

1. Introduction

Meteors and other forms of space debris as they enter the Earth's atmosphere and break apart pose a risk to the structures on the Earth's surface and to people. Therefore, tracking and mitigating potential collisions will prove crucial to protect life on Earth. The team's objective is to use the Nexys Video board to design a real-time detection and response system for tracking and mitigating space debris damage. By integrating ultrasonic range sensors, we can detect incoming objects and their trajectories using control algorithms implemented as a custom IP block in RTL. Then, two RC servos will target the object using lasers and the predicted landing position will be displayed on a screen using the board's HDMI output port. A heatmap of the direction of incoming meteors over time will also be displayed using an array of tri-color LEDs. Also, an alarm will sound if the landing position is accurately predicted.

By designing a custom IP block inside the Nexys Video board it results in a detection and interception system that takes advantage of using dedicated hardware acceleration to detect the incoming objects in real-time, compared to conventional software-based tracking approaches with a high computational overhead. Also, by integrating audio feedback and a visual GUI, this project provides an engaging way to interact with real-time space debris tracking.

2. Project Team

- **Youssef Elhadad**
 - Experience with embedded systems including servos and ultrasonic sensors.
 - Experience with simple verilog-based projects
 - Experience with graphics and frame management.

- **Marko Ciric**
 - Worked at AMD on the GPU team (Geometry sub-system) as a RTL designer focusing on implementing tessellations in RTL
 - Experience with RC servo connectors in embedded system environments
 - Experience with soldering components

- **Damian Pacynko**
 - Experience in using ultrasonic sensors and servos in embedded systems environments
 - Has worked on projects integrating custom IP with a soft processor
 - Experience with soldering

- **Muaz Shash**
 - Experience making custom IP with DSP blocks and ALMs for math functions over co-op.
 - Experience with servos and ultrasonic sensors.
 - Experience with graphics and frame management.

The team has a good breadth of experience and knowledge with designing custom IPs for various purposes, interfacing project relevant peripherals and soldering. We also have experience with working on design teams and are familiar with self-led project management. Damian in addition has prior experience with Vivado which will prove useful with using the software for our project. So, as a team our skills are already mostly specialized in regard to the contents of this project. However, we are concerned about synchronizing the ultrasonic sensors and ensuring they don't interfere with each other when collecting the object's x-y-z coordinates within the required accuracy. To deal with this the team plans to execute the "real-time object trajectory" test listed in the Testing section of the document.

3. Project Description

Our team has decided to make a real-time detection and response system for tracking and mitigating space debris damage. Using an array of ultrasonic range sensors, we can pinpoint an object's location and trajectory using control algorithms implemented as a custom block in RTL. Once the trajectory is known, a laser is directed at the object using two mechanical servos and the predicted landing position will be displayed on a screen. A heatmap of the direction of incoming meteors over time is displayed using an array of tri-color LEDs. An alarm will also sound if the predicted landing position is within a certain bound.

Functional Requirements	Description and Acceptance Criteria
Object location detection	Using an array of ultrasonic sensors, determine an object's x-y-z coordinates (or spherical). Acceptance criteria: Determine position within 3 inches of accuracy.
Object trajectory calculation and laser pointer.	Using a custom IP block, predict the object's position in the next 50ms. Then, point a laser at the object using two servos. Acceptance criteria: Determine the object's future position within 3 inch accuracy, and point at the object with +/- 3 inches accuracy from expected point (due to servo precision).
Object landing position calculation	Using the trajectory calculation, determine the object's landing position. Acceptance criteria: Determine landing position within 5 inches.

Video display/useful GUI	<p>Display the object's landing position on an x-y plane, or the trajectory along the y-z, or x-z plane.</p> <p>Acceptance criteria: Visualize predicted landing position on x-y plane.</p>
On-board audio output	<p>Alert the user with audio when an object is going to land within a certain boundary.</p> <p>Acceptance criteria: Make a noise</p>
Heatmap	<p>Displays the direction of most frequent meteor directions using tri-color LEDs.</p> <p>Acceptance criteria: Displays if the objects have come from the left, center, and right in red, green, or yellow respectively depending on frequency.</p>

Table 1: Functional requirements and acceptance criteria.

To fulfill the mandatory requirements, the Microblaze will be used to keep track of all the incoming meteor directions, display the result using an LED array and play an audio if the object will land within the defined boundary. The custom IP will handle ultrasonic sensor data processing, object location mapping and trajectory calculation. It will also interface with the HDMI IP to display the results on the screen.

We will be using the peripherals listed in the table below:

Peripherals	Amount of Peripherals
Ultrasonic Rangefinder PMOD	6
RC Servo Connectors PMOD	2
Tri-color LEDs	3
3.5mm Audio Jack Speaker	1
Screen	1

Table 2: List of peripherals and counts.

System Block Diagram:

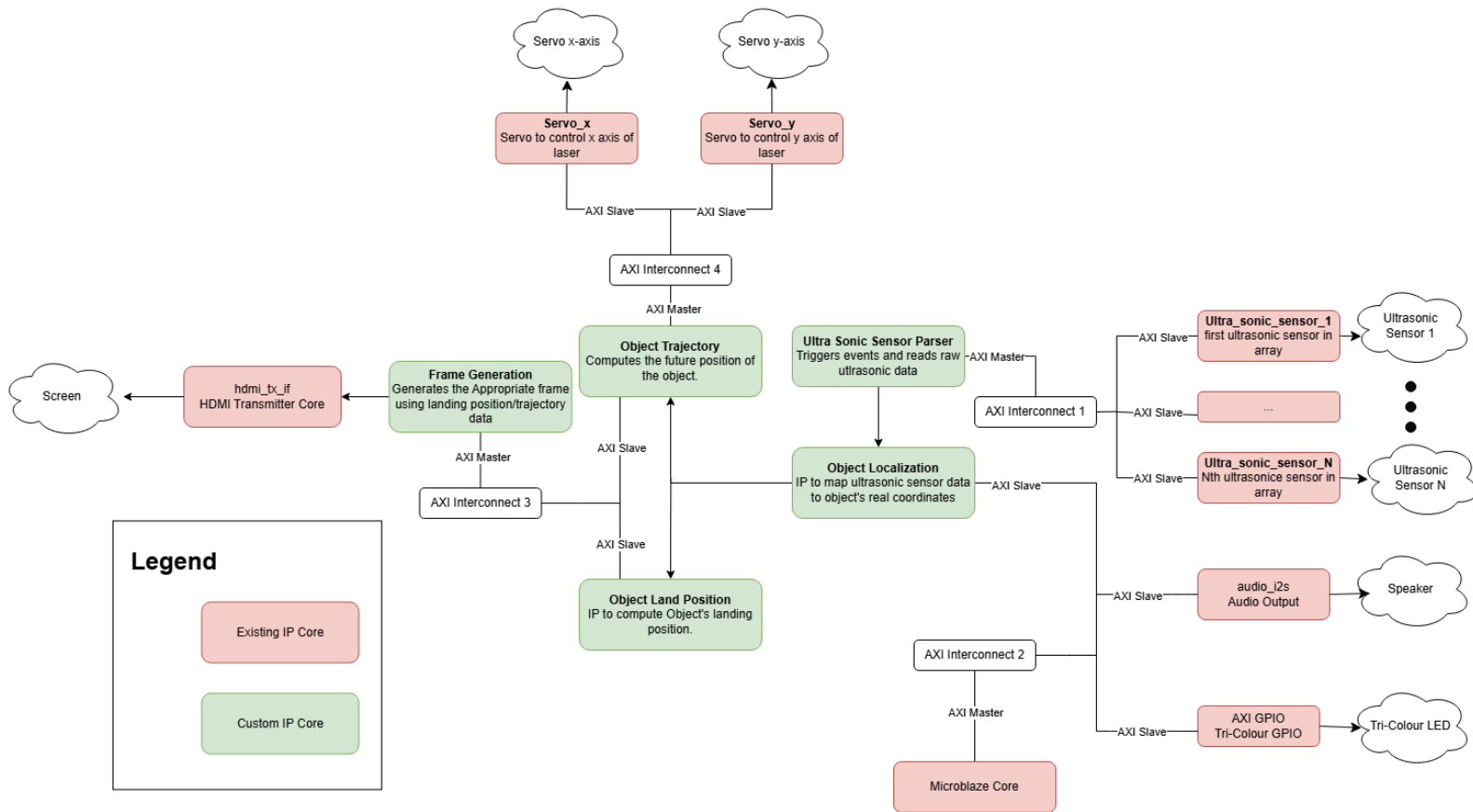


Figure 1: System Block Diagram

4. Testing

Test	Description
Object localization 1	Setup a 6-inch diameter object and determine its location and map them to real life coordinates. Success would mean we can detect the object at any point in the frame and determine its position.
Object trajectory calculation	Validate algorithm on software with experimental points.
Object trajectory calculation 2	Validate algorithm in RTL with experimental points. See if they match software

	implementation.
Real-time object trajectory	Attach a string to a 6-inch diameter object and move it along a trajectory slowly. Compare the future predicted values to the real values. Success would mean the predicted values are within 3 inches to the real values.
Laser tracking	Repeat the previous step but validate the laser can follow the object. Success would mean the laser stays on the object for the entire trajectory.
HDMI test x-y plane 1	Visualize a grid and a circle of radius 5 inches displayed on the monitor at some arbitrary location.
HDMI test x-y plane 2	Throw an object and see if we can predict where it lands on the monitor.
Audio test 1	Always play audio on loop to see if we can get it to work.
Audio test 2	Play audio when an object is predicted to land within our defined boundary.
LED test 1	Toggle the LEDs on loop with three different colors.
LED test 2	Introduce objects from different directions and see if it reacts appropriately.

Table 3: Testing procedures

5. Project Complexity

Ultrasonic Rangefinder PMOD	0.5
Custom IP	1
HDMI Output	1
On-board audio output	0.5
Visualize meaningful results with a GUI	0.75
RC Servo Connectors	0.2

LED Tri-color	0.2
---------------	-----

Table 4: Complexity counts

The total complexity count is 4.15, which is above the minimum threshold of 4 for our team.

6. Risks

Ultrasonic Sensor Inaccuracy

Risk: The ultrasonic sensors critical for triangulating the meteor's position may produce noisy or inaccurate data due to environmental interference or calibration errors. This inaccuracy can lead to errors in trajectory prediction and ultimately misdirect the laser-targeting system.

Mitigation: Conduct extensive calibration and testing of the sensors under diverse environmental conditions. We can set up a system to calibrate the sensors before starting a session.

Integration Challenges

Risk: The real-time processing required for sensor data analysis and trajectory prediction may suffer from delays or synchronization issues. This can disrupt the coordination among various subsystems (detection, tracking, laser targeting, visualization, and audio alerts).

Mitigation: Adopt a modular development approach, testing each hardware component independently before full integration. We will allocate a buffer week in the project specifically for performance optimization and troubleshooting. We will also implement design fallback modes so that if non-critical features (like HDMI visualization or audio alerts) encounter issues, core functions continue to operate reliably.

Scope Creep and PM Challenges

Risk: Integrating multiple advanced features increases overall project complexity. This may lead to scope creep, team miscommunication, and delays in meeting project milestones.

Mitigation: Prioritize core functionalities as mandatory deliverables, while categorizing features such as audio alerts and visualization as optional. In addition, the team will hold regular progress meetings and utilize effective version control and communication tools to ensure all team members are aligned. We will also incorporate buffer periods into the schedule to accommodate unforeseen delays or challenges.

7. Resource Requirements

The peripherals that will be needed for the project are listed in Table 2. The number of ultrasonic sensors required surpasses the amount of sensors available from the course, however we will be using our own modules, which we have enough of.

Furthermore, we will bypass the limit of 4 PMODs by routing 2 ultrasonic sensors per PMOD slot, since each ultrasonic takes up at most 6 headers, whereas the PMOD input has 12 input headers.

8. Milestones

Milestone 1: Initial Design Review & Test Bench Setup

- Finalize overall system design and identify key hardware and software components

Milestone 2: Sensor Calibration and Data Acquisition

- Begin initial tests of sensor outputs under controlled conditions

Milestone 3: Development and Testing of Triangulation and Trajectory Prediction

- Develop the algorithm for triangulating the meteor's position using data from the three sensors.
- Create a predictive algorithm for estimating the meteor's future trajectory.

Milestone 4: Servo Control and Laser Targeting Hardware Integration

- Integrate the servo motors and laser targeting system with the predictive module.
- Calibrate the laser's alignment using target markers

Milestone 5: HDMI Visualization and Audio Integration

- Integrate the HDMI display for visualizing the object's landing position.
- Incorporate audio alert system

Milestone 6: Final Demo Integration

- Finalize the integrated system for a comprehensive demo.
- Showcase the working system with all features including sensor detection, prediction, laser targeting, audio alerts, and HDMI visualization.