International Journal of Science & Technology ISSN (online): 2250-141X
www.ijst.co.in Vol. 5 Issue 1, June 2015

HARDWARE REALIZATION OF DATA FUSION ARCHITECTURE

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Abstract—*This work shows a sensor fusion technique applied to the data received from an ultrasonic sensor and an infrared sensor. PLD platform is used to realize and deploy the hardware for estimating the distance of any obstacle. LCD is used to display the distance of obstacle. Fusion is used for various applications in navigation, robotics, etc and is an application of stochastic filtering. Fusion is used to combine the data provided by different sensors for accurate estimation of the measured variable. SOC platform has ADC interface and ADC is interfaced to sensors. Functional Simulation and Synthesis of the proposed work is done and performance measurements like power, area are measured.*

Keywords— Data fusion, FPGA, Variance, Robotics, Infrared Sensors, Ultrasonic Sensor, Sensor Fusion.

I. Introduction

Mobile robotics depends on sensory data fusion for detailed information on location and for advanced collision avoidance techniques. A developing technology in this field is the data fusion of multiple sensors. The basic necessity for the robot is to be able to be adaptive to the constantly changing surroundings and to be able to adjust to the dynamic environment and doing so, without getting confused and not performing any unexpected task. Robots have made our life easier by helping human beings in many tasks of our day to day life. Robots have also made such tasks possible which are almost impossible for human body to sustain like working in high radiation and going to outer space.

During the period of evolution and adaptation, the concept of data fusion has been used by all living beings to survive in the constantly changing environment around us. For example, it is not possible to tell if a given food item is edible by merely looking at it, we have to use many of our senses like vision, touch, taste and smell to make a judged decision. In the same manner we need data fusion for every other day to day activity as well. Thus to efficiently increase their chances of survival, living beings naturally perform data fusion of different senses to adjust and adapt to their surroundings.

There are different types of sensors present in mobile robots and each of them have their own advantages as well as disadvantages. Each sensor fails in particular condition. Hence the information from every sensor must be considered through optimal localization to ensure expected outcomes and perfect accuracy. Many serious issues may be encountered by different sensors with distinct failure modes and certain uncertainties. In order to overcome these issues, we have to use data fusion techniques like those provided through linear filtering.

Let us suppose a mobile robot has two distinct sensors, namely infrared and ultrasonic and has to find the distance of an object. In such a case, better stability, precision and accuracy will be presented by

ISSN (online): 2250-141X
Vol. 5 Issue 1, June 2015

the infrared sensor when the system is working in noisy environment. In addition to this it will provide a quicker response as compared to the ultrasonic sensor and will be much more economic in comparison.

But in case of infrared sensor, many limitations must be considered which can be classified as its different failure modes, for example while detecting a mirror or a glass based obstacle, the translucence property of the medium of propagation may lead to several errors. Thus encountering a glass-based obstacle obviously deteriorates the accuracy and precision of the robot. But in the same case if we consider an ultrasonic sensor, it will work perfectly as there is no interruption in the signal. But even the ultrasonic sensor fails in a noisy environment. Thus data fusion of different types of sensors is extremely necessary in order to ensure the robot's proper and collision free movement in real world environment.

II. Literature Survey

Real time data fusion has been made feasible due to the use of modern sensors, parallel processing hardware and efficient processing techniques. According to Brooks [1], in order to interact with its surroundings a robot must use its different sensors so that it can overcome the obstacles and other hardships and successfully reach its target and avoid collision. Brook's approach usually has been described as the Subsumption Architecture, and it considers dividing the robot's main controlling system in distinct modules which can function in a parallel fashion and perform a separate and specific task. The contrast for this method has presented by "classical" philosophy [l] which uses dividing the navigation control in order to form a Hierarchical Architecture, in a string of functional levels which is more suitable for planning tasks off-line.

Latest technological developments led to considering of a combined approach by [2] where the well-founded concepts of the subsumption architecture are applied in unification with a more advantageous planning approach. Subsumption architecture is generally low-level and reflexive behaviour related. This strategy helps in creating a navigation architecture which can be actualized based on the application of knowledge of ambience and optical landmarks for trajectory devising. But, this approach had a lot of errors, because it divides the comprehensive architecture in two basic parts namely, The Subsumption architecture and The Hierarchical architecture which have been further branched into many distinct modules. To calculate the final outcome the different modules in the architectures are combined and then the above mentioned architectures are combined. The testing of the system was done only in the limited ambience of the developer's laboratory. No testing was done in any constantly changing environment. Furthermore the structure was not processing on a real time basis.

The implementation of data fusion deployed on hardware using both infrared sensors and ultrasonic sensors was done by [3] for calculating the distance by using an FPGA. Fusion of sensors was done by stochastic filtering by using Kalman filter which is broadly used in the field of mobile robotics and signal processing etc. This method helps in combining the outputs of all the sensors and thus improving the assessment of the measured value and also the ambiguity. The arrangement used Kalman filtering method and the statistical behaviour of the entity to be measured was taken in terms of ambiguity, which was described as the probability density function. The fusion is done using an NIOS II processor and using an Avalon Bus to transfer the data. The system although is designed by using an NIOS II processor that was available for the author, but cannot be afforded by everyone since the NIOS II processor architecture is very high-priced and its usage raises the comprehensive cost of the system since the processor is supposed to be implemented on an FPGA. Furthermore, using of the NIOS II processor depends on its availability in the market. Hence, the implementation of the system is limited and very costly.

Relevance:

The system to be actualized is of importance in robotics and will be of outstanding help to support collision free movement of robots without the need of human surveillance. Furthermore the system can also be used in high radiation environment.

The system can also function in sunlight without any problem in its precision and can also detect mirror or glass or opaque objects in its path or trajectory. It also works efficiently in wet habitat and hence can help in getting genuine statistics for the robot to move without colliding with other robots or any obstacle in its path. It can be implemented in any place and without any need for an additional processor to implement it on FPGA.

III. Proposed System

A fusion technique is designed and implemented to achieve sensory data fusion of the data received from two different sensors. The fusion module consists of hardware for estimating the mean and variance of data from both sensors.

The variables *x1* and *x2* are used to represent two measurements received from two different sensors *s1* and *s2* simultaneously. This is a static case for the fusion process, which involves measurements from two sensors which have associated variances $\sigma1$ and $\sigma2$, respectively.

The variance of the entire system is calculated using mean of the data from both sensors.

$$\text{Mean} = \frac{x1+x2}{2} \qquad \ldots(1)$$

Mean is calculated as seen in equation (1). The hardware for calculation of mean is designed using floating point arithmetic for more precision and accuracy.

The variance of the data received from both the sensors is measured by using the mean calculated by using equation (1). It has mean, $x1$ and $x2$ as inputs. The variance is calculated by using

$$\text{Variance} = \frac{(mean-x1)^2 + (mean-x2)^2}{2} \ \ldots(2)$$

The variance of data from both the sensors is calculated by using equation (2). The variance has been measured using floating point arithmetic for accuracy and precision. The variance obtained is the variation of measurement of the distance of the obstacle from the intended hardware.

The FPGA implementation of the architecture has been described in Verilog language, which includes several interfacing blocks. Different controllers have been designed for the interfacing for different hardware with the PLD platform. Controllers for different hardware modules like ADC, Ultrasonic sensor, infrared sensor and LCD were designed to ensure accurate and error free interfacing of the hardware and problem free working of the entire system.

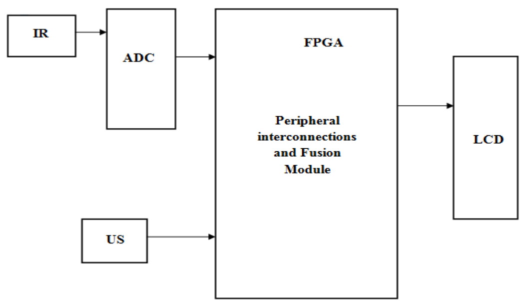

Figure 1: The proposed architecture

The block diagram seen in figure 1, depicts the proposed structure of the architecture, which is comprised of the fusion module, the ADC controller, the Infrared sensor controller, Ultrasonic sensor controller and LCD controller. The sensor data acquisition and their mean and overall variance will give distances in centimeters. Afterwards, the calculated data will be displayed on the LCD.

ISSN (online): 2250-141X
Vol. 5 Issue 1, June 2015

The data from the IR sensors is sent to the ADC where the analog data is converted into digital data and is forwarded to the FPGA, to which the ADC is interfaced. The ultrasonic sensor gives digital output and the ultrasonic controller module takes care of the calculation of distance. The fusion of the data received from both the sensors is done on the FPGA using equations (1) and (2).

Single Precision Floating Point arithmetic is implemented on FPGA to enable successful and precise measurement using equation (1) and (2).

The data received after fusion is converted to fixed point and displayed on the LCD which is interfaced to the FPGA using LCD controller.

All of the above mentioned controller modules are described using Verilog language.

IV. EXPERIMENTATION

The verification of the system has been done using Verilog test bench. The verification of individual modules and the entire system as a whole has been done. For the verification of ADC controller the eoc pin which is a 1-bit input to the FPGA has been made high at the same time the 1-bit rst pin is made low and the eoc pin is again made low after 100ns. The addr[2:0] which is a 3 bit input to the ADC selects the channel through which conversion takes place. It is always kept at “000” as conversion is done only on one channel.

The verification of ultrasonic sensor controller has been done by making one bit trig pin high for 10us and the making it low to initialize the ultrasonic sensor. After the trig has been made low, the amount of time for which echo is high is measured and the distance which is 16 bit, is calculated according to the time for which the echo pin is high.

The verification of the LCD controller module has been done by checking the control pins like rs, rw and en which are all 1-bit pins. The data_in[7:0] is 8-bit input to the LCD module and the data is divided set of 2 nibbles to be displayed on the LCD. Different sets of inputs have to be sent for the initialization of the LCD. They are sent in the form of nibbles by the controller module to the LCD.

The ir_din[7:0] serves as the input to the fusion module which is considered to be the output from the ADC after conversion of the IR sensor data. The output in the form of distance, from the US controller is given as input to the fusion module. In the fusion module the data is converted to 32 bit data in the form of floating point number.

The calculation of the variance and mean is done using floating point arithmetic.

V. RESULTS

The functional verification of the system has been done using MATLAB. The functional simulation of the system has been done and the results were matched to ensure proper implementation of the system.

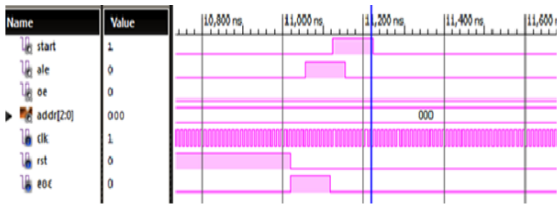

Figure 2: Simulation – ADC Controller module

As seen in figure 2 the simulation of ADC controller shows that as eoc pin goes high the ale pin goes high and after few ns start pin goes high. Both the pins go low after preassigned time. This shows that desired working of the ADC controller has been achieved.

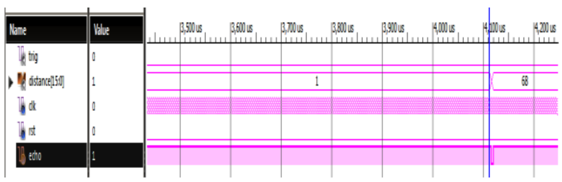

Figure 3: Simulation – Ultrasonic Controller module

ISSN (online): 2250-141X
Vol. 5 Issue 1, June 2015

As seen in figure 3, simulation of ultrasonic sensor controller module shows that the amount of time for which the echo pin is high, distance is calculated by the ultrasonic controller module.

Figure 4: Simulation – LCD Controller Module

As seen in figure 4, the simulation results of the initialization of LCD. This is where the LCD gets initialized. The data_out[3:0] pins are an input to the LCD which is working in 4-bit mode. As soon as the LCD gets initialized as per inputs given by the controller the LCD starts to display the data which it receives in form of nibbles.

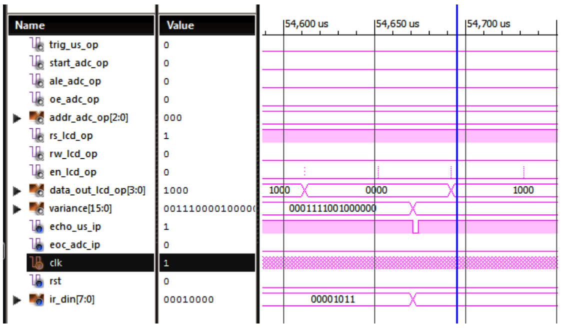

Figure 5: Simulation – Calculation of Variance

As seen in figure 5 simulation of the entire system and the calculation of variance of the data received from both the sensors is shown. The variance is calculated in floating point arithmetic and is converted into fixed point format. The 8 MSBs are the integer and the 8 LSBs are the fraction in fixed point format. The variance is 16-bit data out of which the MSB 8-bits indicate the integer and the LSB 8-bits indicate the fraction according to fixed point format. The mean of the system is displayed on the LCD and hence is given as data_out_lcd_op[3:0] which is given as input to the LCD.

The number of slice LUTs utilized is seen as 62%. Number of bonded IOBs is 58 out of 232 i.e. 25%. Peak memory usage during place and route is 365 MB and the average fanout of all non clock nets is 2.90. Post map static timing report showed the clock to setup time as 6.845 ns. Pad to Pad for each source is seen as near about 240ns for all sources.

The total power used is 0.021 W out of which 0.020 is due to on chip leakage and 0.001 is due to clocks.

VI. Conclusion

This work describes the implementation of a data fusion algorithm, in which two different sensors will be employed. The architecture can be used in several applications such as mobile robotics, in which the data fusion is important for achieving the estimate of the measured variables. The scalability of the implemented system can be reached for more than two sensors, by using a recursive approach.

Sensor fusion is useful in integrating information of different nature through the compensation of the specific limitations of each sensor type and thus helping the system perform better in environments where either of the implemented sensors are vulnerable to failure.

The system proposed in this work is efficient and quick responding as FPGA is capable of doing parallel processes very efficiently in less time, thus reducing the clock cycles and increasing the frequency. Implementing this system on FPGA helps us develop a data fusion system which is independent of microprocessor or microcontroller and can give the outputs on real time basis and requires very less power.

The proposed system is of relevance in robotics and will be of greater help to support collision free commuting of mobile robots without supervision of any human.

ISSN (online): 2250-141X
Vol. 5 Issue 1, June 2015

Moreover, the system can be used in high radiation environment if deployed with suitable sensors.

This system can be used in sunlight without the lack of any precision. Moreover, the system is also able to detect glass, mirror or opaque obstacles in its path.

ACKNOWLEDGEMENT

I would happily like to acknowledge all the faculty members of Electronics and Telecommunication department of Sinhgad College of Engineering, Vadgaon for their constant support and motivation.

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