Department of Computer Science & Engineering
The University of Texas at Arlington

Architectural Design Specification
CSE 4316: Senior Design I
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IGVC Computer Vision Team
IGVC Computer Vision Module

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Revision History

Revision	Date	Author(s)	Description
0.1	10.20.2023	ATN	document creation
0.2	11.06.2023	BJB, JLC, ATN, SD	complete draft

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1 INTRODUCTION

The Product is a Modular component built for the IGVC participating vehicle and serves the purpose of acting as its Computer vision solution. This solution should be capable of identifying obstacles, and road constraints of the IGVC competition course using onboard sensors (Lidar, Cameras) and be able to communicate this information to the path-planning aspect as well as the vehicle competing in the IGVC competition in 2024.

2 System Overview

In summary, the IGVC computer vision architecture involves a network of sensors, sophisticated processing components, and databases working together to enable a ground vehicle to perceive its environment, make informed decisions, and navigate autonomously. This integrated approach is crucial for the successful participation of vehicles in the competition. As our team is working on the computer vision aspect of this IGVC project, this architecture would consist of many sensors including LiDAR sensors, image and data processing components, and databases.

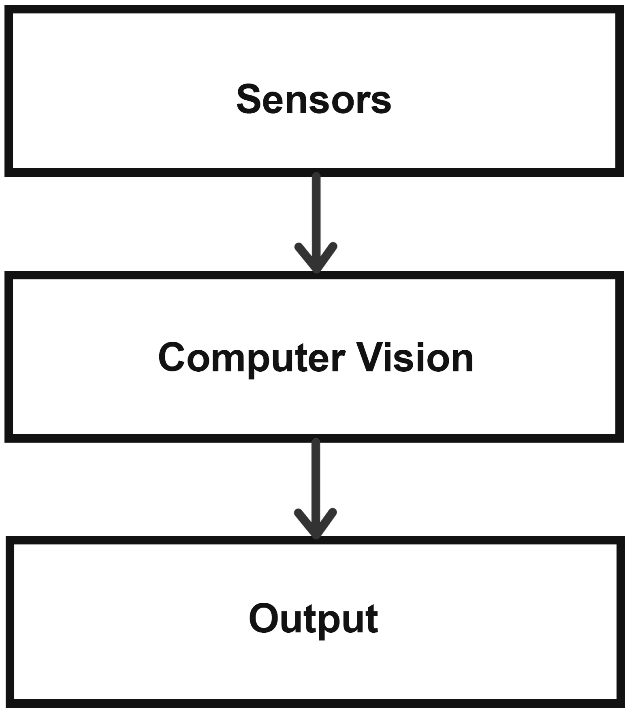

Figure 1: simplified architectural layer diagram

2.1 Layer Sensor Description

The sensors will collect data based on their surroundings and will be sent to different modules for calculations and detection. The camera will process the surroundings and save images to be sent to the Computer Vision module. The lidar sensor will collect distance measurements based on the time it takes pulsed light waves to travel from, and then back to, the lidar sensor. These measurements are then used to generate a precise 3D map of the surrounding environment. Apart from that, it would also include components like a Gyroscope which is a part of the Inertial Measurement Unit (IMU) and its main function is to measure acceleration and angular velocity to provide information about the vehicle's motion and orientation. In the output, it will generate acceleration and gyroscope data.

2.2 Layer Output Description

This layer is concerned with taking inputs from other subsystems and providing outputs to the path planner team as well as the sensor mounts managing the stability of the sensors. The onboard computer will manage the stream of changing parameters of the gyroscope to constantly keep the sensors in a stable state to ensure an ideal input recording environment. A dot matrix map is to be communicated to the Path Planner that is generated from the Computer Vision layer in the off-board computer and is to be packaged with measured distance information to be sent to the path planner at a rate of 10 times a second.

2.3 Layer Computer Vision Description

The Computer Vision will recognize obstacles and detect lanes based on the images provided by the camera sensor to help navigate through the course. The image will be compressed to optimize processing power and time. For obstacle detection, the image processed will be identified through the predefined model actively recognizing the object and outputted as a grid-based representation due to computational resources. Similarly, lane detection will operate the same as obstacle detection including the output. The output may change depending on the IGVC's computational resource since the minimum we need is for the camera to notice a meter or less in front of it for lane detection.

3 Subsystem Definitions & Data Flow

This section shows how the flow of information is passed between different subsystems in the layers between different layers.

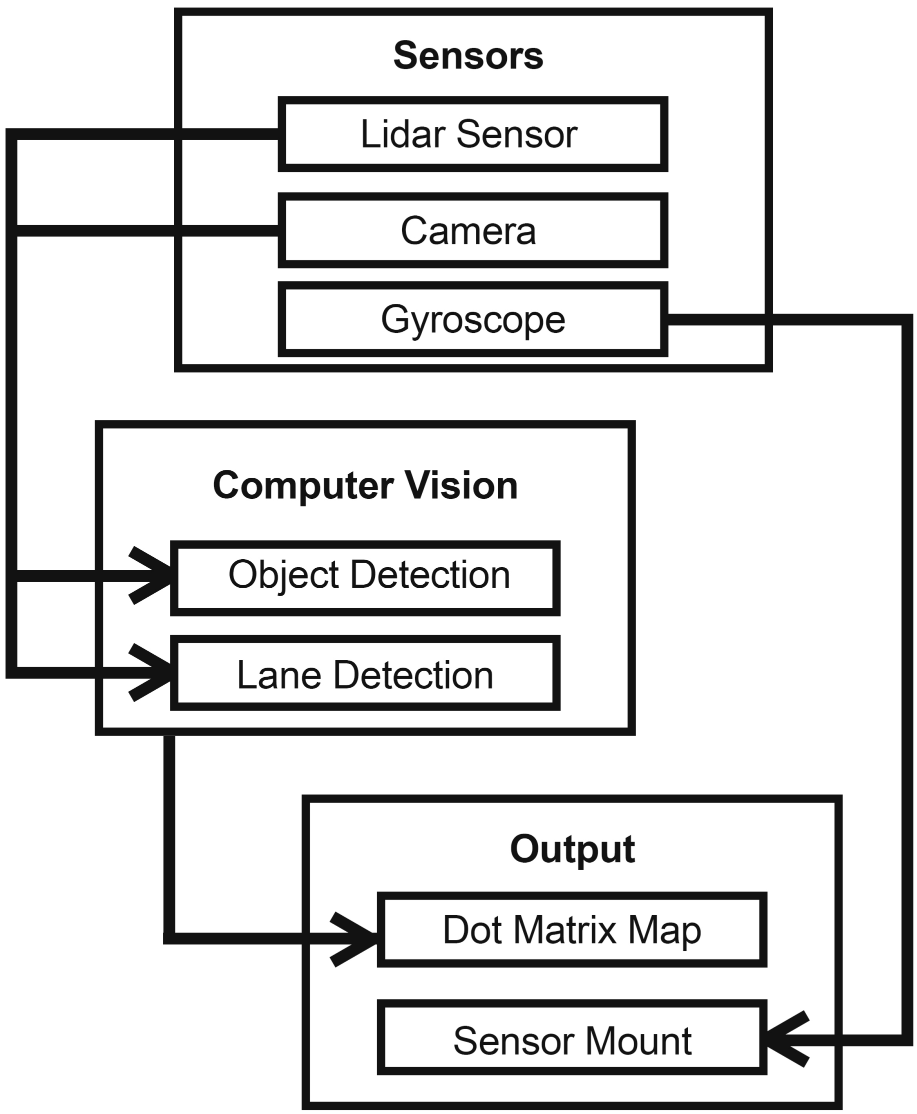

Figure 2: A simple data flow diagram

4 Sensors Layer Subsystems

The Sensors will measure and collect data to provide to the computer vision layer and output layer for the Path Planning team. In the sensors, contains a Lidar Sensor to measure how far an object or surface is, a camera to capture images for recognition, and a gyroscope to measure the vehicle's angular velocity and real time orientation.

4.1 Subsystem Camera

The camera will be mounted on top of the vehicle to optimally capture the surroundings. The camera will process the images in real-time and will be compressed and sent to the computer vision module as input.

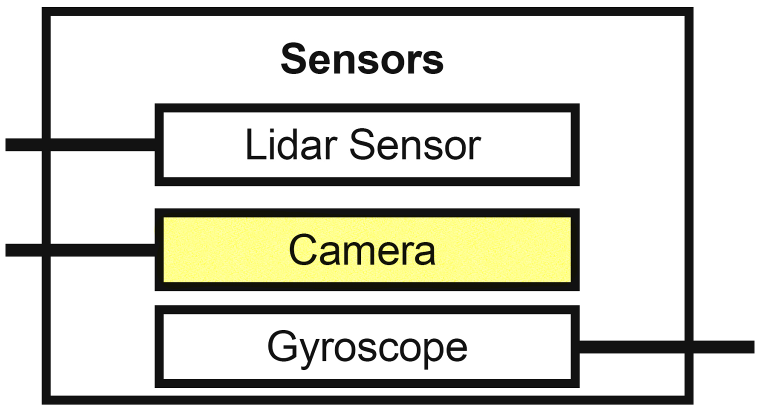

Figure 3: Example subsystem description diagram

4.1.1 Assumptions

Camera hardware is taken into consideration of its resolution, frame rate, and field of view. The calibration of the camera is optimized to fit our computer vision module's design of distortion correction and focal length. The data processing by the camera will be the images based on the frames of the camera, we'll assume the frame rate of the camera to be 25 fps and real-time processing 1 of every 5 frames, and compress the image. Pre-trained model is created that accepts the real-time processed image and outputs the results.

4.1.2 Responsibilities

The camera will be processed in real-time of its surroundings or desired area coverage and the image will be sent to the pre-trained model for object detection and classification. The camera will be placed at an optimal height that covers the majority of the area the IGVC needs to see to navigate around the course. If multi-cameras are needed for later improvements or redesign, then calibration is considered.

4.1.3 Subsystem Interfaces

This subsystem will capture an image and provide the data to the computer vision module.

Table 2: Subsystem interfaces

ID	Description	Inputs	Outputs
#C100	Camera real-time processing compressing image	Captured frames	Compressed image
#C101	Camera real-time processing object recognition	Compressed image	Pre-trained model

4.2 Lidar Sensor

The lidar sensor subsystem is a component that will be enclosed in the custom housing that will be mounted on the ground vehicle. The lidar sensor will emit pulsed light waves in order to generate an accurate, real-time 3D map of the environment, called a point cloud, that will help the ground vehicle navigate obstacles.

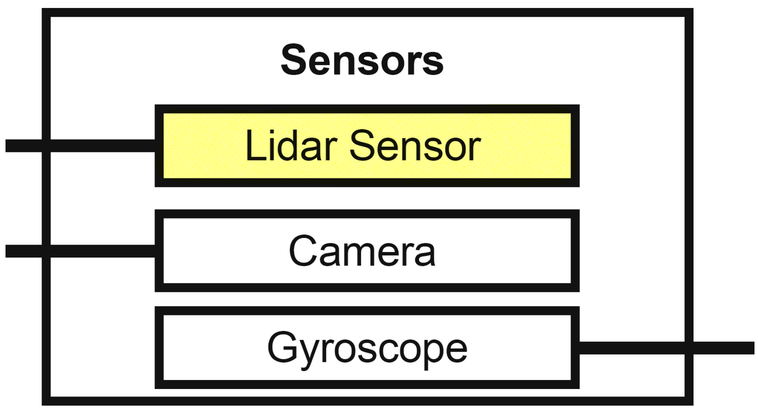

Figure 4: Example subsystem description diagram

4.2.1 Assumptions

It is assumed that the lidar sensor will be properly calibrated, mounted, and aligned on the ground vehicle. All components of the sensor are expected to be functioning at full capacity, as well as the correct exchange of information between the camera and sensor subsystems. It assumed that the the sensor will have the correct detection range, field of view, angular resolution, and laser safety in order to perform all necessary tasks in order for the computer vision module to operate optimally.

4.2.2 Responsibilities

The light waves emitted by the lidar sensor's laser are used to target an object, or surface, and calculate the time it takes for the reflected (back-scattered) light waves to return to the sensor in order to get a measurement of the distance traveled. By repeating this process millions of times per second, the sensor is able process that information in order to generate the 3D point cloud. The point cloud can then be used to map out paths for the ground vehicle to properly navigate the environment and avoid obstacles.

4.2.3 Subsystem Interfaces

Table 3: Subsystem interfaces

ID	Description	Inputs	Outputs
#C102	Lidar Sensor	Light Waves	Light Waves 3D Point Cloud

4.3 Gyroscope

Apart from the lidar sensor and cameras, one crucial device for this project would be a gyroscope, which would be integrated into an Inertial Measurement Unit (IMU). It's main function is to generate information about the vehicle's angular velocity and the real time orientation. Without this part, it would not be possible for the other sensors to generate a correct data.

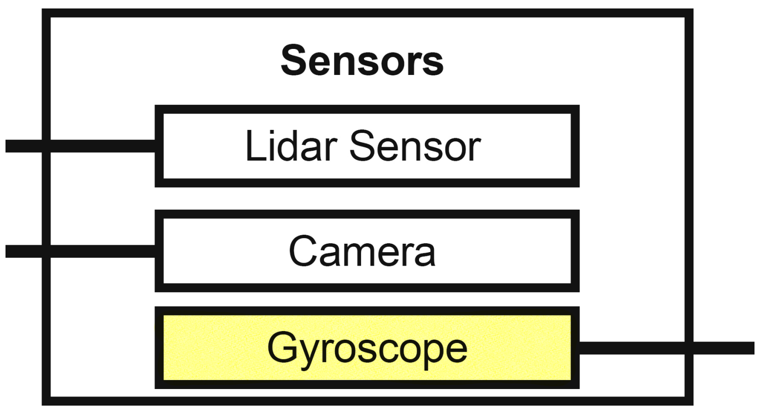

Figure 5: Example subsystem description diagram

4.3.1 Assumptions

When installing a gyroscope in an IMU, several key assumptions would be made to ensure accurate and reliable measurements. These would include assuming orthogonal sensor axes for independence, correct sensor alignment with the reference frame, stable gyroscope bias over time, consistent temperature conditions, negligible zero-rate output, accurate gyro-gyro alignment in multi-gyroscope setups, a stable and noise-free power supply, minimal vibration during measurements, and negligible impact of linear acceleration on gyroscope readings. Careful consideration of these assumptions and appropriate calibration procedures is essential for obtaining precise data from the IMU's gyroscope.

4.3.2 Responsibilities

A gyroscope in this project is as vital as other parts of the vehicle. It has many features and responsibilities which includes:-
Angular Rate Measurement: The primary responsibility of a gyroscope is to measure the rate of angular rotation around its various axes. This information indicates how fast the IMU is rotating in three-dimensional space.
Orientation Tracking: By integrating the angular rate measurements over time, the gyroscope helps

track changes in orientation. It contributes to determining the IMU's current orientation relative to a reference frame.
Motion Sensing: Gyroscopes assist in detecting and quantifying rotational movements, providing data on the IMU's angular velocity. This information is essential for understanding how the IMU is rotating in space.
Stabilization: In applications like robotics and unmanned vehicles, gyroscopes are crucial for stabilization. They help maintain a stable orientation by providing real-time feedback on rotational movements, enabling corrective actions.
Navigation and Dead Reckoning: Gyroscopes are integral to navigation systems. Combined with accelerometers, they contribute to dead reckoning by estimating changes in position based on the known starting point and measured accelerations and rotations.
Control Systems: Gyroscopes are vital components in control systems, where precise knowledge of rotational motion is essential. They provide feedback to control algorithms, aiding in maintaining desired orientations or executing controlled rotations.

4.3.3 Subsystem Interfaces

Table 4: Subsystem interfaces

ID	Description	Inputs	Outputs
#C103	Gyroscope Sensor	Power Supply	Angular Rate Data Raw Sensor Data Data Sampling Rate

5 Output Layer Subsystems

The Output Subsystem controls the output that is sent to the Path Planner team as well as the stabilization instructions that are to be sent to the sensor mounts determined by processing the inputs from the Gyroscope sensor in order to stabilize the sensors.

5.1 Dot Matrix Map

The output that is to be provided to the path planner team is going to be a dot matrix map of what has been detected by the computer vision model with marked detected obstacles, to be sent 10 times every second. A supplementary JSON file including measured distances from the obstacles might also be included in each sent package.

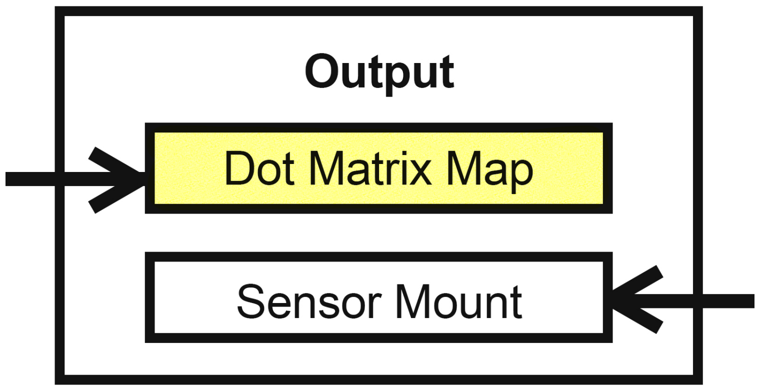

Figure 6: Output subsystem description diagram

5.1.1 Assumptions

It is assumed that these items requested by the path planner team are to be sent via an agreed-upon protocol of wireless transmission through the off-board computer. It is also assumed that the IGVC vehicle remains within range of the off-board computer to transmit the information without experiencing losses.

5.1.2 Responsibilities

The Dot Matrix map to be sent to the path planner team is to be constructed using the Inputs from the computer vision system and then are to be packaged and processed to be delivered to the path planner system.

5.1.3 Subsystem Interfaces

This subsystem will take the provided Obstacle Grid and the Lane Grid from the Computer Vision Layer System to provide to the path Planner team.

Table 5: Subsystem interfaces

ID	Description	Inputs	Outputs
#D100	Output Map to Path Planner	Obstacle Grid Lane Grid	Dot Matrix Map

5.2 Sensor Mount

This is the subsystem that calculates the parameter adjustments necessary for the sensor mounts to be able to stabilize using inputs from the gyroscopes on the onboard computer.

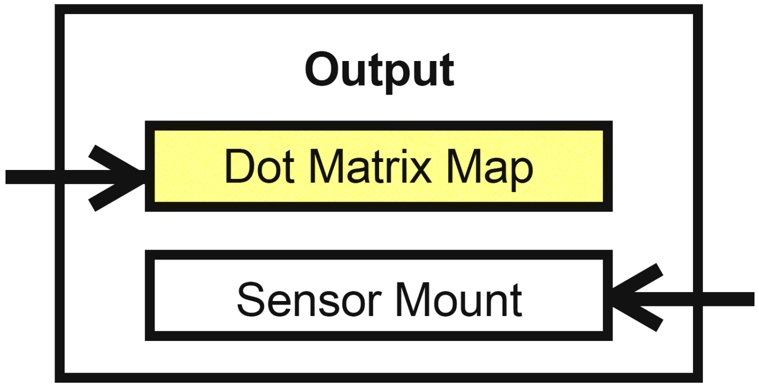

Figure 7: Output subsystem description diagram

5.2.1 Assumptions

It is assumed that the sensor mounts are able to react instantaneously to maintain sensors in their ideal positions and the sensors are able to be calibrated according to the environment they are in and the specifications of the drone to ensure ideal recordings.

5.2.2 Responsibilities

Correctly compute and adjust mount parameters instantaneously to ensure smooth sensor positions for ideal input collection from the sensors.

5.2.3 Subsystem Interfaces

This subsystem will take the current coordinates of the sensor mounts and use the calibrated stable coordinates to obtain the compensation of coordinates needed to stabilize the sensors.

Table 6: Subsystem interfaces

ID	Description	Inputs	Outputs
#S100	Stabilization adjustments	Current Coordinates Stable Coordinates	Compensation parameters

6 Computer Vision Layer Subsystems

The computer vision module will take the surrounding images to identify what the obstacles are and keep track of the lane. The camera will communicate to the computer vision module and give them an image as input and the module will output a grid-based map.

6.1 Obstacle detection

The obstacle detection will take the input given by the camera and will identify the obstacles around their surroundings.

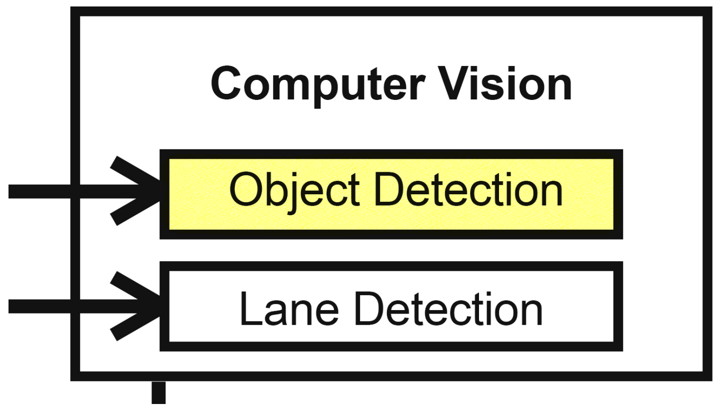

Figure 8: Example subsystem description diagram

6.1.1 Assumptions

A predefined model is provided to help correctly identify the objects. The image has been captured and processed in real-time.

6.1.2 Responsibilities

Correctly classifies the object to dictate the IGVC's actions and behavior when navigating through the course to progress. Depending on the obstacle, whether a cone or ramp, it will influence the IGVC's movements.

6.1.3 Subsystem Interfaces

This subsystem will take inputs from the camera sensor that is used to classify objects in real time.

Table 7: Subsystem interfaces

ID	Description	Inputs	Outputs
#O100	Obstacle classification	Compressed image from camera Predefined model	Obstacle grid

6.2 Lane detection

The lane detection will take the input given by the camera and will identify the edges of the lane to help keep the IGVC in between the lines.

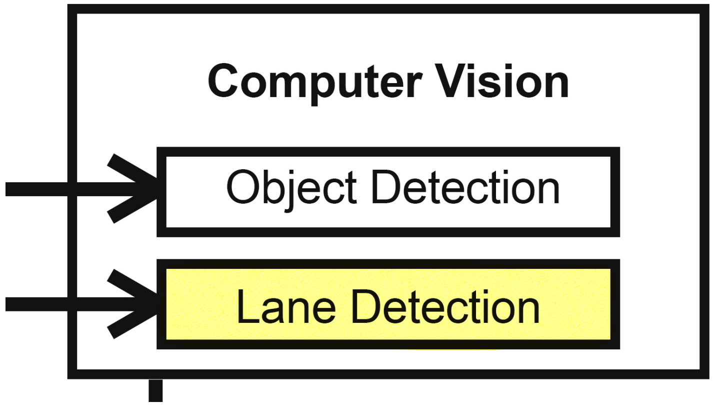

Figure 9: Example subsystem description diagram

6.2.1 Assumptions

A predefined model is provided to help correctly identify if it is a lane. The image has been captured and processed in real-time.

6.2.2 Responsibilities

Correctly classifies the lane depicted by the black lines guiding the IGVC as a boundary. To ensure the IGVC does not go off course and stay in between the lines.

6.2.3 Subsystem Interfaces

This subsystem will take inputs from the camera sensor that is used to detect lanes in real time.

Table 8: Subsystem interfaces

ID	Description	Inputs	Outputs
#L100	Lane detection	Compressed image from camera Predefined model	Lane grid

REFERENCES