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R&D Project Proposal

Object detection in adverse weather conditions using tightly-coupled data-driven multi-modal sensor fusion

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1 Introduction

1.1 Topic of This R&D Project

- What is Sensor Fusion?
  - The process of combining data from multiple sensors to provide a more accurate, reliable, and comprehensive understanding of an environment or situation.
- Fuse different sensor modalities like point cloud, pixels, and time series
- Improve perception in adverse weather conditions e.g., fog, rain, snow, overcast, sleet, night
- Synchronization of multi-modal data
- Process dense and sparse resolution sensors data
- Make use of a data-driven approach
- Geometrically alignments of different sensors
- Real-time sensor fusion with low latency
- Topic naming convention
  - Object detection
    - 2D object detection - car, truck, pedestrian, cycle
  - Adverse weather conditions
    - Fog, snow, rainy, overcast, sleet, dust
  - Tightly-coupled
    - How different modalities are combined at what level
      - Eg. searly fusion, mid fusion/feature fusion, late fusion, ROI fusion, decision fusion
  - Data-driven

    * Using previously collected data or publicly available datasets

  - Multi-modal

    * Using different data modalities

      · Sensors: Lidar, camera, IMU, GPS, infrared, radar

      · Datatypes: Point cloud, image, timer series

  - Sensor fusion

    * Fuse different sensors data to get a better estimation of an environment

1.2 Relevance of This R&D Project

- According to Federal Highway Administration(FHA), adverse weather-related vehicle crashes cause over 5,000 fatalities and over 418,000 injuries each year in the United States. [1]

- The IIHS also found that in snowy weather, the fatal crash rate is 21% higher than on clear roads, while during sleet and freezing rain, the rate is even higher at 37%.

- According to the European Commission, 25% of all road accidents in Europe happen due to adverse weather conditions, from highest to lowest: frost and ice, snow, and rain. [2]

- Autonomous vehicles: according to Marketsandmarkets, the sensor fusion market for autonomous vehicles is expected to reach $ 22.2 billion by 2030 at a CAGR of 25.4% [3]

- According to the Federal Highway Administration (FHWA), poor visibility is a contributing factor in over 7,000 annual crashes in the United States.

- According to the National Highway Traffic Safety Administration (NHTSA), poor visibility was a contributing factor in over 4,000 fatal crashes in the United States in 2018.

- According to the IIHS, in foggy weather, fatal crashes happen at a rate that is 6 times higher than in clear weather.
- According to European Transport Safety Council (ETSC), over 12,000 people die on European roads each year in weather-related accidents, from highest to lowest: frost and ice, snow, and rain.
- Not only this, there are other sectors, for example, healthcare for wearable sensors, precision agriculture, and environmental monitoring, that have also seen the fruitful impact of multi-modal sensor fusion.
- **Healthcare sector**: wearable sensors, estimated that the global wearable device market is expected to reach over $ 54 billion in revenue by 2027, growing at a CAGR of over 13%
- **Precision agriculture and environmental monitoring**: for better crop health and analyze deforestation, $45 billion by 2026, growing at a CAGR of over 20%
- **Aerospace and defense**: including aircraft navigation and control, missile guidance, and military logistics. Expected to reach $4.71 billion by 2025, at a CAGR of 8.2%
- **Industrial automation**: increase the efficiency and productivity of manufacturing processes, as well as reduce the risk of errors and accidents

2 Related Work

2.1 Survey of Related Work

- Bijelic et al. employed a deep learning-based transfer learning approach to address unseen adverse weather conditions [4]
  - 5 sensor modalities C-R-L-FIR-NIR
- K-radar: [5]

  - Released 4D radar dataset
  - Showed baseline network only, and mAP still 41.1%
  - But not compared with other multi-modal architectures and does not use advanced NN techniques

- C-R Fusion: [6]
  - Model inspired by C-L fusion
  - Shows the importance of radar in object detection

2.2 Limitation and Deficits in the State of the Art

- Most existing works fuse RGB images from visual cameras with 3D LiDAR point clouds [7]
- There is no general guideline for network architecture design, and the below questions are still open[8]:
  - "what to fuse" - lidar, radar, color camera, thermal camera, event camera, ultrasonic
  - "how to fuse" - addition or mean, concatenate, ensemble, mixture of experts
  - "when to fuse" - early, mid, late, combination of all
- Previous studies lack comparison with alternative models or datasets
- showing only results for their own baseline models and custom datasets
- None of the multi-modal sensor fusion algorithms handle temporal information [4]
- Not much work available utilizing 4D imaging radar sensor [8]

3 Problem Statement

- Which of the deficits are you going to solve?
- What is your intended approach?
- A thorough analysis and practical implementation of state-of-the-art methods for object detection using multiple modalities including but not limited to camera, lidar, and radar
- Determining an appropriate fusion strategy to exploit the complementary characteristics of various sensors
  - How to fuse camera + 4D radar data
- Fusion of spatial and temporal information from multi-modal sensors
- If required, use CARLA or other simulators to validate the performance of a model
- Conduct experiments and compare outcomes with various models and adverse weather conditions datasets
  - Datasets: K-radar[5], DENSE[4], aiMotive[9]
- How will you compare you approach with existing approaches?

4 Project Plan

4.1 Work Packages

Planning is the replacement of randomness by error. (Einstein). Very much like you would never start a longer journey without a detailed travel plan, you should not start a project without a carefully though out work plan. A work package is a logical decomposition of a larger piece of work into smaller parts following a "divide and conquer" strategy. It is very specific to the problem that you are going to address. Refrain from a rather generic decomposition. If your work plan looks similar to those of your school mates, which may address completely different problems then you have not thought carefully enough about how you approach the problem. It is ok to have two generic work packages *Literature Study* and *Project Report*. Discuss your work packages in the ASW seminar.

The bare minimum will include the following packages:

WP1 Literature Study

WP2 ...

WP3 ...

1. ...

WPy Evaluation of approach and comparison with similar approaches

WPz Project Report

4.2 Milestones

Milestones mark the completion of a certain activity or at least a major achievement in an activity. Milestones are also decision points, where you reflect on what you have achieved and what options you have for continuing your work in case you have not achieved what was planned. Above all, milestones have to be measurable. As above, if your milestones are the same as those of your school mates, then you may not have thought carefully enough about how your project shall progress.

M1 Literature review completed and best practice identified

M2 ...

M3 ...

M4 Report submission

4.3 Project Schedule

Include a Gantt chart here. It doesn't have to be detailed, but it should include the milestones you mentioned above. Make sure to include the writing of your report throughout the whole project, not just at the end.

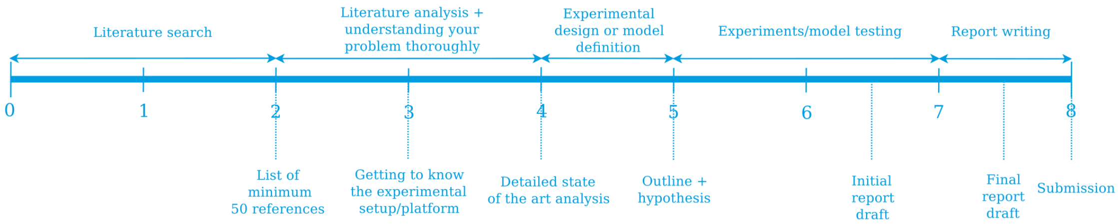

Figure 1: My figure caption

4.4 Deliverables

Minimum Viable

- Project results required to get a satisfying or sufficient grade.

Expected

- Project results required to get a good grade.

Desired

- Project results required to get an excellent grade.

Please note that the final grade will not only depend on the results obtained in your work, but also on how you present the results.

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