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EE102-02

14 March 2025

FPGA-Based Ultrasonic Radar System with Real-Time VGA Display

PURPOSE

This project aims to create an ultrasonic radar system using the Basys 3 FPGA board programmed in VHDL. The system will use ultrasonic sensors to detect distances between the sensors and the objects. An active piezo buzzer will also make a sound when the sensors detect an object. Finally, a radar visual that updates real-time will be displayed on a VGA monitor.

DESIGN SPECIFICATIONS

This project will be built around the Basys 3 FPGA board. The board will interface with several external hardware components including two ultrasonic sensors (HC-SR04) to measure distances, a servo motor (SG90) to rotate the sensor assembly, and an active piezo buzzer to make an alert sound when encountered with an object. The sensor power will be supplied directly from an appropriate 5V power source, while a logic level converter will ensure that the trigger and echo signal lines are correctly interfaced with the FPGA.

On the digital design side, the project will be divided into distinct functional modules in VHDL. The sensor module will be responsible for generating the trigger pulse to activate the sensors and for capturing the echo pulse whose duration will be directly proportional to the distance of an object. Simultaneously, the servo motor control module will generate a PWM signal to rotate the sensor assembly (which normally has a 15° arc) over a 180° arc so that the

full scanning of the environment is maintained. The VGA controller module will generate the necessary horizontal and vertical synchronization signals and map the sensor data to display coordinates. Hence, it will generate a dynamic radar display on a VGA monitor. If a radar display fails to be observed on the VGA monitor using Basys 3 and VHDL, an Arduino will be used as an alternative to display the radar visual and the position of the object. This display will include a radar grid, concentric circles, and plotted dots that represent detected objects. Finally, the buzzer module will monitor the sensor data for object detection. When an object is detected within a specified distance threshold, the module will generate a control signal that activates the buzzer and generates an alert.

METHODOLOGY

The project will begin with the modular design and simulation of individual components. Initially, separate VHDL modules will be developed for the sensor interface, servo control, VGA controller, and buzzer as described in the design specifications. Once individual modules are verified, the next phase involves integrating them into a top-level design. In this integration phase, sensor measurements are synchronized with the PWM control signals' positional data for the display on the VGA monitor. The integrated design will also include a logic level converter interface to translate the echo and trigger signals, along with the incorporation of the buzzer control.

After successful integration in simulation, the design will be implemented on the actual hardware. This stage involves connecting the Basys 3 with all external components. Real-world testing will be conducted for accurate sensor readings, effective servo control to move the

sensors and an accurate, stable, real-time VGA display. Finally, performance adjustments and optimizations will be made based on test results.

PHASES

Phase 1: The focus will be on developing and testing the individual VHDL modules. Especially the sensor, servo and buzzer modules will be tested using simulations as well as hardware testing. After phase 1, the focus will shift to final implementation of the overall radar system and the VGA display.

Phase 2: All modules will be integrated and optimized. The sensors, servo and buzzer will work as expected. Accurate plotting on the VGA and real-time updates will be maintained.

Works Cited

Brown, Stephen D., and Zvonko Vranesic. *Fundamentals of Digital Logic with VHDL Design*. 2nd ed., McGraw-Hill, 2000.

"HC-SR04 Ultrasonic Sensor." SparkFun, www.sparkfun.com/products/13959. Accessed 15 Mar. 2025.

"SG90 Mini Servo Motor." Adafruit Industries, www.adafruit.com/product/1695. Accessed 15 Mar. 2025.