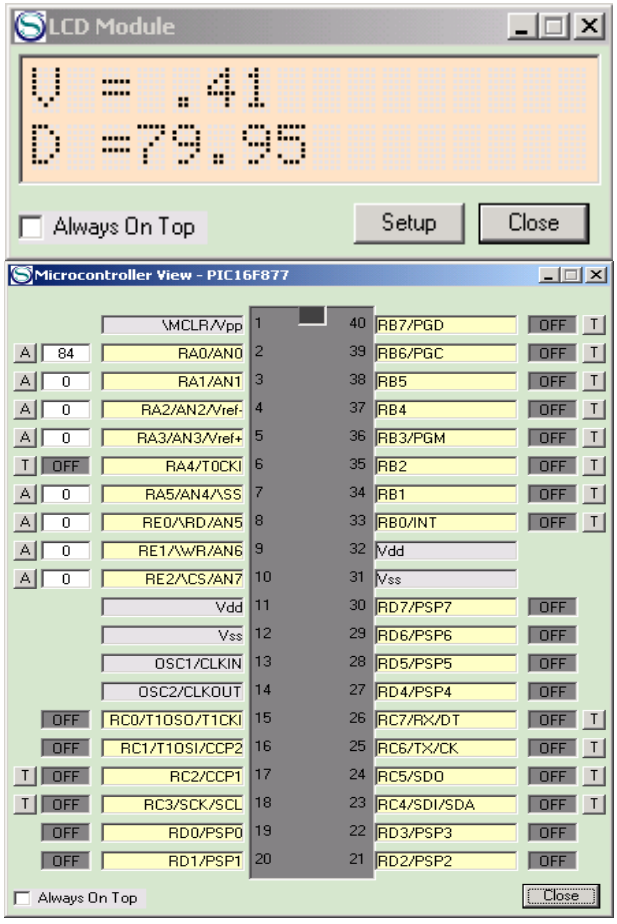

Fig. 5. Simulation using PIC IDE Simulator.

The corresponding manual calculations and comparisons are given in Table 3, where from the seven test points the maximum error between the simulation and the calculation is found to be 0.12 cm

Table 3. Equations and Simulation Derived Values for Errors Calculations.

Input y_b	Equation Value	Simulation	Error
2.10	26.37895 - y_b x 6.82456 = 26.37895 - 2.1 x 6.82456 = 12.047374	12.03 cm	0.02 cm
1.60	33.4569 - y_b x 10.6923 = 33.4569 - 1.6 x 10.6923 = 16.34922	16.36 cm	0.01 cm
1.40	45.20475 - y_b x 18.175 = 45.20475 - 1.4 x 18.175 = 19.75975	19.79 cm	0.03 cm
1.00	58.1508 - y_b x 29.24 = 58.1508 - 1 x 29.24 = 28.9108	28.85 cm	0.06 cm
0.80	79.435 - y_b x 52.375 = 79.435 - 0.8 x 52.375 = 37.535	37.45 cm	0.08 cm
0. 60	117.16933 - y_b x 107.867 = 117.16933 - 0.6 x 107.867 = 52.44913	52.32 cm	0.12 cm
0.45	148.3333 - y_b x166.667 = 148.3333 - 0.45x166.667 = 73.33285	73.44 cm	0.09 cm

6. Final Testing

Finally, the experiment is conducted by developing the special program that is able to interact with the user through the serial port for data entry and display. Fig. 6 shows the experimental set up, where the input represent the digital voltage that is ranging from 0 up to 1023 which are equivalent to 0 volt up to 5 volt. The serial input/output watch (SIOW) from CCS Compiler as shown in Fig. 6 is used to key in the input and display the data received.

Fig. 6. Experimental set up.

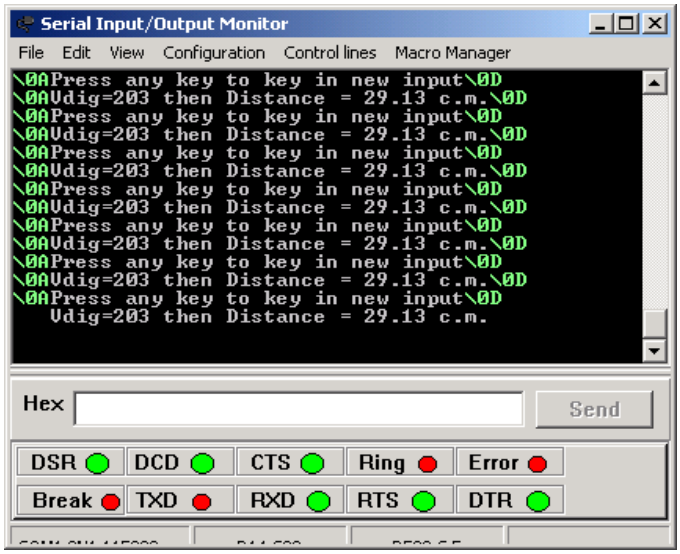

Fig. 6. The SIOW interface.

In response to the input entered, the microcontroller accordingly calculates the corresponding analogue voltage and resultant distance prior to its transfer to a personal computer for display. The results are tabulated in Microsoft Excel spread sheet and again compared to the computational result of the corresponding data. The error of the experimental and the calculation values is ±0.02 cm or ±0.2 mm. Fig. 7 shows the results of the experiment and calculation while Fig. 8 shows the error between the computational and experimental results.

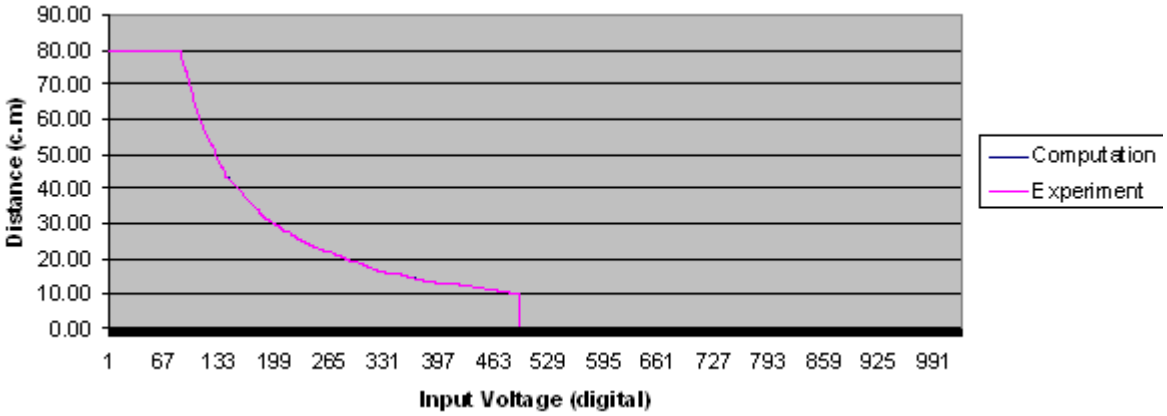

Fig. 7. Experimental and Computational Results.

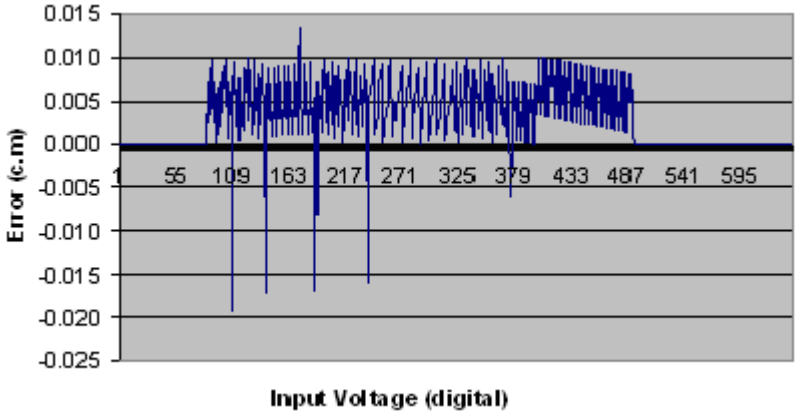

Fig. 8. Error between the Experimental and Computational Results.

The time taken by the microprocessor to solve the above technique is also measured by letting the bit 7 of port B high during the execution of the function. The time taken for the bit to be at high has been measured using oscilloscope to be at 4.86 milliseconds per execution with the operating frequency of 20 MHz. In overall, the sensor produced a precise output with the maximum error of ±0.2 millimetres. If implemented with MICROCHIP PIC16F877A, it requires about 24% of ROM and 16% of RAM, which is equivalent to about 2 K byte. This proves the excellence of the technique suggested for the solution of non-linearity problem with sensors fro smart applications at the cost of a bit of time taken.

7. Conclusions

The level and distance measurement project by using the GP2D12 SHARP distance sensor has been tested and verified to be as expected. It proved that the proposed simple method and procedure applied

to develop the project is applicable in solving the nonlinear response of smart sensor applications. The simple implementation and progressively diminishing error make it really suitable for number of precise measurement applications. In addition this method eliminates the chances of errors as a result of external circuitry due to degradation and environmental damage as a result of result of temperature and physical contacts.

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