Master in Photonics – "PHOTONICS BCN"
Master ERASMUS+ "EuroPhotonics"

MASTER THESIS PROPOSAL

Dates: February 2024 - September 2024

Laboratory: Centre for Sensors, Instrumentation and systems Development (UPC-CD6)
Institution: Universitat Politècnica de Catalunya (UPC)
City, Country: Terrassa, Spain

Title of the master thesis:

Development of a Digital Twin of a LIDAR sensor for multimodal AI dataset generation

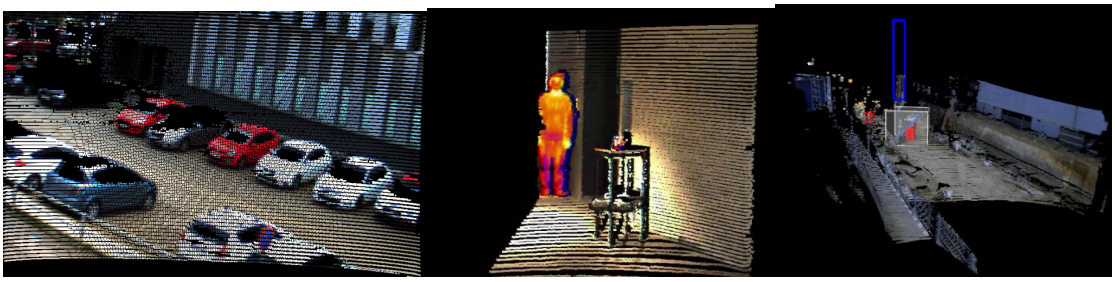

Figure. (Top) Some examples of point clouds (3D images) combined with colour and temperature information from our multimodal LiDAR system and our current 3D AI-perception.

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Keywords: Computer Vision, Digital Simulation, LiDAR, Sensors, Artificial Intelligence

Summary of the subject (maximum 1 page):

With the disruption of autonomous vehicles in recent years, LiDAR (Light Detection And Ranging) devices have aroused lots of interest for becoming the "eyes" of the vehicles for perceiving their environment. LiDAR devices provide the depth information that cameras lack and have larger spatial resolution than radars. Several imaging modes may be thus incorporated to such perception systems, but acquirting large datasets is a cumbersome experience which, at present, delays AI development.

The current approach for autonomous vehicles is to combine data from 2D and 3D sensors (sensor fusion) with the LiDAR at its core for avoiding system failures when the environmental conditions are adverse (low illumination, fog, rain, …) and increasing the confidence of the detections. Nonetheless, Artificial Intelligence (AI) based perception requires large volumes of data to train and validate their performance (accuracy, robustness, failure modes, etc) under all conditions. This is extremely important for critical applications that do not permit false alarms or failure modes such as autonomous driving, railway, aircraft and security. These datasets must be:

- **Representative**: should encompass a wide variety of samples that are representative of the real-world scenarios the AI system will encounter.
- **Diverse**: should include diverse instances, covering different variations, backgrounds, lighting conditions, and perspectives, to ensure the AI model's robustness.
- **Sufficient Volume**: sufficiently large to capture the complexity and diversity of the task at hand. Larger datasets often lead to better generalization.
- **Balanced**: should have a balanced distribution of classes or categories to prevent bias and ensure that the AI model learns equally from all relevant examples.

Therefore, datasets need be large and diverse enough to accomplish the above requirements, soand acquiring them is time-consuming, but above all, it is cumbersome, time-consuming, and it becomes difficult to control the repetitiveness of the conditions. Nowadays, there are few publicly available datasets like KITTI or nuScenes, which meet the above conditions.

To mitigate the risks and accelerate the development of novel AI applications, one of the solutions in Computer Vision (CV) is to parametrize and create digital models that mimic the sensors' behaviour. Then, sensors can be simulated under a controlled environment using simulation engines such as Unreal Engine. They are known as **Digital Twins** and they are becoming increasingly crucial. For instance, CARLA Simulator or TrainSim are recent simulation platforms for autonomous cars and trains respectively that are based in Digital Twins of multiple sensors.

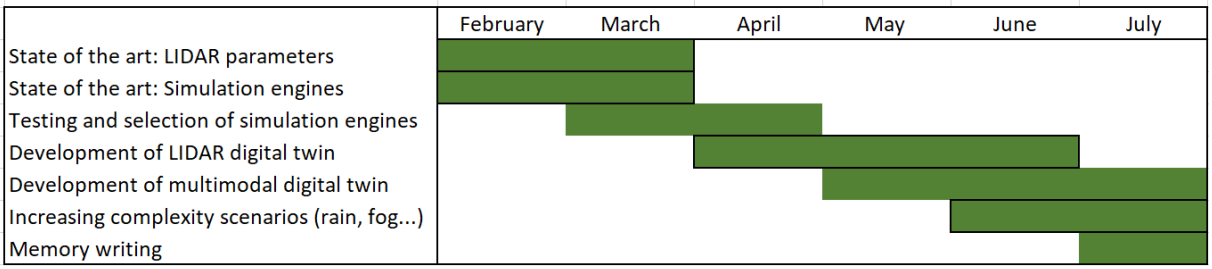
The aim of this TFM is to design and develop a digital model that simulates the a multimodal sensor based on 3D LiDAR (L3CAM) under the mentioned simulation engines. Therefore, the student will be required to study and understand the physics beyond the sensors, especially the solid-state MEMS-based LIDAR. Then, the student will need to identify the critical parameters

that define the imaging properties of the sensor (Field-Of-View, range, detectivity, output data, …) and propose a feasible model that will be implemented in a programming language (C++ or python). Finally, the student will validate the Digital Twin proposing a set of testing & validation campaigns with its real-world twin (the physical sensor).

The student will make decisions on different technical aspects such as code performance, generated output, efficiency, … getting confidence and experience in working in real-world applications and getting involved in technical teams. It must be highlighted that the student will be co-working with the team so he/she can get support from them when needed.

Work plan

During the first weeks, you will be introduced to the multimodal LiDAR device with technical staff of CD6 assigned to support you in your project for proper progress. From there, you will explore about LiDAR imaging, revise the state-of-the-art about imaging (cameras) and MEMS mirror scanners, and understand the main LIDAR trade-offs and parameters linked to its performance. You'll then explore the state of the art of simulation engines and get introduced to the Unreal and CARLA frameworks. Then you will introduce the main parameters to customize the lidar generation to given scenes and explore the automated generation of lidar and image datasets in different environments. A tentative (non-binding) expected project development timing is proposed next.



Additional information:

- CD6 offers internship allowances for BSc and MSc students with grants depending on the value of the interns, given full time dedication is granted.
- Interns join a consolidated research team with several PhDs and Postdocs related, involving an international team with several years of experience in the topic proposed.
- CD6 offers a multidisciplinary environment with electronics and mechanics workshops, and specialists and technicians in metrology, optics, mechatronics, and electronics.

- Necessary skills (Must have):
  - Full-time dedication.
  - Proactive attitude to do research in a market-oriented environment.
  - Collaborative work and communication skills.

- Critical thinking and problem-solving.

- Recommended skills (Nice to have):
  - Interest in application-driven experimental work for solving real-world problems.
  - Programming (MatLab, Python and the DNN packages, C++ appreciated)
  - Search of resources, both scientific and technical.
  - Self-motivated, objective-driven, capable of autonomous working within a multidisciplinary team.

- Miscellaneous:
  - This thesis contents will be developed in collaboration with a company and will be considered confidential.
  - Possibility of joining the Centre for a PhD/Project Manager career in case of common interest.
  - Early incorporation recommended.