Hochschule
Bonn-Rhein-Sieg
University of Applied Sciences

Bonn-Aachen
International Center for
Information Technology

R&D Project Proposal

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

Kevin Patel

Supervised by

Prof. Dr.-Ing. Sebastian Houben
M.Sc. Santosh Thoduka

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1 Introduction

1.1 Topic of This R&D Project

- Imagine driving on a winding mountain road at night, with fog and rain obscuring your view, your vehicle's self-driving system struggles to detect objects ahead due to the challenging weather conditions. Suddenly, a deer jumps out in front of your car, causing the system to issue an alert and apply the brakes in time to avoid a collision.

- This scenario highlights the importance of object detection in adverse weather conditions for self-driving cars. Visual cameras, which are commonly used for object detection, may be distorted or obscured by rain, fog, snow, or low light, making it difficult to accurately detect objects on the road [1] [2] [3].

- To address these challenges, this project aims to implement a multi-modal sensor fusion system that combines cameras, radar, and lidar sensors. By fusing data from multiple sensors and leveraging advanced machine learning algorithms, the goal is to enhance object detection's range, accuracy, and reliability in adverse weather conditions.

- The focus will also be on synchronizing multi-modal data, processing dense and sparse resolution sensor data, and using a data-driven approach to optimize object detection performance.

- However, this project also faces several challenges. For example, different sensors may have different resolutions and sampling rates and may require sophisticated calibration and alignment techniques to ensure the accurate fusion of their data. Furthermore, processing large volumes of sensor data with minimal latency requires efficient and scalable algorithms and hardware architectures.

- The proposed system will be trained on a diverse dataset to ensure robustness and adaptability in different weather and lighting conditions. The system's effectiveness will be evaluated by extensive experiments and by comparing existing state-of-the-art methods.

- Despite the challenges, the project has the potential to revolutionize object detection in adverse weather conditions, with applications ranging from self-driving cars to surveillance and security systems. By fusing multiple sensor data sources and optimizing their fusion, situational awareness can be enhanced, enabling safer and more efficient operations in various domains.

- This research aims to facilitate safe and efficient self-driving in adverse weather conditions, prioritizing the safety of passengers, other drivers, and pedestrians on the road. To accomplish this, the proposed approach is to develop a sensor fusion system that operates with minimal latency, enabling data processing from multiple sensors in near real-time.

- Topic naming convention:
  - Object detection
    - Refers to the task of detecting objects within an image or video stream.
    - In this project, the focus is on detecting 2D objects such as cars, trucks, pedestrians, and cyclists.
  - Adverse weather conditions
    - Refers to conditions such as fog, snow, rain, overcast skies, sleet, and dust.
    - These conditions can make object detection more challenging due to reduced visibility or other environmental factors.
  - Tightly-coupled
    - Refers to how different modalities of data are combined and integrated at different levels.
    - Rather than relying solely on early, mid, or late fusion techniques, a combination of features at different levels is employed to achieve optimal fusion results.
  - Data-driven
    - Refers to the use of previously collected data or publicly available datasets to improve object detection performance.
  - Multi-modal
    - Refers to the use of different data modalities to improve object detection performance.
    - Examples include sensors such as lidar, camera, IMU, GPS, infrared, and radar, with different datatypes such as point clouds, images, and time series data.
  - Sensor fusion
    - Refers to the process of fusing data from different sensors to get a better estimation of an environment and improve object detection performance.

1.2 Relevance of This R&D Project

- The relevance of the research project lies in the fact that weather phenomena have a significant negative influence on traffic and transportation, which can lead to accidents, injuries, and fatalities.
- The statistics show that adverse weather conditions, such as rain, snow, sleet, and fog, contribute to a high number of vehicle crashes and fatalities worldwide.
- For example, in the United States, over 30,000 vehicle crashes occur on snowy or icy roads each year, causing over 5,000 fatalities and 418,000 injuries due to adverse weather-related crashes, according to the Federal Highway Administration (FHA) [4].
- The Insurance Institute for Highway Safety (IIHS) 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%. Moreover, poor visibility is a contributing factor in over 7,000 annual crashes in the United States, according to the FHA, and in over 4,000 fatal crashes in 2018, according to the National Highway Traffic Safety Administration (NHTSA) [5].
- In Europe, adverse weather conditions cause 25% of all road accidents, with frost and ice, snow, and rain being the highest contributing factors, according to the European Commission and the European Transport Safety Council (ETSC). Over 12,000 people die on European roads each year in weather-related accidents [6].
- The project's results will benefit various sectors, including autonomous vehicles, healthcare, precision agriculture, environmental monitoring, aerospace and defense, and industrial automation.
- The sensor fusion market for autonomous vehicles is expected to reach $22.2 billion by 2030 at a CAGR of 25.4%, according to Marketsandmarkets [7].
- In the healthcare sector, wearable sensors are estimated to reach over $1.5 billion in revenue by 2030, growing at a CAGR of over 18.3% [8].

- For precision agriculture and environmental monitoring, the market is expected to reach $10.5 billion by 2026, growing at a CAGR of over 12.6% [9].
- The aerospace and defense sector, including aircraft navigation and control, missile guidance, and military logistics, is expected to reach $23.83 billion by 2027, at a CAGR of 4.21% [10].
- Even the industrial automation sector benefits from the sensor fusion technology as it can improve the efficiency of the production process and reduce the cost of production.

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 [11]
  - 5 sensor modalities C-R-L-FIR-NIR
- K-radar: [12]
  - 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: [13]
  - 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 [14]
- There is no general guideline for network architecture design, and the below questions are still open[15]:
  - "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 [11]
- Not much work available utilizing 4D imaging radar sensor [15]

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[12], DENSE[11], aiMotive[16]
- 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.

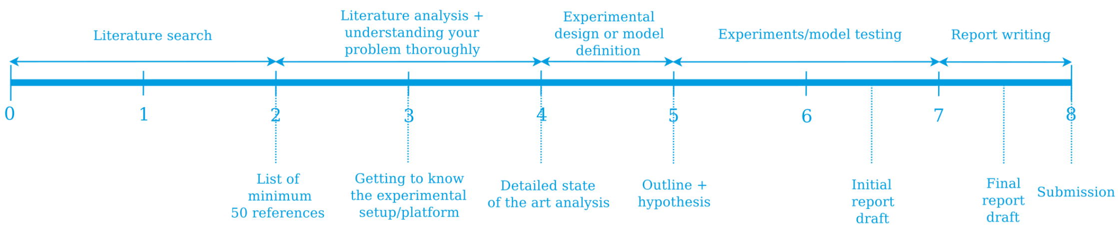

Figure 1: My figure caption

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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