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FPGA Implementation of Data Fusion Algorithm for Distance Measurement

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Abstract **– Sensors play an important role in our everyday life because we have a need to gather information and process it for some tasks. Working with several types of sensors in practical application such as mobile robotics involves several uncertainties that can be overcome using sensor fusion techniques. Smart devices require reliable and different types of sensory data, fusing them to obtain better information regarding their objectives. Different types of sensors are often fused to acquire information which cannot be acquired by a single sensor alone. Sensor fusion is particularly applicable for mobile robots for object detection and navigation. The sensor fusion techniques that have been developed so far for detecting an obstacle are costly and complex. So a new technique is proposed which can detect an obstacle, judge its distance using infrared and ultrasonic sensor with the help of an FPGA. Here we propose a Data fusion technique in which central limit theorem is used as fusion algorithm, which is implemented using MATLAB. The hardware implementation has been done on Papilio one board using Arduino IDE. The proposed technique is less costly than previous techniques both in terms of economic feasibility and in terms of computation.**

Keywords **– Data Fusion, FPGA, Arduino IDE, Central Limit Theorem, Papilio One Board.**

I. INTRODUCTION

Mobile robotics is one of the progressive technological fields which probably will play an important role in the 21st century. The most serious problem for the mobile robot navigation is obstacle detection and their localization. The determination of obstacle position should be as accurate as possible in order to support robot self-localization procedures.

Using external sensors, a robot can interact with its surroundings in a flexible manner. For example, a robot can manipulate a target object flexibly based on sensor data without intervention by a human operator [2]. Even though much development happens in recent years, none of the location sensor has ability to take perfect measurements in all situations.

This paper concentrates on the sensors used in mobile robot systems to avoid obstacles and find out the distance to an obstacle with the help of an FPGA. The task of the sensor system is not only collecting the information but to translate it to meaningful data to the control system. So in the case of practical application such as mobile robotics, working with several types of sensors creates several uncertainties will cause serious problems, which can be overcome by using efficient sensor fusion techniques [1]. Sensor fusion roughly means integration of information from different types of sensor into a unified interpretation. Without sensor fusion it is impossible for the robot to know where it is, where it needs to go, where the path is, which path to take or has it reached the destination yet. So sensor fusion is a technique that permits to combine the information provided by the sensors and improve the data rather than the case single sensor used [1]. Fig.1 shows the general pattern of multi sensor fusion model.

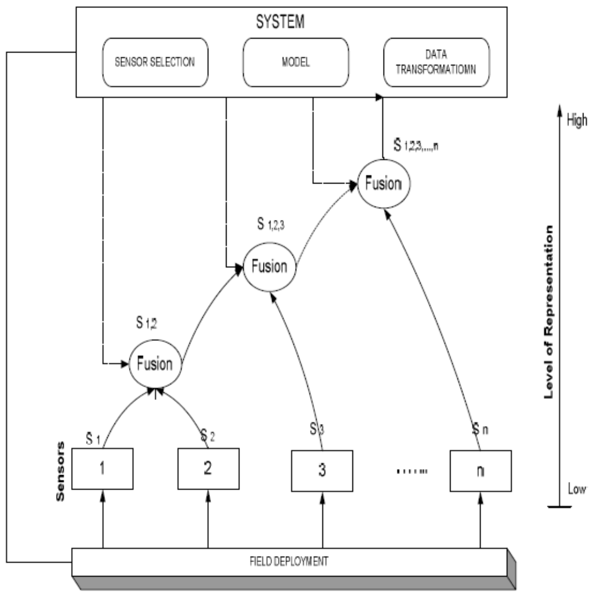

Fig.1. General Pattern of Multi Sensor Fusion

Even though many types of sensors are available, we will lean down to two major categories of ultrasonic and infrared sensors. In the case of a mobile robot, for finding out the distance from an obstacle, it mainly uses two sensors Ultrasonic (US) and infrared sensors (IR). In this IR sensor is cheaper in cost and faster in response than Ultrasonic sensor.

However, they have non-linear characteristics and they depend on the reactance properties of the object surfaces. Their inherently fast response is attractive for improving the realtime response of a mobile robot. It has sharp focus, but its reflectivity is less from dark surface, more over it has serious limitations in the case of detecting glass or mirror based obstacles [1, 4]. On the other hand US sensor is based on sound wave propagation they are useful under conditions of poor lighting and transparent objects. However, US sensors have limitations due to their wide beam width, sensitivity to specula surfaces. US sensors are reflected from black surfaces but it does not have sharp focus. It also depends on the temperature. So combination of these two sensors will allow us to scan the object and form its representation which closely matches the original object [5].

Here Ultrasonic and infrared sensors are used in complementary fashion, where the advantages of one can compensate for the disadvantages of the other sensor. The robot then combines the information from the two sensors to build a more accurate output [10]. Here use of efficient data fusion algorithm for infrared and ultrasonic sensors using FPGA which overcomes many problems related to complexity and intends to provide higher performance and less power consumption. This can be used in many applications based on the degree of the accuracy. The key requirement for developing any innovative system is to integrate a sufficiently friendly interface and reliable that can provide a high degree of accuracy.

In modern days the use of FPGA has obtained a special attention of the scientific community for solving computational problems. They support accurate, fast signal processing. Traditional hardware circuitry and computer software algorithms can be replaced by FPGAs for field computation. Furthermore, FPGA algorithms provide reconfigurable and programmable features which have great potential for flexible implementation of sensor fusion experiments. FPGA provides many advantages over traditional method such as performance, prototyping capabilities, and reliability. When comparing FPGA-based design with traditional method, it exhibits much accuracy and it is much faster. This paper explores the implementation of an efficient data fusion technique using FPGA.

II. Related Works

A lot of related works have been carried out in this area by different researchers and academicians. As of now many workable solutions are available, still the complexity involves when large numbers of sensors (heterogeneous) require in the applications such as mobile robotics. A. H. G. Al-Dhaher, E. A. Farsi and D. Mackesy presented a paper [6] for Data Fusion Architecture – An FPGA Implementation. It described the architecture for multisensory data fusion based on adaptive Kalman filter. They used many sensors that measure same quantity and each output is fed to Kalman filter. A correlation coefficient is described for each Kalman filter between the measured data and predicted output was used as an indication of the quality of the performance of the Kalman filter. Based on the values, noise covariance matrix was made using fuzzy logic technique.

One of such recent work in this area has been presented by Milton E. Conde, Sergio Cruz, Daniel M. Munoz, Carlos H. Llanos, and Eugenio L. F. Fortaleza [1]. It was an FPGA implementation Kalman Static Estimation Algorithm, using and the architecture was described in VHDL language and includes a NIOS II processor and several interfacing blocks. The gain state and variance of the estimate are found out using Kalman Static estimation algorithms. The scalability of the system will be higher with two sensors by using recursive approach.

III. System Implementation

This work shows the hardware implementation of sensor fusion technique that can be applied to both Ultrasonic and Infrared sensors for measuring the distance using FPGA. Here we propose a sensor fusion technique which is less costly and less complex, that will allow an autonomous robot to detect an obstacle, and the distance to that obstacle. Our system uses an Infrared range sensor and an Ultrasonic range sensor to achieve this. We use the range data collected by the ultrasonic sensor and infrared sensor for object detection. Here we use Central Limit theorem as fusion algorithm. The basic block diagram of the entire system is shown in Fig.2

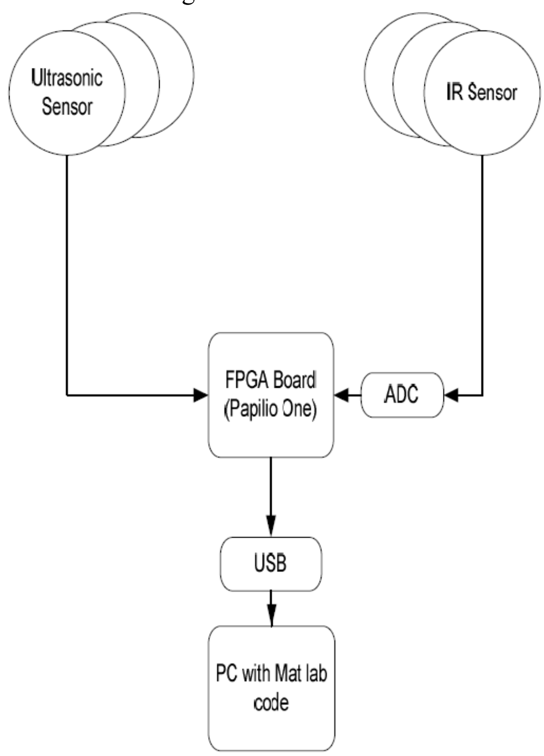

Fig.2. Block diagram of the proposed system

Obstacle can be detected using mainly by two methods:

- Range-based obstacle detection.
- Appearance-based obstacle detection.

In range-based obstacle detection, sensors scan the area and detect any obstacle within the range and the sensors

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also try and calculate the range between the robot and the obstacle. In appearance based obstacle detection, the physical appearance of the obstacle is detected from the environment, usually by image processing. Here we are using range based obstacle detection.

A. Design of Hardware

The entire fusion system is incorporated with a low cost, high performance Papilio one board with Spartan 3E XC3S250E processor as main core and two sensors for collecting data from the obstacle. The information from the infrared sensor is collected and converted to digital data before sending to FPGA. On contrary ultrasonic sensor's data is interfaced to FPGA directly. We are using Papilio one FPGA board for the design and implementation of the proposed work. The processor supports maximum clock frequency of 32 MHz and the fusion techniques will be coded in Arduino. The processed data will be transmitted to PC.

Here Central Limit theorem is applied as fusion algorithm using MatLab coding. The final output will be a “bell curve”; the exact position of the obstacle will be the center value of the bell curve. This generated data can be used for many applications, especially in robotics in a cost effective manner. Fig.3 shows the sensor fusion system arrangement. The different parts of the entire system is,

- Ultrasonic sensor - HC-SR04
- Infrared sensor - SHARP GP2Y0A21YK0F
- Analog to Digital Converter - PCF8591
- Papilio one Board
- Desktop computer

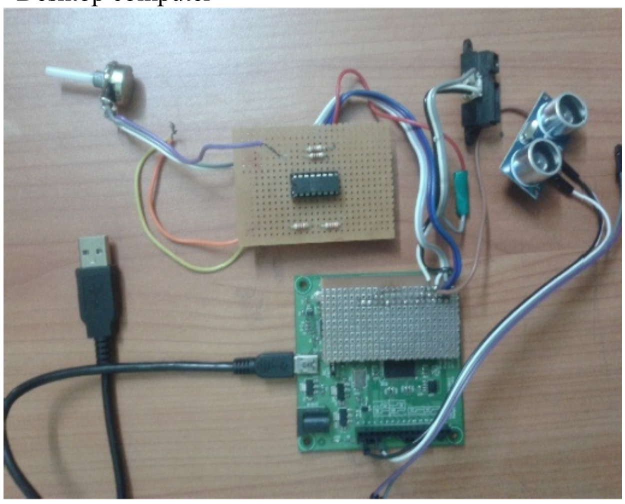

Fig.3. Sensor fusion system arrangement

B. Central Limit Theorem

Central limit theorem states that in a given condition, the mean of a sufficiently large number of independent random variables, each with finite mean and variance, will be approximately normally distributed [15]. In our implementation the CLT is applied as below

- We will take *n* number of samples or readings from both of the sensors and will put it an array.
- Value of *n* can be decided as per experimental accuracy, consistency and memory supported by FPGA.
- The mean of these readings will be distributed as per Gaussian curve i.e. bell shaped.
- Our final reading of sensor fusion will be center value of Gaussian curve.

If we are trying to find out the mean of a large number of samples by averaging samples, our estimate will be approximately normal, even though we don’t know what distribution is generating the original data [15]. The central limit theorem says that the computed values of the average will be distributed according to the normal distribution commonly known as a "bell curve"[14] as shown in Fig. 4.

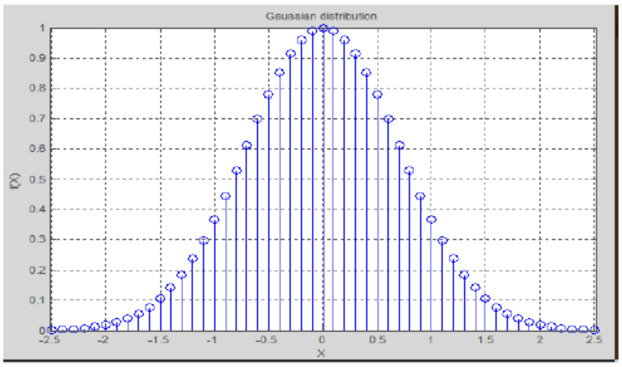

Fig.4. Normal distribution or bell curve

Let X_1 and X_2 denote two sensor measurements with noise variances σ_1^2 and σ_2^2 respectively. One way of obtaining a fusion of data, X_3 is to apply the Central Limit Theorem,

$$X_3 = \sigma_3^{\,2}(\sigma_1^{\,-2} X_1 + \sigma_2^{\,-2} X_2) \qquad (1)$$

Where

$$\sigma_3^{\,2} = (\sigma_1^{\,-2} + \sigma_2^{\,-2}) \qquad (2)$$

The Central Limit Theorem demonstrates that for non normal data, the distribution of the sample means has an approximate normal distribution, no matter what the distribution of the original data looks like, as long as the sample size is large enough (usually at least 30) and all samples have the same size [15].

C. Characterization of sensors

The sensors used to perform functional tests were HCSR04 (ultrasonic sensor) and SHARP GP2Y0A21YK0F (infrared sensor). Ultrasonic sensor provides 2cm - 400cm non contact measurement function, the ranging accuracy can reach to 3mm [11]. The modules includes ultrasonic transmitters, receiver and control circuit. It will send a trigger signal with an operating frequency of 40 kHz and raises its echo. We can calculate the distance through the time interval between sending trigger signal and receiving echo signal [11].

GP2Y0A21YK0F is a distance measuring sensor unit, composed of an integrated combination of PSD (position sensitive detector), IRED (infrared emitting diode) and signal processing circuit [10]. This device outputs the voltage corresponding to the detection distance. In order to obtain the observations the object will keep at different positions and will take the readings. The output of the infrared will be analog in nature for converting in to digital by ADC PCF 8591.Here for interfacing I2C protocol is used. This will give the output in digital format.

IV. Results

We implemented the first part of the block diagram, i.e. ADC interfacing using I2C protocol. The program, written in Arduino is loaded into the Papilio One board using I2C interfacing. The Fig.4 shows the output of infrared sensor with I2C interface.

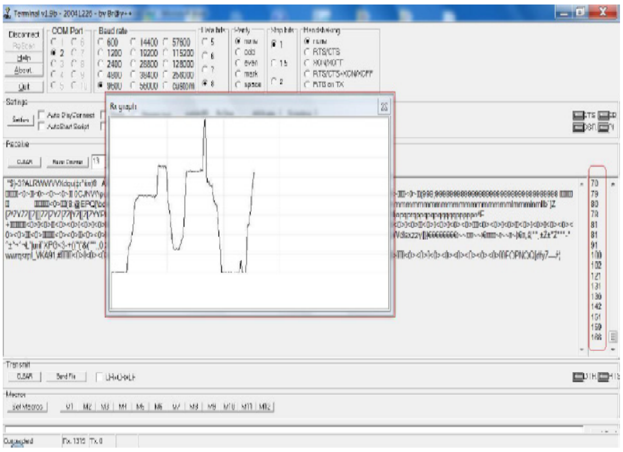

Fig.5. Sensor interfacing output

V. Conclusion

A novel Data fusion technique based on Central limit theorem as fusion algorithm is presented. The proposed work is FPGA based implementation of Data Fusion Architecture for Ultrasonic and Infrared sensors to find out the distance to an obstacle. The approach is less costly than the other existing techniques both in terms of economic feasibility and in terms of computation. Its low computational complexity leads to less hardware resource requirements without compromising the speed of operations. These would be probably most useful advantages in the field of applications such as robotics and we are aiming its implementation in a cost effective manner.

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