Topic: Assistive Technologies using sensors data and producing spatial soundscape

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Abstract

The main aim of the project is to develop an advanced driver assist system(ADAS) using data from LiDAR and spatial audio rendering to enhance situational driving awareness. The main focus of the project is to extract data from the LiDAR, the distance and angle of the surrounding objects with respect to the car, that will then form the foundation for the spatial audio cue generation. The project involves LiDAR point cloud processing, data extraction and visualization. While in the initial stages the project aims to demonstrate the potential of combining the technologies to create a more harmonized and intuitive and a low visually demanding driver assist system. The research contributes to the growing field of multimodal ADAS, addressing the need for reduced cognitive load and enhanced safety in modern driving environments[1][2].

Background and Motivation

The modern driving environment is increasingly complex, demanding and needs the driver to be constantly attentive and vigilant. Traditional ADAS systems are heavily visual-based and can sometimes overwhelm the drivers with information, thus potentially increasing cognitive load and lowering the reaction times of the drivers[3]. With this project, we address the need for more intuitive methods of conveying critical information without overwhelming the driver by leveraging the human auditory system's natural ability to process spatial cues. [4]
Integrating LiDAR technology with spatial audio rendering creates more opportunities for creating a less visually dependent ADAS. The LiDAR provides high-precision 3D mapping of the vehicle's surroundings, while the spatial audio generated can convey this information in an easy non-visual spatial manner[5][6].

Objective

The primary objectives of this project are:

1. Developing a LiDAR processing pipeline to calculate the object distance and angle.
2. The information extracted from the LiDAR will be utilized in the development of spatial audio cues and collision detection in subsequent work (not part of this project).

Research Question

How can the integration of the processed LiDAR data analysis create an effective and instinctual driver assist system that will reduce the cognitive load and enhance situational awareness of the driver?

Scope

The scope of the project includes:

1. Extracting the data obtained from a LiDAR and processing it to get the distance and angle calculations.
2. Extracting and visualising OBD-II data for performance analysis of the vehicle.
3. Create a base framework for spatial audio rendering systems from the extracted LiDAR data.
4. Analysing catalytic converter light-off time, speed-elevation mapping, fuel economy optimization, and GIS map visualization from the extracted OBD-II data.

[The project does not yet encompass real-time integration or on-road testing of the combined systems.]

Literature Review

LiDAR technology has become common application in ADAS and autonomous vehicle systems. Late-modern design has focused on enhancing the methods of handling data to provide greater object detection and tracking speed and accuracy[7]. Automotive spatial audio has been studied for the capacity to maximize driver attentiveness and reduce cognitive burden[8].

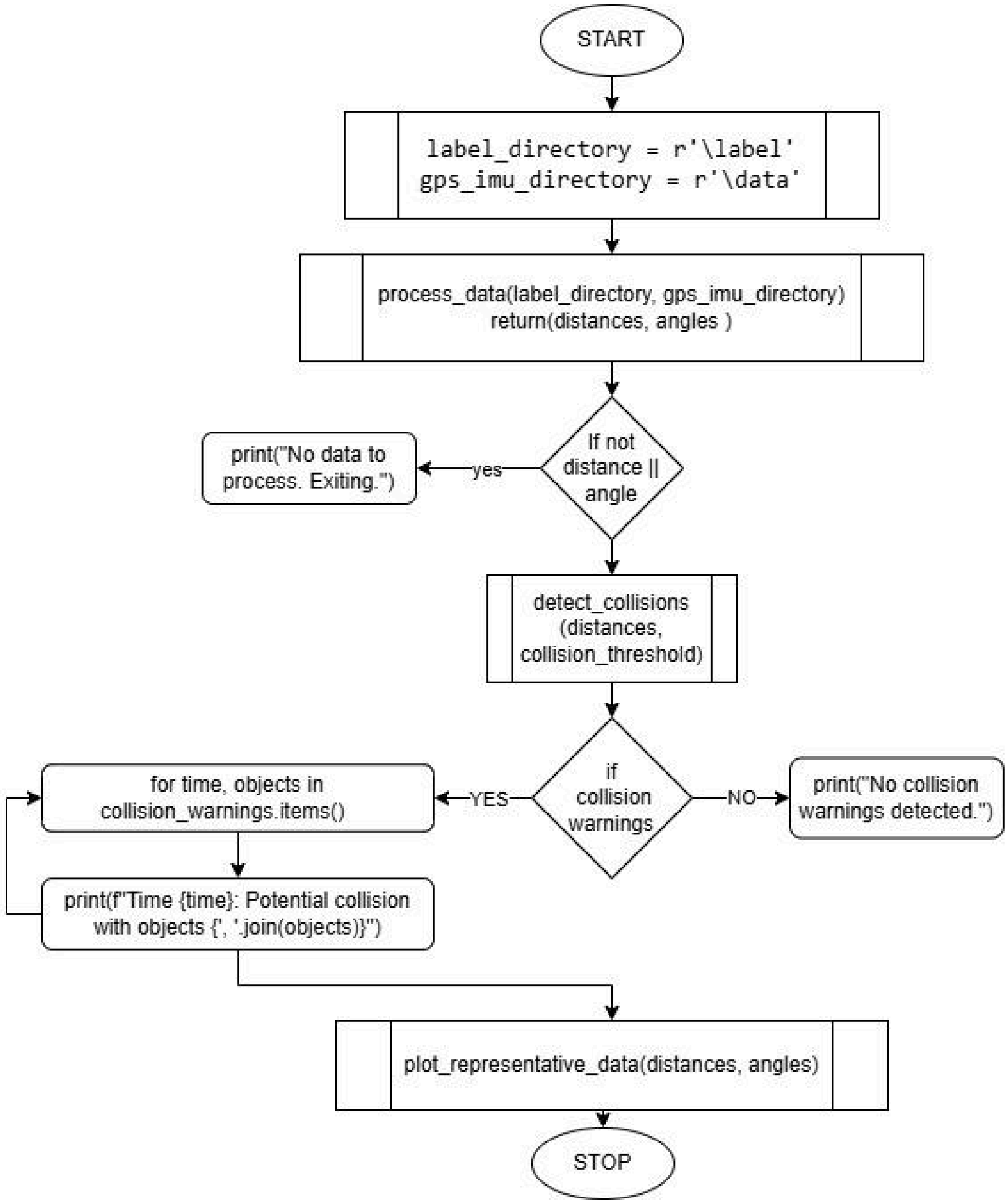
In the analysis of OBD-II data, numerous fields of vehicle performance optimization have been researched. There are papers that have analyzed driving behavior and its correlation with fuel consumption and those that have analyzed the possibility of using OBD-II data in predictive maintenance.

Comparative Discussion

This project is unique in combining LiDAR-derived spatial awareness with auditory feedback, a lack of current ADAS research that presumes visual interfaces almost to a fault. The addition of OBD-II data analysis also opens up the system to greater possibilities for integrated driver assistance.While prior research has explored spatial audio for use in vehicles, our approach of directly mapping LiDAR-derived spatial data to audio cues is novel. This has the potential to create a more accurate and responsive auditory space for drivers. This twofold role of both driver assistance and vehicle optimization is what differentiates our research from more limited ADAS research.

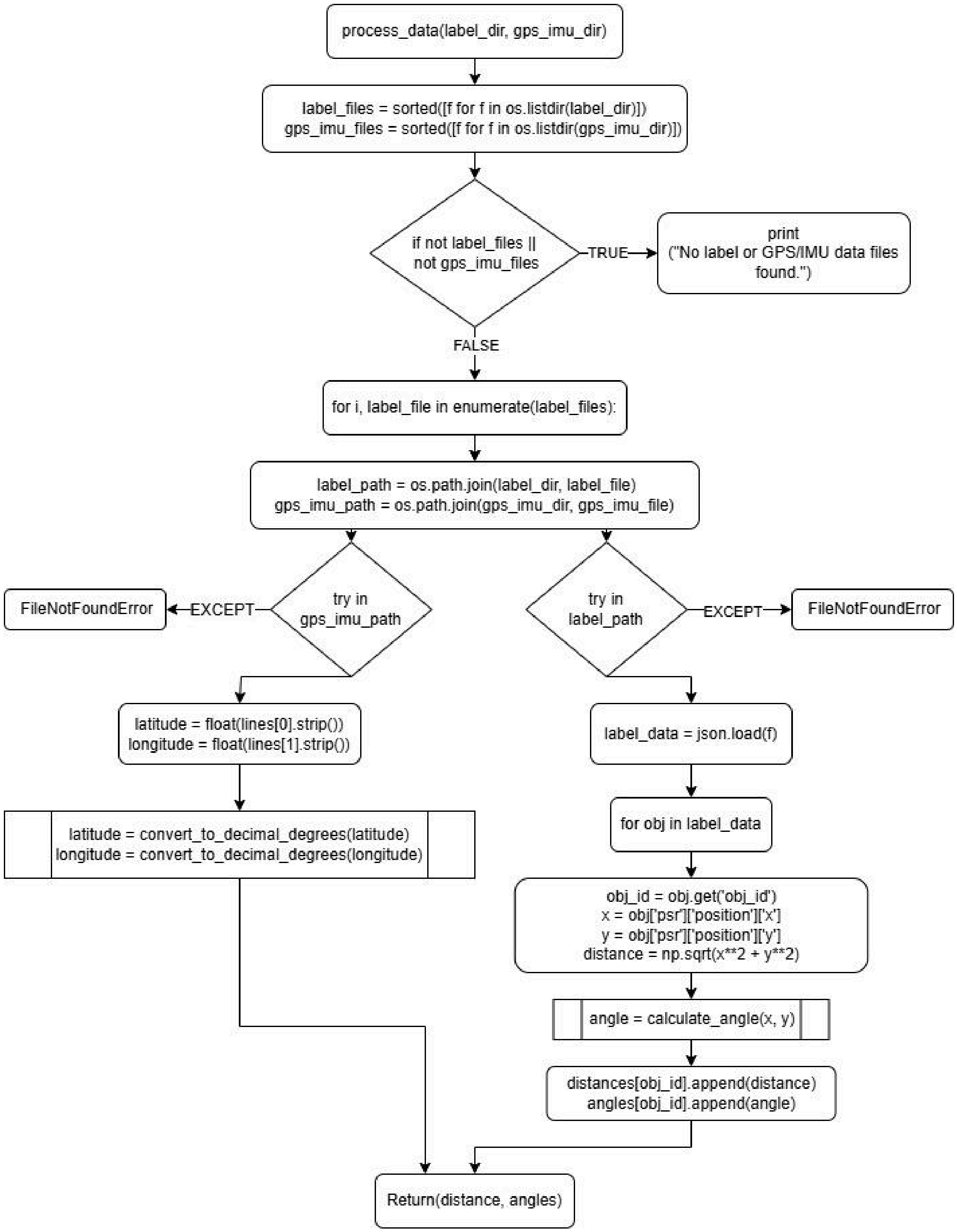
Methodology

Flow of drivers code



Explanation for drivers code:

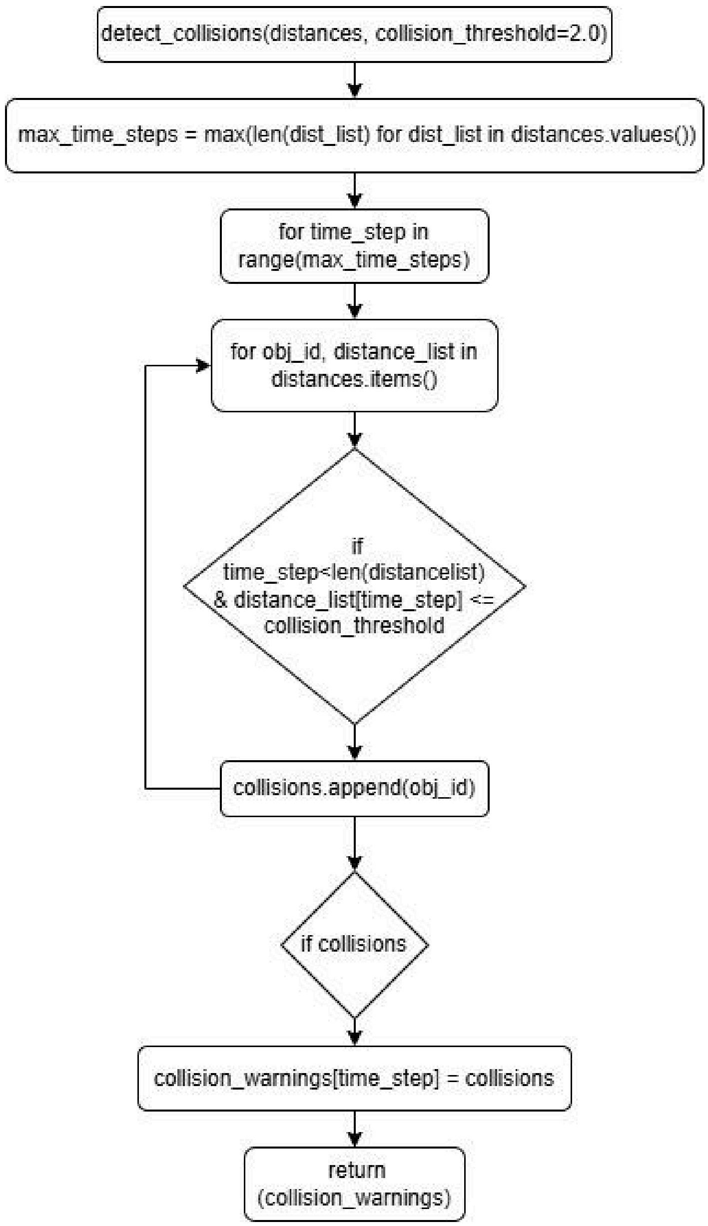
This is the main execution point of the driver program. It sets up the label and GPS/IMU data directories, then calls process_data to loop over the above data. If there is no data to process, it exits with a message. Otherwise, it proceeds to look for possible collisions based on a 2.0-meter threshold. The program then proceeds to print out any collision warnings, with time and colliding objects. If there are no collisions, it does inform the user. Then, whether collisions have been found or not, the code ultimately calls the plot_data function to graphically represent the processed data in terms of distances, angles, and collision warnings that would have been observed. This driver code thus ties the program's data processing, collision detection, and graphing aspects all together nicely.



Flow of sub-code

Explanation for function process_data:

The function process_data operates on label and GPS/IMU data within directories provided with label_dir and gps_imu_dir as arguments. It starts off with empty dictionaries for distances and angles, lists JSON label files and TXT GPS/IMU files in directories, and returns empty dictionaries when no files are present. The function iterates through label files, reads matching GPS/IMU data, converts GPS coordinates to decimal degrees, and reads JSON label data. It calculates distance and angle from the origin for every object in the label data and puts them into the dictionaries with object IDs. It expects one-to-one correspondence of label and GPS/IMU files but does not utilize the GPS data directly in its calculation. It also outputs dictionaries of distances and angles per object.



Flowchart for the function collision detection.

Mathematical Formulations

1. Distance Calculation:
   The distance from the vehicle to an object is calculated using the Euclidean distance formula in 2D space:
   $d = \sqrt{(x^2 + y^2)}$
   Where:
   d = distance to the object
   x = x-coordinate of the object relative to the vehicle
   y = y-coordinate of the object relative to the vehicle
2. Angle Calculation:
   The angle of an object relative to the vehicle's forward direction is calculated using the arctangent function:
   $\theta = \text{atan2}(y, x)$
   Where:
   θ = angle in radians
   x = x-coordinate of the object
   y = y-coordinate of the object
   This angle is then converted to degrees:
   $\theta\_degrees = \theta * (180 / \pi)$
3. Coordinate Conversion:
   To convert GPS coordinates from ddmm.mmmm format to decimal degrees:
   decimal_degrees = degrees + (minutes / 60)
   Where:
   degrees = int(coordinate / 100)
   minutes = coordinate - (degrees * 100)
4. Collision Detection:
   A simple threshold-based collision detection is used:
   if d ≤ collision_threshold:
   collision_warning = True
   Where:
   d = distance to the object
   collision_threshold = predefined safety distance (e.g., 2.0 meters)

Tools and Technologies used

1. Libraries:
   - json: For parsing JSON files containing label data.
   - numpy (imported as np): For numerical operations and array handling.
   - matplotlib.pyplot (imported as plt): For creating plots and visualizations.
   - os: For file and directory operations.
   - math: Specifically for atan2 and degrees functions used in angle calculations.
2. Other Technologies:
   - LiDAR: While not a software technology, the code processes LiDAR data, which is a key technology for spatial sensing in autonomous vehicles.

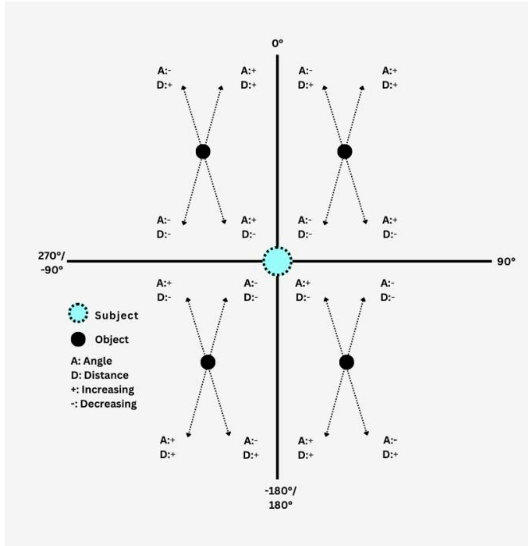
- GPS/IMU: The code also processes GPS (Global Positioning System) and IMU (Inertial Measurement Unit) data for vehicle positioning.

Results

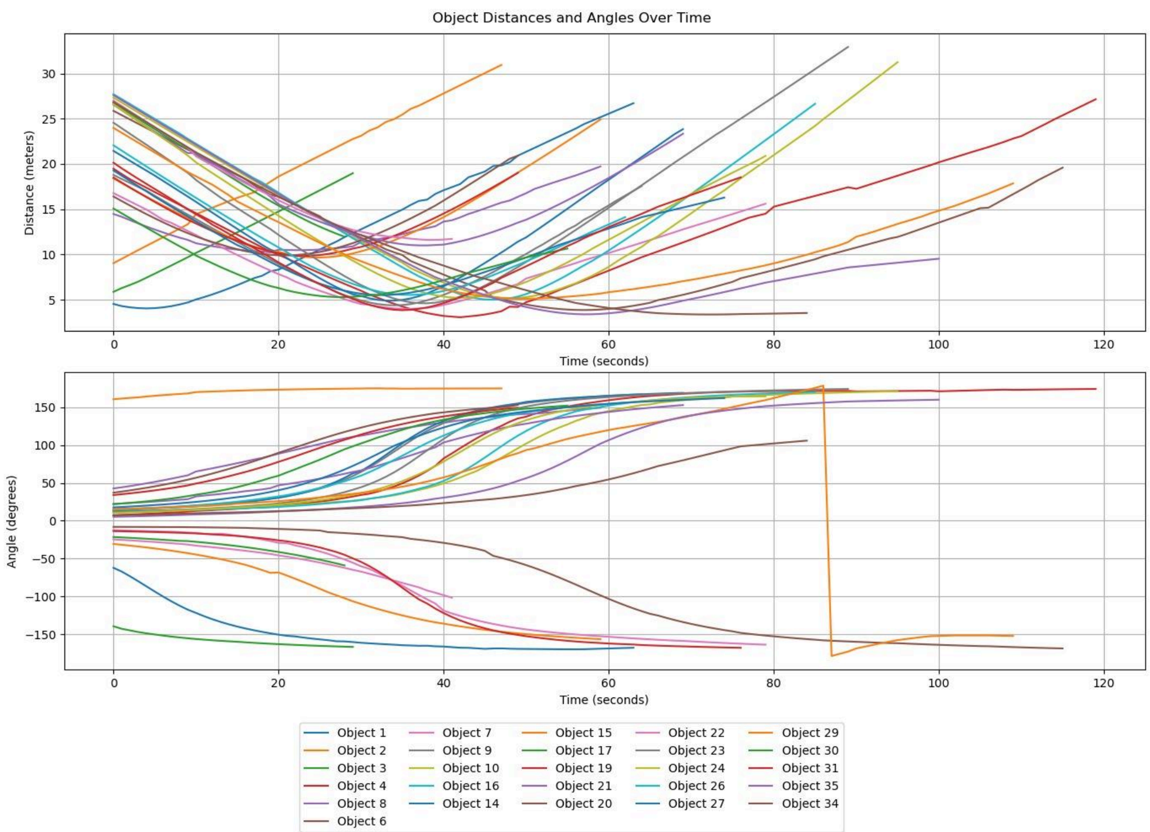
Results for the LiDAR data extraction ie. the data and angle of the objects with respect to the subject.

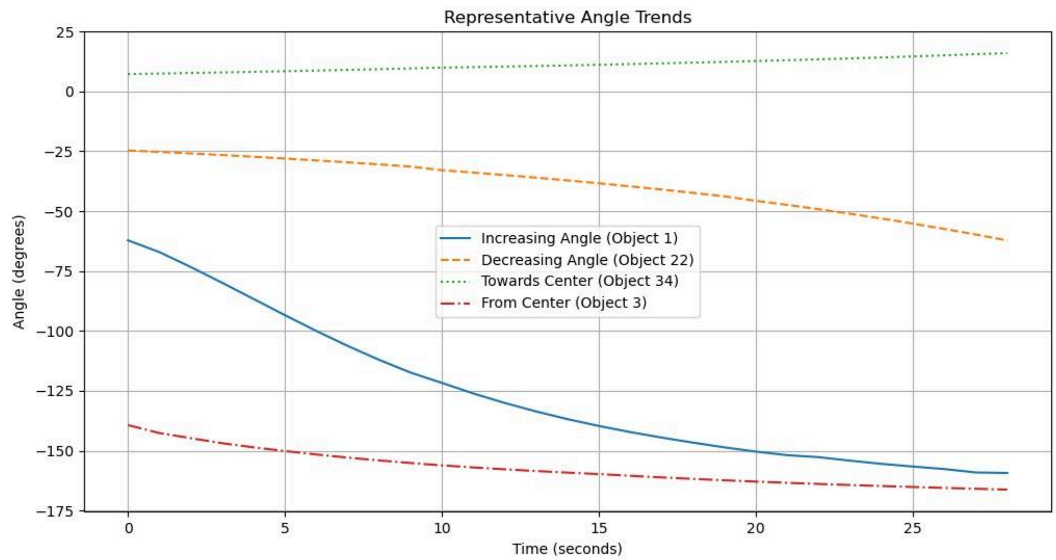
Object movement trends

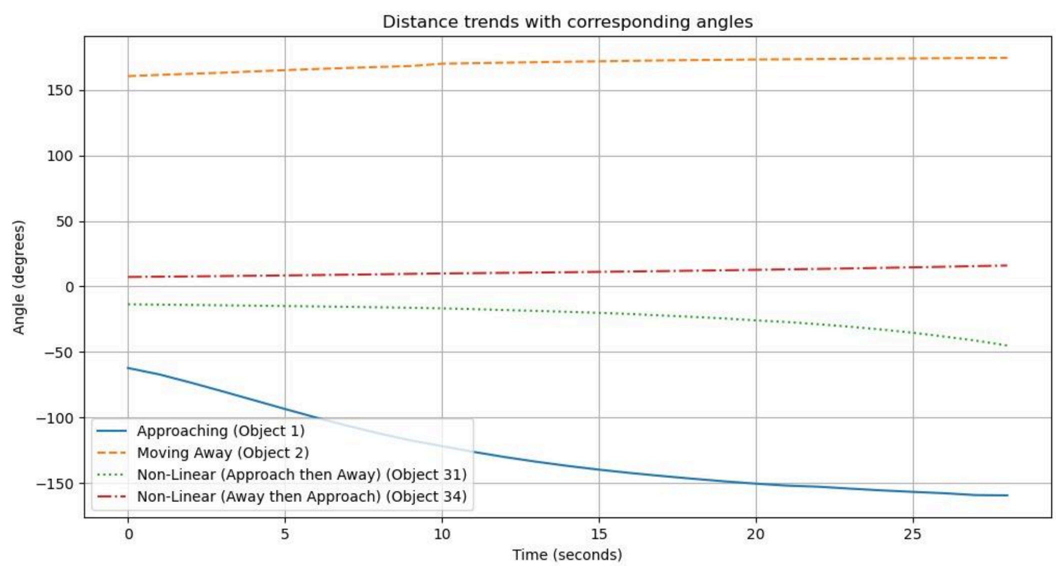
Angle Range	Angle Change	Distance Change	Quadrant	Position	Movement Relative to Subject
0 to 90	Increasing	Increasing	Front-Right	In front	Moving away
0 to 90	Increasing	Decreasing	Front-Right	In front	Moving closer
0 to 90	Decreasing	Increasing	Front-Right	In front	Moving away
0 to 90	Decreasing	Decreasing	Front-Right	In front	Moving closer
90 to 180	Increasing	Increasing	Back-Right	Behind	Moving away
90 to 180	Increasing	Decreasing	Back-Right	Behind	Moving closer
90 to 180	Decreasing	Increasing	Back-Right	Behind	Moving away
90 to 180	Decreasing	Decreasing	Back-Right	Behind	Moving closer
180/-180 to 270/-90	Increasing	Increasing	Back-Left	Behind	Moving away
180/-180 to 270/-90	Increasing	Decreasing	Back-Left	Behind	Moving closer
180/-180 to 270/-90	Decreasing	Increasing	Back-Left	Behind	Moving away
180/-180 to 270/-90	Decreasing	Decreasing	Back-Left	Behind	Moving closer
270/-90 to 360/0	Increasing	Increasing	Front-Left	In front	Moving away
270/-90 to 360/0	Increasing	Decreasing	Front-Left	In front	Moving closer
270/-90 to 360/0	Decreasing	Increasing	Front-Left	In front	Moving away
270/-90 to 360/0	Decreasing	Decreasing	Front-Left	In front	Moving closer

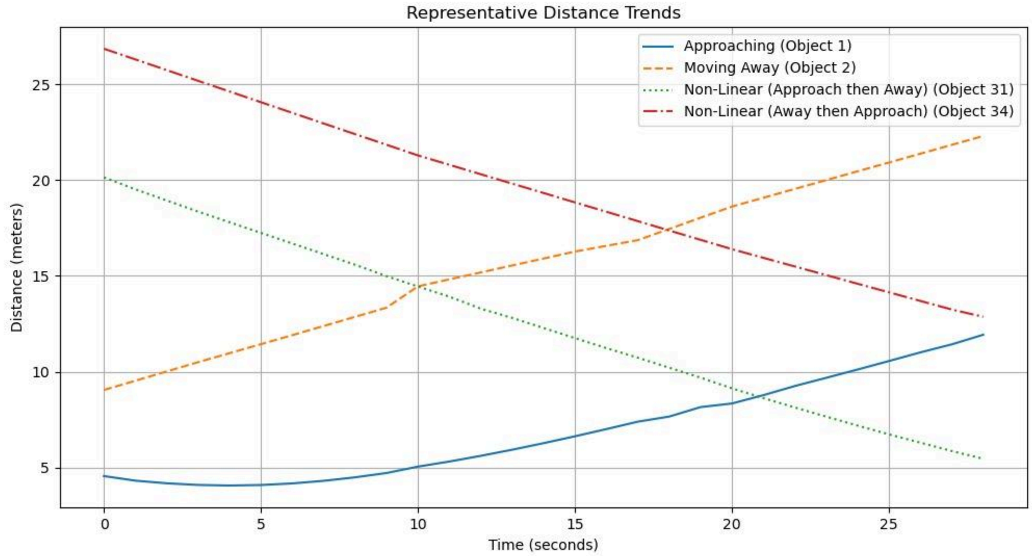


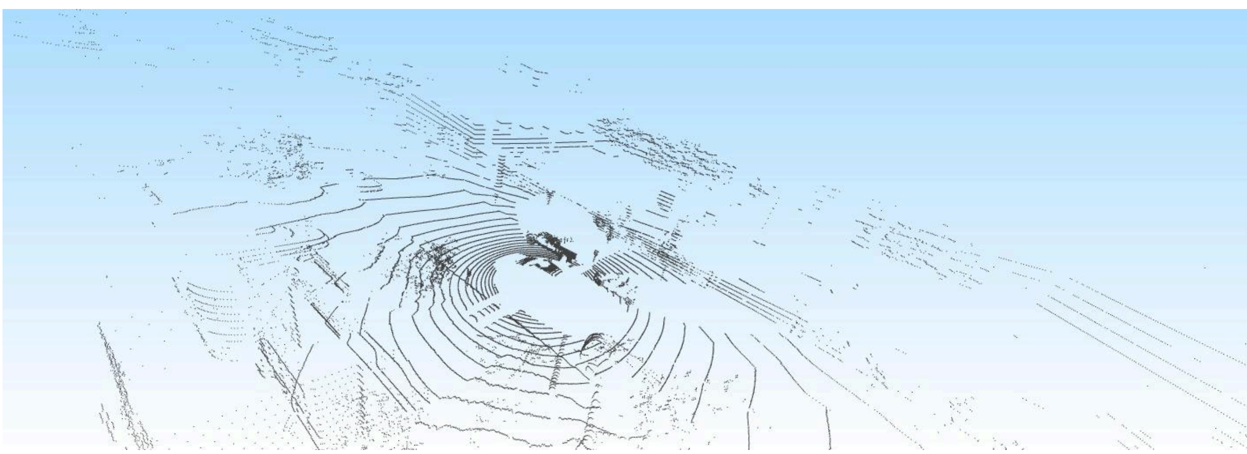
<u>Graph illustrating object movement with respect to subject by examining incremental and decremental changes in the objects' distance and angle</u>




Representative Angle Trends
Angle (degrees)
Time (seconds)
Increasing Angle (Object 1)
Decreasing Angle (Object 22)
Towards Center (Object 34)
From Center (Object 3)


Distance trends with corresponding angles
Angle (degrees)
Time (seconds)
Approaching (Object 1)
Moving Away (Object 2)
Non-Linear (Approach then Away) (Object 31)
Non-Linear (Away then Approach) (Object 34)





Visual representation of point cloud data

Discussion

Interpretation of results

The successful extraction of distance and angle information from LiDAR data represents a crucial first step in developing a spatial audio-based driver assistance system. This lays the groundwork for creating an intuitive auditory representation of the vehicle's environment. The OBD-II data analysis provides complementary insights into vehicle performance, which can be used to further enhance the overall driving experience and efficiency.

Conclusion and Future work

Summary of Findings

1. LiDAR data processing is able to recover object distances and angles successfully, providing the basis for spatial mapping.
2. The data extracted and processed is further used to detect objects and alert the driver of any collisions and will be further used to generate spatial audio. (further work)

Implications

The integration of LiDAR and spatial audio will unlock next-generation driver assistance. As a foundation for spatial audio rendering, this research could create more natural and less intrusive interfaces for the delivery of critical information to drivers. Additionally, analysis of vehicle performance data could result in improved fuel efficiency and reduced emissions via driver feedback and vehicle optimization[8].

Future Work

1. Application of spatial audio rendering methods on processed LiDAR data.
2. Conducting user tests to study the efficacy of spatial audio signals for driver assistance.
3. Object detection and prediction improvement work based on machine learning techniques on LiDAR data.
4. Scope determination for personalized audio profiles per driver's requirement and vehicle models.

This research is an entry point into an end-to-end, audio-based driver assistance system that has the potential to significantly enhance car performance and road safety.

Citations:

1. Personalized Spatial Audio - The holy grail called HRTF
2. Three ways to determine distance using LiDAR - YellowScan
3. US11190900B2 - Spatial audio array processing system and method - Google Patents
4. Data output type LiDAR | Scanning Range Finder | Principle, Glossaries | HOKUYO AUTOMATIC CO., LTD.
5. Full article: LiDAR Data Processing for Digitization of the Castro of Santa Trega and Integration in Unreal Engine 5

6. LiDAR Explained – Understanding LiDAR Specifications and Performance
7. On the Relative Importance of Visual and Spatial Audio Rendering on VR Immersion
8. LiDAR Basics: The Coordinate System | HackerNoon