SMARTCARS

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Executive summary

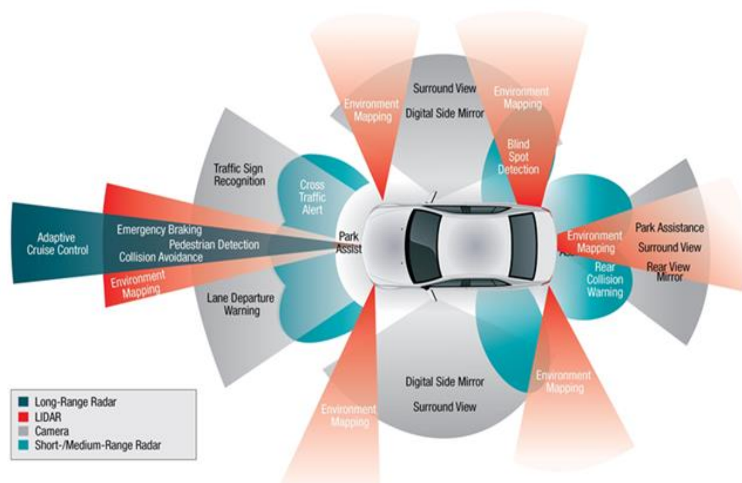
Currently, the world is experiencing a paradigm shift in the area of autonomous driving. The automotive industry is moving from partial driving assistance (Level 2) to conditional driving automation (Level 3). There are multiple obstacles to deploying level-3 autonomous driving, such as (lack of) regulations, business models, technology, and - quite important - costs. Nowadays, level-3 cars require the use of a high number of sensors such as cameras, radars, and LiDARs, which need to cooperate to have a very detailed knowledge of the surrounding environment. The use of these sensors makes the cost of the car increase drastically. Among all, the impact of LiDARs (Light Detection and Ranging) is the one affecting the most the price of the car sold to the final users. Indeed, a 3D LiDAR, a sensor that provides a high-resolution 3D view of the car's surroundings as it goes, costs several thousand dollars.

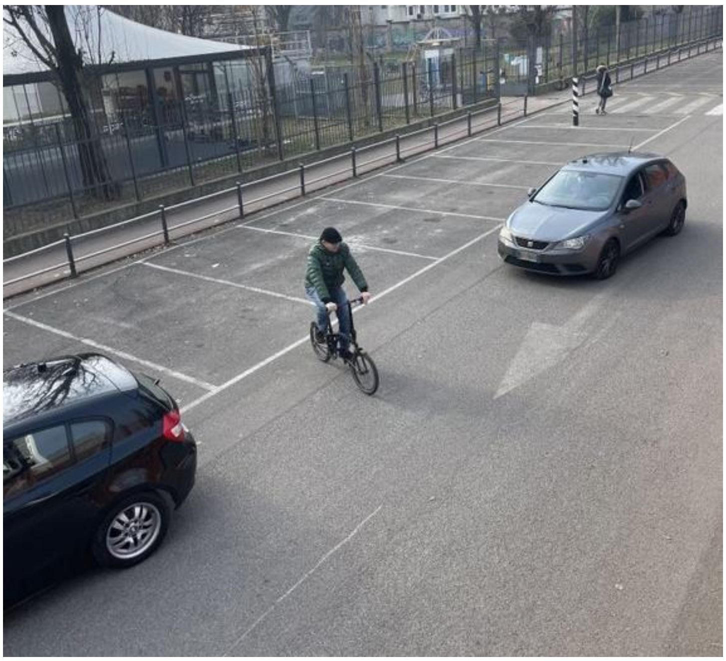
The SMARTCARS project aims at abating the costs while still guaranteeing reliability by replacing 3D LiDARs with 2D LiDARs: small, power-efficient, and cost-effective sensors, with an average price of 200 dollars. This can be achieved by a cooperative approach, merging the information retrieved by multiple LiDARs in order to get a comprehensive understanding of the surroundings. The idea is not to simply mount multiple 2D LiDARs on the same vehicle and merge their data, but instead to exploit the features provided by the 5G technology to share real-time data with LiDARs of other cars.

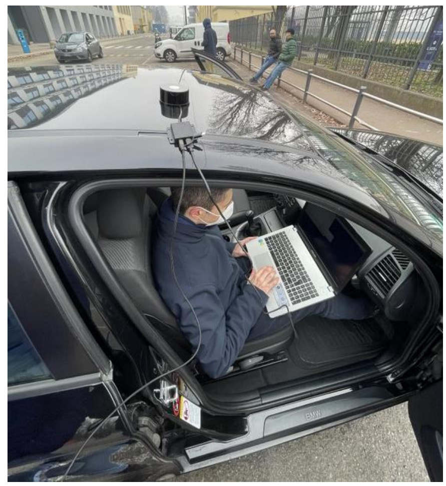
The system we designed consists of a high-level architecture that accounts for the steps needed to make the data valuable and interpretable by each vehicle. Using machine learning and signal analytics tools (DBSCAN, SLAM, Hough Transform), the SMARTCARS team aimed to develop a solution that could break down the economic constraint represented by the high cost of 3D LiDARs, as well as pay more attention to an undervalued aspect of technological research in this field, namely that of cooperation between several vehicles through the mutual exchange of sensor data. Since we obtained some positive outcomes from the developed system, we can assert that our solution is technically feasible and works in specific and controlled situations. We then outlined how the project could be improved and developed so that external institutions could benefit from all the work done.

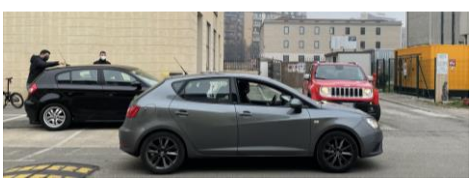
Key Words

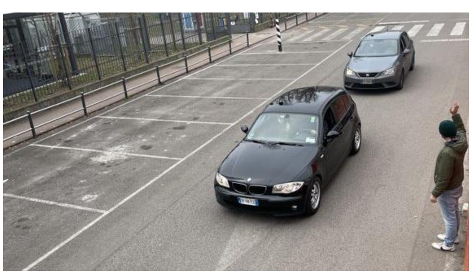
LiDAR; DBSCAN; SLAM; point cloud; 5G technology











Project description written by the Principal Academic Tutor

Vehicles' price is a critical factor for the mass scale diffusion of autonomous driving. Most of nowadays working and reliable fully autonomous cars mount multiple sensors (Radar, LiDAR, Cameras) to perceive the surrounding environment. However, such sensors are costly and, on their own, can increase the price of the car by 100%. There are different approaches in the automotive industry to face this issue. A crucial competitive advantage is finding a way to perceive the surrounding environment effectively while keeping the overall price low.

SMARTCARS is an experimental project investigating the possibilities of cost-effective sensors in connected autonomous cars. The project's core idea is to study how to increase the amount of environmental information that a car can gather when communicating with other intelligent vehicles through low-latencies channels (5G). In other words, relying on the fusion of multiple, low-cost, diffused data sources rather than equipping the car with expensive sensors.

At the kickoff, the team considered Radars, and the team gained awareness of this kind of sensor. However, due to price and logistic constraints, and the team competences, we agreed to shift the project's focus from Radar data analysis to bi-dimensional LiDAR. This sensor is fairly simple still preserving the conceptual imaging problems planned, it is low price made and was available off-the-shelf for different scene simulations. During the project, three different real data acquisitions were performed. These sessions allowed the team to collect testing data in progressively more complex situations, mocking urban scenarios.

Team description by skill

Our team has a strong technical imprint, being composed only of engineers. However, belonging to different courses of study has allowed us to have a very broad portfolio of skills needed to tackle a project that must be approached from different points of view. Each of us played a key role in the project and we had the opportunity to learn a lot from each other.

Pietro is a Computer Science student. He has extensive knowledge of operating systems and programming languages, so he was the main developer and maintainer of the software interface and implementation of the algorithms used in the project, with the main use of Python language.

Giacomo is a student of Control System Engineering. He was responsible for designing, developing, and implementing solutions that control dynamic systems. Within the team, he is the main expert when it comes to using sensors and understanding the tools needed to easily access and process sensor data. His background also includes knowledge of Simulink, software for modelling, simulation, and analysis of dynamic systems, which we used in the early stages of the project, and MATLAB, used mainly for the SLAM algorithm.

Monica and Paolo are both Mathematical engineers. Their strong mathematical background allowed us to go into more detail about the theoretical aspects of the algorithms and transformations used (such as the Hough Transform), ensuring the feasibility of our procedure. They are able to tackle, with the mindset of an engineer, problems related to complex systems, in which there is a strong interdisciplinary character, using methodologies from the various fields of Applied Mathematics.

Javier is a student of Aeronautical Engineering. He has specific skills in design, operation and maintenance of on-board systems that also require high efficiency and safety. His expertise in designing, testing and implementing parts, systems and procedures has been fundamental in the data acquisition campaigns.

Goal

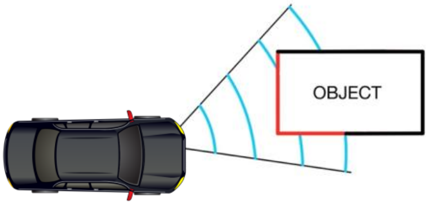
The goal of the project is to develop an object tracking algorythm using data acquired thorugh multiple 2D Lidar sensors. The final purspose is to be able implement this to vehicles on the road so through merged data from sensors of different cars it is possible to build a real time 3D environment to detect obstacles.

To acheive the main goal of the project the activities were divided in five phases which involved more specific goals for the first part the goal was to review the literature on the technology and develop stakeholder analysis. The second pahse was focused in purchasing the sensors and some initial data acquisition campaigns. The third part required data acquisition campaigns in real-life contexts with car-mounted sensors, the fourth phase respectively concerned about data post-processing and implementation algorithms. Finally, the fifth phase connected all the previous points with the goal of merging data from multiple sensors and some GPS testing was also developed.

Understanding the problem

Nowadays, level-3 cars require the use of a high number of heterogeneous sensors such are cameras, radars, and LiDARs which need to cooperate to have a very detailed knowledge of the surrounding environment. The use of these sensors, make the cost of the car to increase drastically. Among all, the impact 3D LiDARs is the one affecting most the price of the car sold to the final users. Furthermore, these types of LiDAR require a considerable amount of space to be mounted on the car.

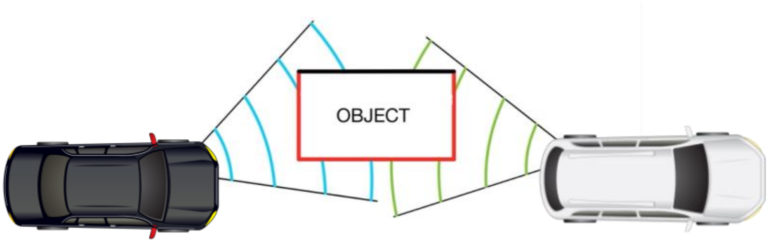
To reduce the cost and spatial impact of a 3D LiDARs, SMARTCARS decided to replace 3D LiDARs with 2D LiDARs, small, power-efficient, and cost-effective sensors, with an average price of 200 dollars. The main limitation oh these sensors is the quantity and quality of information about the environment they can extract. Indeed, a 2D LiDAR can sense a single plane of the surrounding space, and the various objects are detected as simple lines. Using the data of 2D LiDARs locally does not provide any improvements since the information would be too limited. For instance, Figure above represents a 2D LiDAR sensing a 3D object with a rectangular shape (viewed from above). Only pieces of two sides of the object can be detected, and no assumptions can be made on the object's shape, dimension, and functionality.



2D LiDAR sensing a 3D object (view from above)

The only way to allow data coming from 2D LiDARs in the context of self-driving vehicles is to use a cooperative approach, merging the information retrieved by multiple LiDARs to better understand the objects present in the space. The idea is not to simply mount multiple 2D LiDARs on the same vehicle and merge their data but instead to exploit the features provided by the 5G technology to share real-time data with LiDARs of other cars. In this way, the surrounding would be seen from different points of view, allowing many more details on the obstacles in the space.

For example, Figure above shows how the same object shown before would be seen by combining the views of multiple sensors placed at different points in space. With this configuration, three sides of the object are completely visible. Therefore, part of its shape, as well as the position of the object, is now known. This is possible with just two LiDARs, but in an urban context, dozens of cars would be able to exchange information and reconstructs the surrounding environment with high precision.



Two 2D LiDARs sensing a 3D object

Exploring the opportunities

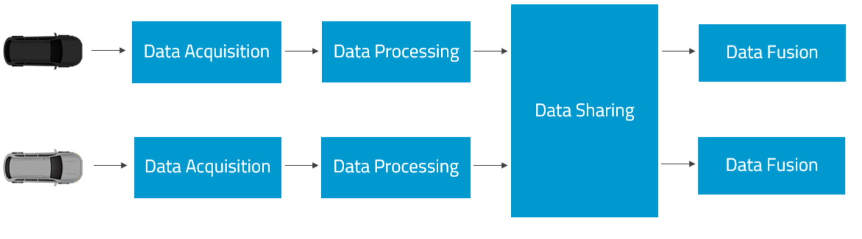
Cooperative perception is a widely explored field of study. Many researchers address the problem of insufficient environment perception information as the main obstacle to the advent of fully autonomous vehicles. As said, an innovative and accessible solution to increase surrounding information is to exploit the communication between vehicles and infrastructures.

Vehicles must be able to share data at high-speed, exploiting a low-latency communication channel. The development of 5G technologies will solve the bandwidth issue, allowing it to operate in real-time in a diffuse and multi-agent system. The introduction of this technology will pave the way to a totally new paradigm in the mobility field, opening several opportunities in terms of perception of the surrounding environment. Once the data transmission problem has been solved, it is essential to manage the data flow, developing a high-level architecture that defines how these data can be used and fused.

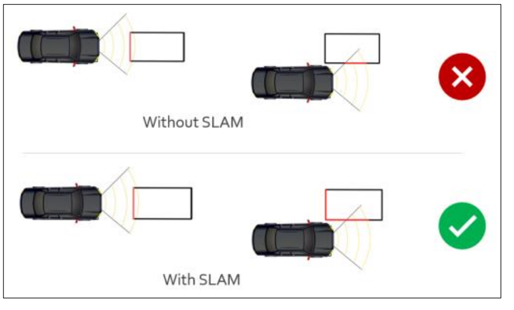
The main solutions explored in literature suggests different way of merging data collected by different vehicles, integrating them in the perception pipeline. Enlarging the amount of data that a single car can collect improves the reconstruction of the surrounding environment, enhancing the overall robustness and safety.

Generating a solution

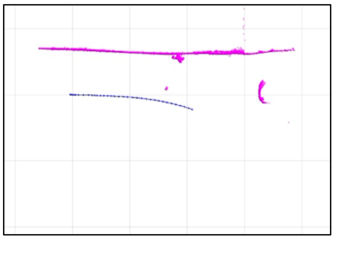
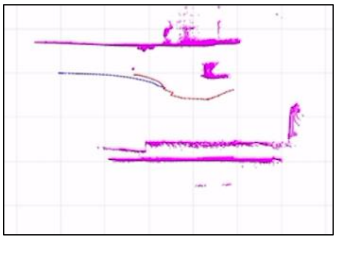
Merging the data sensed by LiDARs placed on different self-driving vehicles is quite a complex task, and many steps are required to process and improve the useful information. Specifically, each of the autonomous vehicles needs to go through four different phases:



1. Data acquisition: the LiDARs mounted on each vehicle sense the environment and produce a point cloud at each scan
2. Data processing: the raw data of each LiDAR is processes to extrapolate useful information needed the cooperative approach. The tam developed a custom algorithm composed by four steps:
    - Object Detection: identification of objects of a point cloud using the DBSCAN clustering algorithm.
    - Object Tracking: the team developed the Centroid Tracking Algorithm which allowed to keep track of the position of each object during the duration of a scene.
    - Frame Alignment: the points of a frames are rotated when the car turns. To align back all the points of each frame the Hough Transform has been exploited.
    - Simultaneous Localization and Mapping: the car with the LiDAR needs to reconstruct the sensed environment and localize the objects of the scene. To implement this feature, the team exploited a SLAM algorithm.



3. Data Sharing: the cars exchange the information about the processed point clouds via 5G connections. The team simulated with step to avoid an increase in the project complexity.
4. Data Fusion: once each car has the data of multiple vehicles, it can merge them. This is possible knowing the initial position of each vehicle and their displacements during a scene.

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