An Efficient Data Fusion Architecture for Location Estimation Using FPGA

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Abstract

Data fusion is an important part in today's life, especially in the smart world where devices are becoming smarter. 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 techniques that have been developed so far for detecting an obstacle are costly. Hence, 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 Architecture with central limit theorem as fusion algorithm. The system implementation have 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.

1. Introduction.

Sensors play an important role in our everyday life because we have a need to gather information and process it for some tasks. Successful application of sensor depends on sensor characterization accuracy, performance, cost and reliability. The paradigm of multi sensor fusion techniques and sensor technologies are used in micro sensor based application in robotics, defence, remote sensing, equipment monitoring, and biomedical engineering and transportation systems. Mobile robotics is one of the progressive technological fields which probably will play an important role in the 21th century. Using highly developed sensors, mobile robots can accomplish very sophisticated tasks even in human environment.

Sensor is a device that detects and responds to some type of input from the physical environment. The specific input could be light, heat, motion, moisture, pressure, or any one of a great number of other environmental phenomena. Working with several types of sensors in a practical application such as mobile robotics involves several uncertainties represents a serious problem, which can be overcome by using efficient fusion techniques [1]. Even though many types of sensors are available, we will lean down to two major categories of Ultrasonic and Infrared.

Sensor fusion roughly means integration of information from different types of sensor into a unified interpretation. Improvement in performance and size, driven by the technology, has enabled adoption of more sensors. This growing branch of applied informatics aims at the production of comprehensive, precise, and near real-time situation pictures, which are basic for further decisions or actions. Important applications exist in logistics, advanced driver assistance systems, medical care, public security, defence, aerospace, robotics, industrial production, precision agriculture, track monitoring.

2. Theoretical Background.

The most crucial problem for the mobile robot navigation is obstacles detection and their localization. The determination of obstacle position should be as accurate as possible in order to support robot self-localization procedures. In order to increase its efficiency the recognition of some feature of obstacles shapes should be done. Even though much advancement happens in recent years, none of the location sensor has ability to take perfect measurements in all situations. Exact knowledge of the position of a vehicle is a fundamental problem in heterogeneous sensor applications such as mobile robotics. In search for a solution, researchers and engineers have developed a variety of systems, sensors, and techniques for location estimation.

In the case of a mobile robot, for finding out the distance from an obstacle it mainly uses two sensors Ultra sonic (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 real-time 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 [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].

Multiple sensors can be used on a mobile robot so that it can perceive its environment with better accuracy than if either sensor were used alone. Sonar and infrared sensors are used here in a complementary fashion, where the advantages of one compensate for the disadvantages of the other. The robot then combines the information from the two sensors to build a more accurate map. Here use of efficient data fusion architecture 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 is obtaining 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 similar accuracy computer based implementation but is much faster. In order to satisfy strict pointing requirements, there is a need for complex state estimation algorithms to compensate for low accuracy sensors, however traditional micro controller/processor based approaches often lack the power required to meet the real-time computing deadlines. This paper explores the implementation of an efficient data fusion technique using FPGA.

3. Sensor fusion Techniques.

Data fusion is a technique that is used to combine data from multiple sources and gather that information into discrete, actionable items in order to achieve inferences, which will be more efficient and narrowly tailored than if they were achieved by means of disparate sources [5]. Figure 1 shows the basic sensor fusion model.

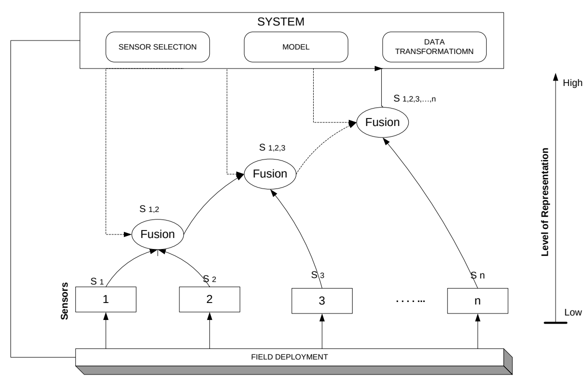

Figure 1: General Pattern of Multi Sensor Fusion.

A lot of works are carried out in field of location estimation using sensors in the recent past with different technologies. Some of them are explaining here below.

3. 1 Bayes filters.

Bayes filters probabilistically estimate a dynamic system's state from noisy observations [2]. Bayes filters represent the state at time t by random variables

x_t. At each point in time, a probability distribution over x_t, called belief, Bel (x_t), represent the uncertainty .This technique sequentially estimate uncertainty over the state space conditioned on all information contained in the sensor data. The illustration of Bayes Filter is

$$Bel(xt) = p(x_t \mid s_1, s_2, ..., s_t) \qquad (1)$$

Where s_1, s_2… s_t are the sensor observations.

The computation uses certain assumptions that dynamic system is Markov—that is, the current state variable xt contains all relevant information to make the computation obedient. This is true and provide near accurate result when the object is stable. In contrary if the object is in motion state, it add ambiguity in the computation. This is override by update Bayes filter by providing new observations.

Bayes filters are an abstract concept in that they provide only a probabilistic framework for recursive state estimation. In order to implement Bayes filters require the perceptual model, dynamics and representation of belief .The properties of the different implementations of Bayes filters strongly differ in how they represent probability densities over the state xt.[2]

3. 2 Kalman filters.

A Kalman filter is an algorithm that estimates the state of a discrete time controlled process described by the linear stochastic equation [1]. KF incorporates all information that can be provided to it. It processes all available measurements, regardless of their precision, to estimate the current value of the variables of interest. It provides an estimate of the current parameters using current measurements and previous parameter estimates.

$$X(k) = Ax_{k-1} + B_k u_k + w_{k-1} \qquad (2)$$

With measurement

$$Z_k = H_k x_k + \gamma_k \qquad (3)$$

Where X_k is System state vector, Wk is the process noise, γ_k is the measurement nice. H is the measurement transfer matrix. A is a transition matrix and B relate to the control input.

In order to use Kalman filtering it is important to analyze the statistical behaviour of the value to be measured. Kalman filters are optimal estimators, which mean the initial uncertainty is Gaussian and the observation model and system dynamics are linear functions of the state. Most of the real time problem, the systems may not provide linear characteristic, so we use extended Kalman filter, which will linearize the system [2].

The main advantage of Kalman filter is its computational efficiency but it can represent only unimodal distributions. So Kalman filters are best when the uncertainty is not too high [2].

3.3 Multi hypothesis Tracking.

The Multiple Hypothesis Tracking algorithm, proposed by Donald Reid in 1979, is considered by some the preferred algorithm for difficult tracking situations. Multihypothesis tracking can overcome Kalman filter's limitation to unimodal distributions. MHT represents the belief as mixtures of Gaussians [2].

$$Bel(X_t) \approx \sum_i w_t^{(i)} N(x_t; \mu_t^{(i)}, \Sigma_t^{(i)}) \qquad (4)$$

The MHT tracks each Gaussian hypothesis using a KF. MHT require computationally more expensive resources and require sophisticated techniques [2].

3.4 Grid Based Approaches.

These approaches overcome the restrictions imposed on Kalman filters by relying on discrete, piecewise constant representations of the belief. For indoor location estimation, grid-based filters tessellate the environment into small patches, typically between 10 cm and 1 m in size. Each grid cell contains the belief that the person or object is in each cell. A key advantage of these approaches is that they can represent arbitrary distributions over the discrete state space and can solve estimation problems [2]. The mobile-robot localization community has shown that metric approximations provide accurate position estimates in combination with high robustness to sensor noise Grid based approaches disadvantage is the computational and space complexity required to keep the position grid in memory and to update it for every new observation. Because the complexity grows exponentially with the number of dimensions, we can apply grid-based approaches only to low dimensional estimation problems, such as estimating a person's position and orientation.

3.5 Topological Approaches.

We can avoid the computational complexity of grid-based methods using non metric representations of an environment. For instance, many indoor environments provide a natural way to represent a person's location at a symbolic level such as the room or hallway the person is currently in. Such representations result in topological implementations of Bayes filters, each node in the graph corresponds to a location, and the edges describe the environment's connectivity, typically given by hallways. The motion model p (xt, xt-1), which describes where a person walks, can be trained to represent typical motion patterns of individuals moving through the environment [2].

Topological approaches advantage is their efficiency, because they represent distributions over small, discrete state spaces. Their disadvantage is the representation's coarseness. Estimates provide only rough information about a person's location. Topological approaches are typically adequate if the sensors in the environment provide only very imprecise location information.

4 Related Works.

A lot of work has been carried out in this topic by 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.

One of such recent work in this area [1] has been presented by Milton E. Conde, S´ergio Cruz, Daniel M. Mu˜noz, 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 if the system can be reach more than two sensors by using recursive approach.

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 multisensor data fusion based on adaptive Kalman filter. That used many sensors that measure same quantity and each 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. Predicted outputs.

5 Proposed Work.

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 both in terms of economically and computationally, 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.

5.1 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 sensors for collecting data from the obstacle. The basic block diagram of the entire system is shown in figure 2, the data from the Infrared Sensor is collected and converted to digital data before feeding to FPGA. On contrary Ultrasonic sensor's data is feed to FPGA directly. The core of the system is FPGA where Central Limit theorem will be applied as fusion algorithm. 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 transmit to a PC and output will show with help of Mat Lab .This generated data can be used for many applications, we aim for probably most useful in Robotic applications in a cost effective manner.

5.1 Central Limit Theorem.

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

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

As per Wikipedia definition, in probability theory, the central limit theorem (CLT) states that, given certain conditions, the arithmetic mean of a sufficiently large number of iterates of independent random variables, each with a well defined expected value and well defined variance, will be approximately normally distributed. That is, suppose that a sample is obtained containing a large number of observations, each observation being randomly generated in a way that does not depend on the values of the other observations, and that the arithmetic average of the observed values is computed. If this procedure is performed many times, the computed average will not always be the same each time; 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".

Let S_1 and S_2 denote two sensor measurements with noise variances σ_1^2 and σ_2^2, respectively. One way of obtaining a combined measurement S_3 is to apply the Central Limit Theorem, which is also employed within the Fraser-Potter fixed-interval smoother, namely

$$S_3 = \sigma_3^{\,2}(\sigma_1^{-2} S_1 + \sigma_2^{-2} S_2) \qquad (5)$$

Where

$$\sigma_3^{\,2} = (\sigma_1^{-2} + \sigma_2^{-2}) \qquad (6)$$

The Central Limit Theorem basically says 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.

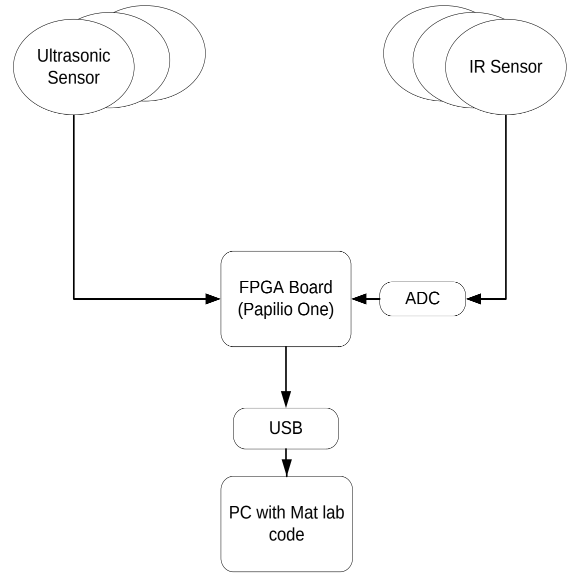

Figure 2 – Block diagram of the proposed system

As shown in the diagram, the data from the Infrared Sensor is collected and converted to digital signal before feeding to FPGA. The core of the system is FPGA where Central Limit theorem will be applied and processed. On contrary Ultrasonic sensor's data is feed to FPGA directly. We would prefer to use Papilio one [8] FPGA board for the design and implementation of the proposed work. This is based on XILINX Xc3S250E processor that supports maximum clock frequency of 32 MHz .The Fusion techniques will be coded in Arduino IDE using supported language and is transmit to FPGA in its native format. The processed data will transmit to a PC and shown with help of Mat Lab PC. This generated data can be used for many applications, we aim for probably most useful in Robotic applications in a cost effective manner.

6 Conclusion.

A novel Data fusion architecture 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 com promising 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.

7. References

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