Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 6, 2021, Pages. 12330 - 12338
Received 25 April 2021; Accepted 08 May 2021.

An Analysis and Implementation of FPGA Implementation of Ultrasonic Sensor

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Abstract:
This research explores the development of high precision and ultrasonic ranging in real-time, and develops and completes the architecture and hardware implementation of an FPGA powered ultrasonic device. The program will easily fix the shortcomings of usability, testing, real-time and calculating precision of the conventional ultrasonic ranging method. The system will satisfy vehicle avoidance necessity, autonomous navigation, etc. Ultrasonic range is commonly used in manufacturing, agriculture, transportation, climate, health defense, energy calculation and other scientific fields, along with the increasing advancement of science and technology. Ultrasonic performance metrics such as precision calculation, distance measurement, durability assessment, etc. play a role in enhancing accuracy and reliability of controls within the applicable application context, optimizing production productivity and fostering science and technical advancement. It's a really necessary role to perform. On the market today, typical ultrasonic barrier automobiles utilize an 8-bit or 16-bit mono device as the key controller responsible for gathering echoes and producing drive signals to power vehicles to avoid obstacles. This paper describes the simulation effects of the ultrasonic controller by testing the predicted performance results and providing the necessary input details.
Keywords: - FPGA, Powered Ultrasonic Device, 8-bit or 16-bit mono device as the key controller.

I. Introduction

FPGA is a high-precision logic device with fast running speed, rich internal resources and reconfigurable strength. This thesis puts forward some new ideas for realizing high performance ultrasonic ranging system. This thesis investigates the high precision and real-time ultrasonic ranging technology, and designs and completes the design and hardware realization of an ultrasonic system based on FPGA***(Chinnaiah et al. 2015)***. The system can effectively solve the shortcomings of traditional ultrasonic ranging system in reliability, debugging, real time and measuring accuracy. The system can meet the requirement of the vehicle avoiding, automatic navigation, etc. Along with the rapid development of science and technology, ultrasonic ranging is widely applied in industry, agriculture, transportation, environment, safety protection, the energy measurement and other scientific fields. The performance indexes of ultrasonic ranging such as measuring precision, measuring distance and measuring reliability and so on, has a very important role to improve the control precision and reliability of the related application system, enhance production efficiency, and promote the development of science and technology. At present, the mainstream of ultrasonic obstacle avoidance car on the market mostly uses 8-bit or 16-bit single chip microcomputer as main control chip which is responsible for receiving the echo, and producing drive signals, and then controlling the car to avoid obstacle. Although the cost is low, the measurement precision of the transit time and drive efficiency of ultrasonic

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transducer are both very limited. Compared with traditional SCM, FPGA as a kind of high-density field programmable logic devices not only solves the lack of custom circuits, but overcomes the shortcomings of original programmable gate device that the gate circuits are limited***(Al-Omary, 2010)***. And FPGA has many features such as perfect efficiency, portable, easy to operate, good secrecy performance, subtle real-time performance, high integration (Beasley et al., 2019; Herman et al., 2018).

1.1 Ultrasonic sensor

An ultrasonic sensor is an electronic device that measures the distance of a target object by emitting ultrasonic sound waves, and converts the reflected sound into an electrical signal. Ultrasonic waves travel faster than the speed of audible sound (i.e., the sound that humans can hear). Ultrasonic sensors have two main components: the transmitter (which emits the sound using piezoelectric crystals) and the receiver (which encounters the sound after it has travelled to and from the target).

Ultrasonic sensors can be used for many applications, including precise detection of objects and contactless monitoring of fill levels**.**Ultrasonic sensors work in much the same way as radar and sonar. Ultrasonic transceivers (consisting of a set of an ultrasonic transmitter and receiver) convert energy into ultrasound. They generate high frequency sound waves and evaluate the echo which is received back by the sensor. The time interval between sending the signal and receiving the echo (time-of-flight, TOF) is calculated in order to determine the distance to an object.The characteristics of the ultrasound signal are interesting for use in indoor positioning systems (IPS). Ultrasonic technology has several advantages, including high signal stability, high frequency, high sensitivity and high penetrating power**.** The sensors are easy to use and safe during operation for nearby objects, persons, or material***(Hernández et al, 2002; Xie& Wang, 2011).***

1.2 Ultrasonic Sensor Work

Ultrasonic sensors work by emitting sound waves at a frequency too high for humans to hear. They then wait for the sound to be reflected back, calculating distance based on the time required. This is similar to how radar measures the time it takes a radio wave to return after hitting an object.While some sensors use a separate sound emitter and receiver, it's also possible to combine these into one package device, having an ultrasonic element alternate between emitting and receiving signals. This type of sensor can be manufactured in a smaller package than with separate elements, which is convenient for applications where size is at a premium***(Li et al., 2013).***While radar and ultrasonic sensors can be used for some of the same purposes, sound-based sensors are readily available—they can be had for just a couple dollars in some cases—and in certain situations, they may detect objects more effectively than radar.For instance, while radar, or even light-based sensors***(García et al., 2014),*** have a difficult time correctly processing clear plastic, ultrasonic sensors have no problem with this. In fact, they're unaffected by the color of the material they are sensing.On the other hand, if an object is made out of a material that absorbs sound or is shaped in such a way that it reflects the sound waves away from the receiver, readings will be unreliable.If need to measure the specific distance from your sensor, this can be calculated based on this formula:

Distance = ½ T x C

(T = Time and C = the speed of sound)

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At 20°C (68°F), the speed of sound is 343 meters/second (1125 feet/second), but this varies depending on temperature and humidity.
Specially adapted ultrasonic sensors can also be used underwater. The speed of sound, however, is 4.3 times as fast in water as in air, so this calculation must be adjusted significantly.

II. Review of Literature

Li & Li (2019),Thispaper achieves an FPGA system, which is specifically designed for the industrial ultrasonic application. The FPGA system contains a feedback sensing circuit module and an adaptive Kalman filter (AKF) module. Industrial ultrasonic application system can be described as a time-varying nonlinear system, which directly relates to the temperature and the pressure of objects at certain timing.
Herman et al. (2018),This paper addresses some selected techniques for direction of arrival estimation using air-coupled ultrasound and custom hardware computational solutions. The main issue of the presented work is to perform a study of some hardware architectures capable to handle multichannel information processing in the real-time and its validation using experimental data.
Seyedroudbari et al. (2018),In this paper, an Ultrasonic Radar is introduced that is capable of detecting an object in 3D space and mapping the detected object's position on a 2D graph. Using time-of-flight methodology, an ultrasonic sensor proves to be a cheap and easy way of detecting an object. In fact, the most crucial problem for mobile and robot navigation systems is their ability to detect and localize obstacles.
Li & Zhang (2017),In this paper, they present a FPGA (field-programmable gate array) based automatic rail testing system which has multiple transmitting and receiving channels. The real-time signal processing is carried out in the FPGA including filtering and envelop detection. The 2D B-scan image is processed in the host computer for the flaw detection. Currently, the processing system is able to work for a rail testing vehicle with the speed higher than 20 km/h.
Hernández et al. (2017),this paper presents the design of a system in charge of managing a beacon unit used for the deployment of ULPS in wide spaces. The design consists of a system-on-chip architecture based on a field-programmable gate array device. The proposed system allows the flexible run-time configuration of a beacon unit in terms of the data to be transmitted and the bandwidth and frequencies used. The design has been successfully validated in an ULPS installed in a highly complex environment, where a robot has been correctly positioned during navigation.
Chiu & Lee (2017),This paper designs and fabricates an intelligent wheel robot which can walking and avoid obstacles autonomously. The obstacle avoidance is achieved by using fuzzy control technique. In order to turn angle rapidly for the wheel robot, they adopt three distance value and turning angle in last state between the obstacle and robot to design the fuzzy sets.
Rao et al. *(2017),*this paper presents a new way to measure the distance of an obstacle using an ultrasonic sensor with FPGA. As the wired measurements may not be accurate due to manual errors but here, they use non-wired device i.e., ultrasonic sensor to measure the distance of an obstacle that present in front of the sensor.
Chinnaiah et al. (2014),this paper presents a shortest path algorithm for FPGA based robot which can assist in industrial environment for various tasks. When a desired task is assigned to the robot, it chooses a shortest path from the source to the destination. Path planning is an

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important issue for an autonomous robot to fulfill any desired task. This paper overcomes tracking path issues, estimates the exact position, and improves effective localization and accuracy using land mark determination (RFID). With the help of ultrasonic sensors, the robot overcomes all the obstacles in its path. By using obstacle avoidance approach, a robot can perform a desired task using optimal resources. When a navigation task is assigned to the robot, it starts from there evaluating shortest distance to reach the destination.

Risman et al. (2014),This paper presents a PVDF sensor design of an ultrasound power measurement system that is compact and simple in construction, easy and user friendly, but at the same time provides a reliable power measurement result. The power meter is designed using PVDF sensor and Altera Cyclone II Field Programmable Gate Array (FPGA) technology. Results show that this in-house power measurement system is able to measure 0.5 MHz – 10 MHz of the frequency range and 1 mW/cm2 to 10 W/cm2 of the intensity range.

Conde et al. (2013),this paper shows the hardware implementation of a sensor fusion technique applied to both an ultrasonic and an infrared sensor, for estimating the distance, using an FPGA. Sensor fusion is a natural application of stochastic filtering area (such as Kalman filters), being applied extensively in different areas such as mobile robotics, signal processing, bioengineering, among others. This technique permits to combine the information provided by the sensors, improving the estimate of the measured variable, as well as its uncertainty.

Huang &Newman (2012),In this paper a fall detection system is presented that automatically detects the fall of a person and their location using an array of ultrasonic wave transducers connected to a field-programmable gate array (FPGA) processor. Experimental results are provided on a prototype deployment installed at an assisted living community. The system can provide a cost-effective and intelligent method to help caregivers detect a fall quickly so that patients are treated in a timely manner. In addition to room monitoring and local alert functions, the system incorporates a personal computer and wireless connection to enable remote monitoring of patient's activity and health status.

Xie& Wang (2011),In this paper they introduce the method of measurement of wind speed and direction based on an embedded system with multiple ultrasonic sensors. The system includes front-end circuits and back-end circuits. The Front-end circuits include the sensor’s low-voltage drive circuit, preamplifier circuit, filter circuit, the voltage comparator circuit and the signal isolation circuit. Back-end circuits include the signal generator circuit, the signal detection circuit, FIFO circuit, LCD driver circuit and UART protocol Circuit. Using low voltage drive drives the sensor can reduce the debugging of the system. The system can launch and receive ultrasonic signal, and get the time of flight of ultrasonic signal according to design precision after verification. All control and processing are in Field Programmable Gate Array (FPGA). FPGA is the very key factor in system design.

III. Methodology

The objective of this thesis is given below:

- Implemented an ultrasonic sensor to measure and visualize distances on the Nexys 4 DDR FPGA 7-seg Display and LEDs.

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- Incorporated a buzzer that sounds according to proximity by using a single multiplexed clock signal.
- We know that sensor needs 5V but the Nexys 4 is only able to give 3.3V. So, we use a booster or an external power supply.

Ultrasonic sensors emit short, high-frequency sound pulses at regular intervals. At the velocity of sound, the sound pulses propagate in the air. The sound of pulses strikes an object, and then they are reflected back as echo signals to the sensor, then the echo signal computes the distance to the target based on the time-span between emitting the signal and receiving the echo.

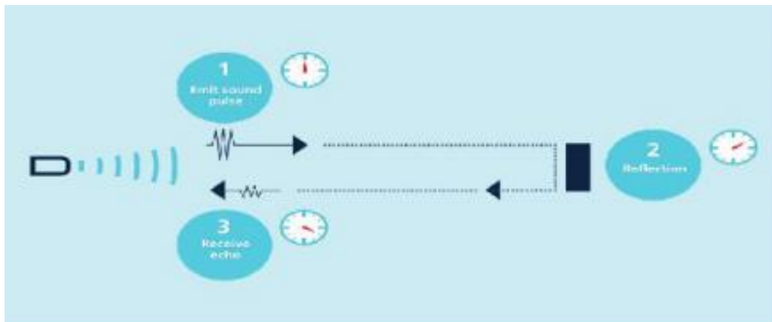

Fig: Ultrasonic principle

By measuring the time, the distance to an object is determined and not by the intensity of the sound. Ultrasonic sensors are excellent at suppressing background interference. The use of ultrasound can be classified into two main groups namely,

- Active ultrasound
- Passive ultrasound

Active ultrasound exhibits, physical or chemical effects when applied. Then reaches the highest values when generated. Speed of sound is dependent on the type of environment in which it moves, and the current temperature of the environment. The output of passive ultrasound output is generated only at lower values. In this paper to measure the spring heights during the car movement, ultrasonic sensor has been mounted onto the back of a car and equipped with four potentiometer sensors. To record the ultrasonic sensor and the potentiometer outputs a portable digital recorder is used. Sensor tests asphalt and rough ground and the four potentiometer outputs have been used to compute a distance reference value to be compared with the ultrasonic measured distance. By adding the tire deformations to the spring heights measured by the potentiometers, end spring heights, have been estimated which in turn used to identify the plane of the vehicle body. The distance reference value that corresponds to the distance the ultrasonic sensor should produce has been determined by putting the measuring head coordinates into the identified plane equation. For many applications ultrasonic plays a vital role not only for distance measurement but also around the world, indoors and outdoors in the harshest conditions, namely liquid level control, full detection, thread or wire break detection, robotic sensing, stacking height control and also for people detection for counting based upon proximity detection and range measurement. If the detect point is independent of target size or material reflectivity

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proximity detection is used and change in movable distance is calculated by means of ranging measurement***(Sumathi&Janakiraman, 2010).***

IV. Result and Discussion

These modules are designed using VHDL and synthesized using Xilinx Integrated software environment (ISE). The design is simulated using ISim. The design implementation is done on Xilinx xa3s50-4vqg100 device.

control_maxsonar Project Status (05/22/2020 - 22:51:09)			
Project File:	ultrasonic.xise	**Parser Errors:**	No Errors
Module Name:	control_maxsonar	**Implementation State:**	Synthesized
Target Device:	xa3s50-4vqg100	**• Errors:**	No Errors
Product Version:	ISE 13.3	**• Warnings:**	3 Warnings (0 new)
Design Goal:	Balanced	**• Routing Results:**	
Design Strategy:	Xilinx Default (unlocked)	**• Timing Constraints:**	
Environment:	System Settings	**• Final Timing Score:**	

Device Utilization Summary (estimated values)			[-]
Logic Utilization	**Used**	**Available**	**Utilization**
Number of Slices	34	768	4%
Number of Slice Flip Flops	35	1536	2%
Number of 4 input LUTs	63	1536	4%
Number of bonded IOBs	17	63	26%
Number of GCLKs	2	8	25%

Detailed Reports					[-]
Report Name	**Status**	**Generated**	**Errors**	**Warnings**	**Infos**
Synthesis Report	Current	Fri 22. May 22:51:07 2020	0	3 Warnings (0 new)	0

Figure 2 Design summary of top module of ultrasonic sensor.

In figure 2 shows the design summary of ultrasonic sensor. Design summary tells us all project specification and percentage utilization of FPGA device***(Ahmad et al. (2016).***

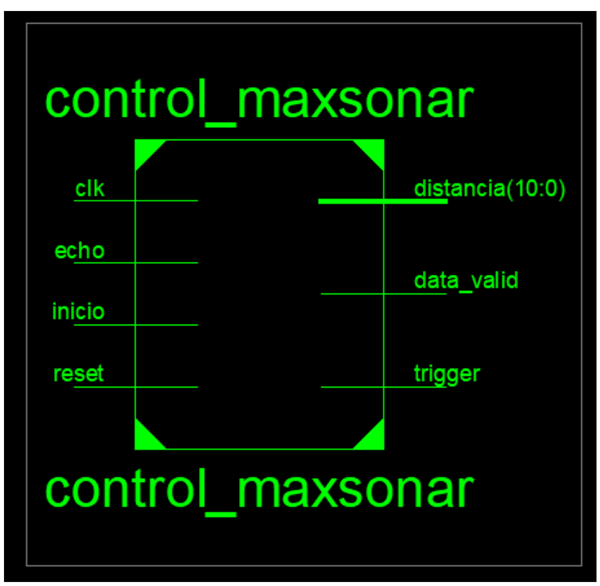

Figure 3 RTL Schematic of top module of controller of ultrasonic sensor

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In figure 3 shows the external architecture of controller of ultrasonic sensor. There are four input and three output pins. Clock echo inicio and reset are input pins and datancio out, data valid trigger are output pins.
Figure 4 shows that internal RTL schematic of controller of ultrasonic sensor. It clearly shows all the internal devices and connect to each other.

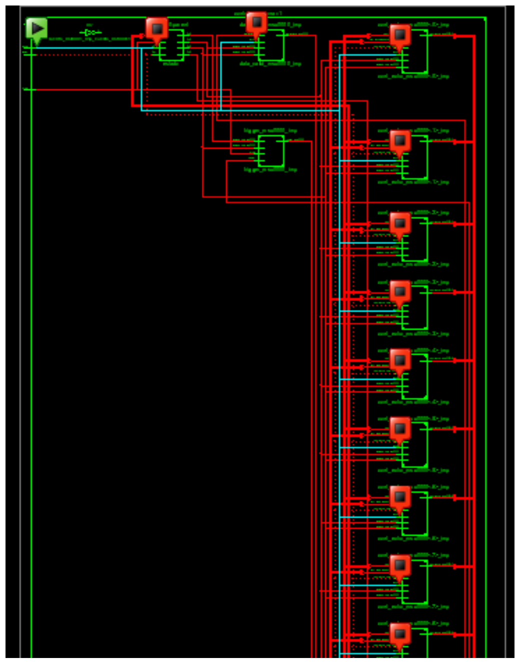
Figure 4 Internal RTL schematic of top module of controller of ultrasonic sensor

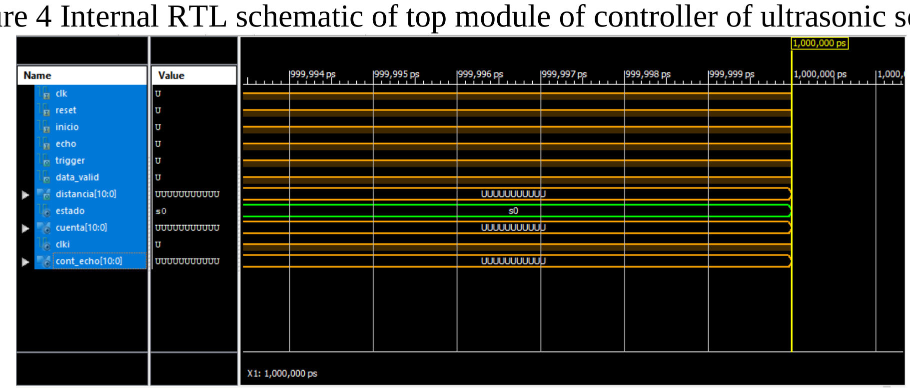

Figure 5 Simulation result of controller of ultrasonic sensor
Figure 5 shows the Simulation result of controller of ultrasonic sensor. We check the expected output results to give required input data.

V. Conclusion and Future Work

The data can quickly correct compatibility, checking, real-time and measuring accuracy of traditional ultrasonic ranging system. The device addresses traffic avoidance requirements, automatic steering, etc. Ultrasonic spectrum is widely used in engineering, livestock, shipping, environment, safety protection, energy measurement and other research areas, as well as promoting science and technology. Ultrasonic efficiency measurements such as precision estimation, distance analysis, longevity evaluation, etc. play a function in improving the quality and functionality of controls within the relevant application sense, maximizing production profitability, and fostering research and technological advancement. Playing is a very important function. Currently, standard ultrasonic barrier cars use an 8-bit or 16-bit mono system as the main controller responsible for capturing echoes and generating drive signals to enable vehicles to clear obstacles. This article explains the ultrasonic controller's simulation effects by checking expected output outcomes and presenting appropriate feedback information.

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