Design of Parking Assist System Based On Distance Measurement Using Ultrasonic Sensor and FPGA

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Abstract: -The Ultrasonic Distance Measurement System using Spartan Edge 7 FPGA is designed to provide real-time object detection and alerting functionality for parking systems. The system measures the distance of an obstacle using the HC-SR04 ultrasonic sensor, processes the data on the Spartan Edge 7 FPGA, calculates & displays the distance on seven segment display and activates an onboard buzzer if the distance falls below a defined threshold of 10 cm. By utilizing FPGA's high-speed parallel processing capabilities, the system achieves accurate distance calculations with minimal latency. A voltage level shifter ensures compatibility between the FPGA's 3.3V GPIO logic and the sensor's 5V logic requirements. The implementation demonstrates the practical use of FPGAs in embedded systems for automation and safety-critical applications.[1]

Keywords—FPGA

I. INTRODUCTION

In modern parking systems and obstacle detection applications, real-time distance measurement is crucial for ensuring safety and convenience. Whether in automated parking systems, robotics, or industrial automation, accurately determining proximity to objects helps prevent accidents and enhances operational efficiency. Traditionally, such systems are implemented using microcontrollers or processors. However, this project explores the advantages of using an FPGA-based solution to achieve real-time processing with minimal latency and maximum flexibility.[2][3]

The Spartan Edge 7 FPGA was chosen as the core hardware for its robust processing capabilities, low power consumption, and compatibility with peripheral devices. The system utilizes the HC-SR04 ultrasonic sensor, known for its precision in measuring distances up to 400 cm, a seven segment display to display the distance and an onboard buzzer for audio alerts when the distance drops below a threshold. Since the HC-SR04 operates at 5V logic levels and the FPGA operates at 3.3V, the TXS0108E bidirectional voltage level shifter ensures seamless communication between these devices.

This system demonstrates the power of FPGAs in embedded systems, leveraging their parallel processing and reconfigurable logic for a time-critical application. By implementing the distance measurement and threshold logic in Verilog, the system performs reliable real-time measurements, enabling immediate audio feedback to alert users of obstacles. [4]

The project showcases a practical application of FPGAs in the domain of safety systems, with potential for scalability and integration into larger automation frameworks.

II. LITERATURE SURVEY

Navigation of an object is widely used for target detection, security range monitoring in border, parking assistance for vehicles, wild life photography and so on. In such systems the objects are detected and their exact location is found by distance measurement. The distance measurement is done using ultrasonic sensor, infra-red beams, and LASER beams with additional electronic hardware. The distance measured and choice of sensor depends on type of applications and also surrounding environmental issues like temperature, humidity, fog etc. For short distance measurement ultrasonic sensor is used. In this technique time taken for signal to reach the target and come back as reflected signal is calculated.

The design such systems mainly concentrates on the accuracy of measurement of distance, kind of sensors used, distance coverage, power utilization, compactness and also the cost. In this paper, distance measurement of an object using ultrasonic sensor with separate transmitter, receiver and FPGA is done. Main purpose of utilizing ultrasonic sensor and FPGA is to accomplish low-cost, low power, easily portable and accuracy as well as speed. The FPGA based systems have faster processing capability with low power use and are easily reconfigurable.

FPGA is a high-precision logic device with fast running speed, rich internal resources and reconfigurable strength. This paper puts forward some new ideas for realizing high performance ultrasonic ranging system. This paper 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. 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.[5]

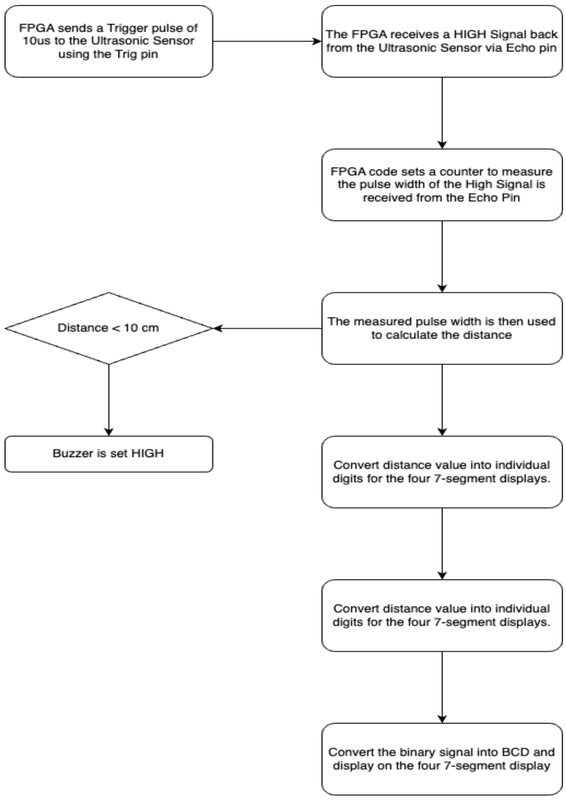
III. SYSTEM DESIGN & CIRCUIT IMPLEMENTATION

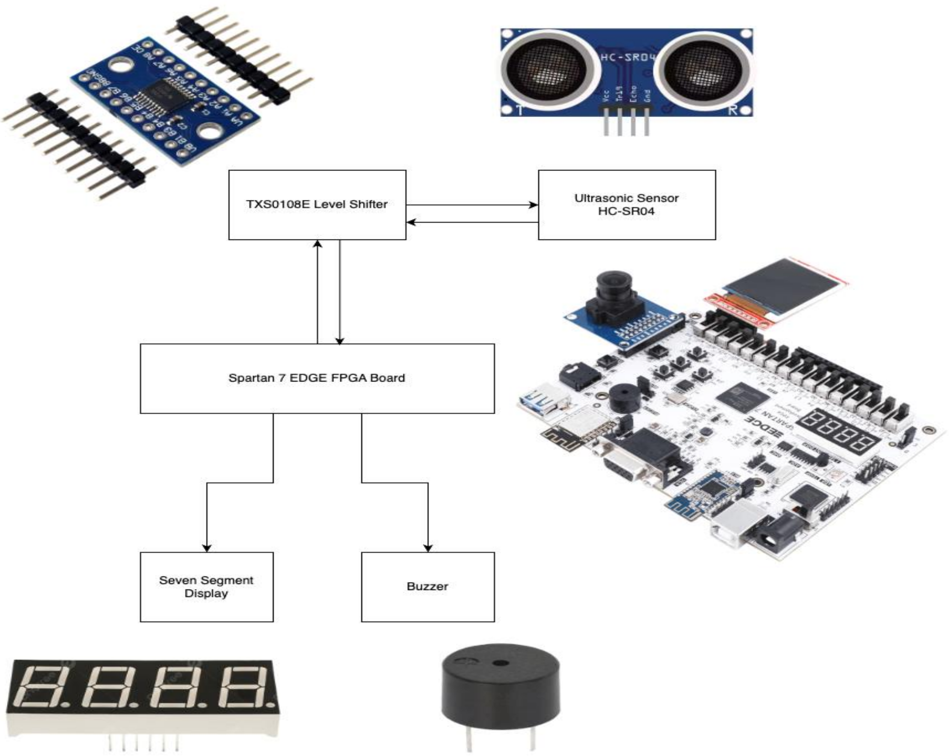
A. Flowchart

The Ultrasonic Distance Measurement System is built around the Spartan Edge 7 FPGA, which integrates the ultrasonic sensor, a level shifter, four 7 segment displays and an onboard buzzer. The system design is divided into functional blocks to facilitate understanding and implementation.

B. Block Diagram

The block diagram provides a high-level visual representation of the Ultrasonic Distance Measurement System, highlighting the interaction between the FPGA, ultrasonic sensor, level shifter, and buzzer blocks





C. Hardware Requirements

1. Spartan Edge 7 FPGA Board[6]

Features:

a. Based on the Xilinx Spartan-7 FPGA.
b. Supports a variety of peripheral interfaces and GPIO pins.
c. Includes an onboard buzzer for audio feedback.

Role in Project: The FPGA processes the ultrasonic sensor's echo signal, calculates the distance, and drives the buzzer if the threshold is crossed.

2. HC-SR04 Ultrasonic Sensor

Features:

a. Operating Voltage: 5V.
b. Detection Range: 2 cm to 400 cm.
c. Precision: ±3 mm.
d. Interface: Trigger and Echo pins.

Role in Project: Measures the distance of an object by emitting and receiving ultrasonic waves.

3. TXS0108E Level Shifter

Features:

Bidirectional voltage level shifting for 3.3V to 5V logic.

Supports up to 8 channels.

Role in Project: Converts the 3.3V GPIO signals from the Spartan Edge 7 to 5V logic required by the HC-SR04 sensor and vice versa.

4. Buzzer

Features:

Makes Alarming sounds when given a high pulse.

Role in Project: Provides audio alerts when the object distance is below 10 cm.

5. Four Seven Segment Display

Features:

Integrated on the Spartan 7 Edge FPGA board

Role in Project: Displays the distance in cm.

6. Interconnect Components

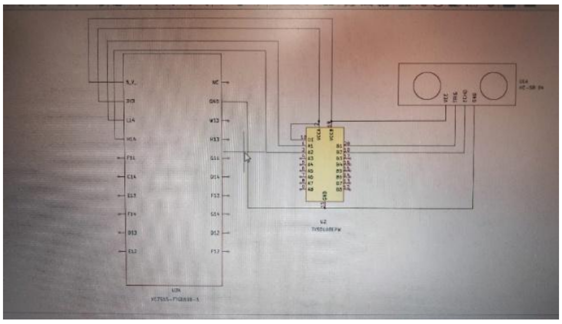
Jumper Wires: For connecting FPGA GPIO pins, level shifter, and the ultrasonic sensor.

Breadboard: For prototyping and easier wiring of components.

7. Power Supply

5V power source supplied to the FPGA and sensor via USB or an external adapter.

D. Wiring Diagram



IV. DESIGN CHALLENGES AND SOLUTION

The design of an FPGA-based ultrasonic distance measurement system presented multiple challenges, ranging from hardware compatibility to timing accuracy. Each issue required careful analysis and implementation of innovative solutions. Below is a breakdown of the primary challenges and how they were resolved:

1. Voltage Level Compatibility

The ultrasonic sensor module operates at 5V logic levels, whereas the FPGA board uses 3.3V logic. Direct communication without proper interfacing risked damaging the FPGA pins and led to unreliable signal recognition.

Solution:

A bidirectional level shifter was introduced between the ultrasonic sensor and the FPGA. This ensured proper voltage translation for both input (echo signal from the sensor) and output (trigger signal sent from the FPGA). The level shifter used a combination of MOSFETs and pull-up resistors for efficient voltage conversion without introducing significant delay.

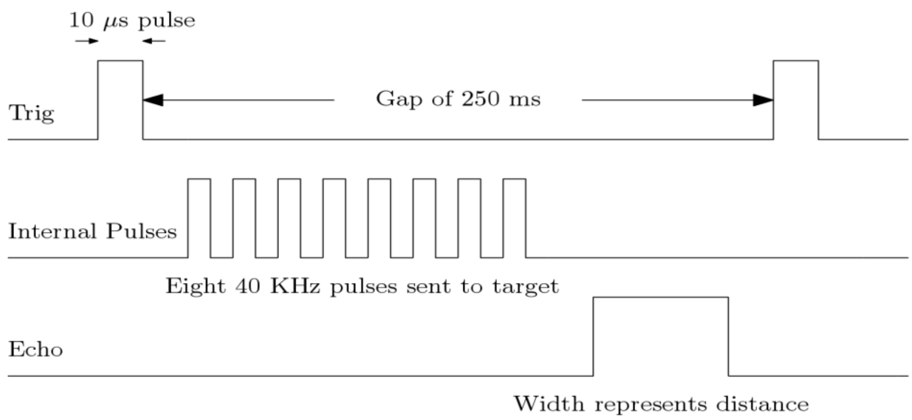
2. Timing Constraints for Trigger and Echo Signals

The ultrasonic sensor's operation requires precise timing for the trigger signal (10 µs pulse) and accurate measurement of the echo pulse width, which corresponds to the distance. FPGA timing violations could result in inaccurate measurements.[7]

Solution:

To address this, a dedicated clock division module was implemented in Verilog. The system clock (50 MHz) was divided down to generate the necessary timing for the trigger pulse. A finite state machine (FSM) was also implemented to manage the trigger, echo, and distance calculation processes sequentially, ensuring timing requirements were met.

Timing Diagram: The timing diagram illustrates the operation of the HC-SR04 ultrasonic sensor in conjunction with the FPGA, showcasing the interaction between the Trigger and Echo signals, as well as the FPGA's internal processing. This helps in understanding the sequence of events during a distance measurement cycle.



Timing Sequence:

1.*Trigger Pulse Generation*
The FPGA sends a 10 µs HIGH pulse on the Trigger pin of the HC-SR04 to initiate a distance measurement cycle.

2.*Ultrasonic Wave Emission and Reception*
The HC-SR04 emits an ultrasonic burst (8 cycles of 40 kHz sound waves).
The Echo pin remains LOW during this time.[8]

3.*Echo Pulse High:*
When the ultrasonic wave is reflected back to the sensor, the Echo pin goes HIGH. The duration for which the Echo pin remains HIGH corresponds to the time taken by the sound wave to travel to the object and back

Distance Calculation Formula -

The distance was calculated using the formula:
Distance (cm)=(Pulse Width × Speed of Sound (cm/s))/2

With the speed of sound approximated at 34300 cm/s, the distance calculation became:
Distance (cm)=(Count×Time Per Cycle × 34300)/2

Spartan 7 Edge Clock = 50 MHz

Time Per Cycle = 1/50000

Distance (cm) = (Count × 34300)/(2 * 50000)

3. Resource Utilization
FPGAs have limited resources, and the addition of a level shifter, ultrasonic sensor logic, and other peripherals could strain the device’s capacity.

Solution:The Verilog code was optimized to minimize resource usage. This included:

a) Using counters instead of dedicated timers to reduce hardware duplication.
b) Implementing state machines with minimal states to simplify control logic.
c) Sharing resources like clocks across multiple modules where possible.

V. PERFORMANCE METRICS

Evaluating the performance of the FPGA-based ultrasonic distance measurement system is crucial to ensure its reliability and practicality. The metrics considered included accuracy, latency, and range. Here's a detailed analysis of the system's performance:

1. Accuracy
Accuracy refers to how closely the measured distance matches the actual distance.

Testing Setup:
The system was tested with objects placed at distances ranging from 5 cm to 200 cm (the range of the ultrasonic sensor). A ruler or tape measure was used for ground truth measurements.

Observations:
The system demonstrated a high degree of accuracy within the mid-range (20 cm to 150 cm), with deviations of less than ±1 cm.

At very short distances (<10 cm), inaccuracies arose due to the sensor's blind zone, where echo signals become difficult to detect.

At longer distances (>150 cm), errors increased slightly due to signal attenuation and environmental factors (e.g., temperature and humidity).[9]

Calibration:
To improve accuracy, calibration was performed by adjusting the distance calculation formula to account for environmental factors and the FPGA's clock tolerance.

2. Latency
Latency is the time taken by the system to measure and report the distance.

Measurement:
The total latency includes the time for:
Sending the trigger pulse (10 μs).
Waiting for the echo signal to return (dependent on the distance).
Processing the echo duration in the FPGA.

Results:
For a maximum range of 200 cm, the total latency was approximately 15 ms.
For shorter distances (e.g., 50 cm), the latency dropped to around 3.5 ms.

Optimization:
The latency was minimized by using a 1 MHz clock for timing the echo signal, allowing for fine granularity without excessive computation.

3. Range
The range defines the minimum and maximum distances the system can measure accurately.

Minimum Range:
The ultrasonic sensor's blind zone (typically 2 cm to 4 cm) limits the minimum measurable distance.
During testing, the system reliably measured distances starting from 7 cm.

Maximum Range:
The theoretical maximum range of the ultrasonic sensor is 400 cm, but practical testing showed reliable measurements up to 200 cm.
Beyond 200 cm, the echo signal weakened due to attenuation and background noise, leading to occasional missed readings.

Improvement Possibility:
Enhancing the sensor's power or using an amplifier could increase the range further.

VI. FUTURE SCOPE AND CONCLUSION

The ultrasonic sensor-based system has proven to be an efficient and effective solution for real-time distance measurement and object detection. However, there are numerous avenues for future enhancements that can further expand its capabilities and applications. Below are some key areas where the system could evolve in the future:

Multi-Sensor Support Wireless Communication and IoT Integration, Integration with Displays and User Interfaces.[10]

The ultrasonic sensor-based system designed for real-time distance measurement and object detection represents a significant step toward improving efficiency, safety, and sustainability in various applications such as smart parking, robotics, and autonomous systems. The implementation of FPGA allows for high-performance processing and flexibility, making it a powerful solution compared to traditional microcontroller-based systems.

VII. ACKNOWLEDGEMENT

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