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Modeling Rain Impacts on the Detection Performance of FMCW Radar Sensors

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***Abstract*— FMCW radar sensors are crucial for autonomous vehicles, known for their ability to measure depth and cost-effectiveness. However, rain poses a significant challenge to their reliability, especially in detecting targets. Our study seeks to comprehend the influence of rain on FMCW radar performance, with a specific emphasis on assessing its effects and devising strategies for managing them. Rain interferes with radar signals by weakening and scattering them as they travel through the air. This interference makes it difficult for radar to accurately detect targets amidst the background noise created by rain. Additionally, heavier rain worsens the problem by further weakening radar signals. To address the challenges posed by rain on radar sensor performance, this study focuses on developing a model that accurately reflects the impact of rain on the data collected. The approach involves constructing a specialized platform to simulate rain conditions realistically. By conducting experiments on this platform, this study hopes to learn more about how rain affects radar performance under different rain intensities and durations.**

By examining the interaction between rain and radar waves, this research seeks to understand how various rain characteristics, including rain intensity and raindrop size, impact radar performance. The radar sensor was housed within this platform, waterproofed to ensure its functionality under rainy conditions. Systematic experiments were conducted, varying the intensity and duration of rainfall, to assess the impact on radar performance. Data was collected under both rainy and clear conditions, allowing for a comparative analysis of radar performance. This experimental setup will elucidate how much radar signals are weakened or scattered by rain. The goal of this study is to not only figure out how rain impacts radar performance but also find ways to make radar more reliable in rainy conditions. By advancing the understanding of how rain affects radar and developing more accurate rain models, this work aims to improve the dependability of autonomous driving technologies in adverse weather conditions.

Contributions: The primary contribution of this study is the development of a model that delineates the impact of rain on FMCW radar performance. Additionally, it establishes a standardized experimental measurement and data processing protocol to derive this model. This protocol is adaptable to FMCW radar sensors with varying parameters and different levels of rainfall. The significance of this work lies in its potential to enhance the accuracy and reliability of radar sensors under adverse weather conditions, thereby improving the safety and efficacy of autonomous vehicles. By addressing the variability of rain effects, this model also facilitates more robust design and calibration of radar systems, ensuring better performance across a range of environmental conditions.

Challenges: The challenges associated with this work begin with constructing a rain simulation experimental platform at a relatively low cost, which enables controlled measurement of performance impacts. Waterproofing the radar sensors is also critical to replicate real-world usage conditions accurately. In data processing, the separation of target information from rain-induced point clouds is essential to mitigate noise interference and ensure precise evaluations. Furthermore, identifying appropriate metrics to measure performance impacts and constructing a mathematical model based on these metrics add layers of complexity, as they must accurately reflect the radar's capabilities under varied weather conditions. Each challenge requires meticulous execution to ensure that the research findings are both robust and applicable to real-world scenarios.

Procedure: The detailed procedure for constructing the model is as follows:

Step 1: Measure the detection range of the FMCW radar sensor. Begin by accurately determining the range within which the radar can effectively detect objects.

Step 2: Construct a rain simulation experimental platform of appropriate dimensions. Design and build an experimental platform that can simulate various rainfall intensities and patterns. The platform must be large enough to accommodate the full detection range of the radar.

Step 3: Waterproof the radar and deploy it on the platform. Apply waterproofing measures to the radar sensor to protect it from water damage and to mimic the conditions it would face in a real-world vehicular environment. Once waterproofed, the radar is deployed near the edge of the platform to maximize the use of space.

Step 4: Divide the radar's detection range into uniformly distributed test units. The radar's detection area is segmented into evenly spaced test units to measure the impact of rain on radar performance at different locations within the range.

Step 5: Deploy targets in each test unit and capture data under both rainy and clear conditions. Place test targets at the center of each test unit. Perform experiments by capturing radar data when the platform simulates both rainy and clear weather conditions.

Step 6: Analyze the data from different conditions to assess the impact of rain on radar performance within each test unit. Collect and compare the data obtained from the radar under the two different weather conditions. Analyze how rain affects the radar's ability to detect and track objects in each test unit, noting any variance in performance.

Step 7: Fit the data from the test units to derive a continuous function that represents the impact of rain across the radar's detection range, thereby constructing the model. Use statistical or mathematical modeling techniques to fit the collected data into a continuous function. This model will quantify the radar's performance degradation due to rain and will provide a predictive tool for understanding radar behavior in adverse weather conditions across its entire detection range.

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