

Comparative Analysis of Indoor Controlled Climatic Chamber and Outdoor Cold-Climate Testing under Adverse Weather Conditions

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Abstract:

Cold climates pose critical challenges to autonomous vehicle (AV) operation, particularly through snow and ice accumulation and the degradation of sensor perception and reliability. Accurate assessment of these impacts requires testing methodologies that capture both controlled physical processes and the complexity of real-world environmental conditions. This study presents a comparative framework that integrates controlled indoor experiments conducted in the ACE Climatic Chamber at Ontario Tech University (Oshawa, Canada) with full-scale outdoor measurements obtained during natural snowfall events. The indoor experiments enable systematic control of key environmental parameters such as temperature, precipitation intensity, particle size distribution, and flow conditions, allowing for repeatable investigation of snow-sensor interactions, accumulation mechanisms, and their effects on vision-based perception systems. In contrast, outdoor campaigns capture realistic atmospheric variability, including transient wind fields, heterogeneous snow properties, and vehicle-induced flow effects, which directly influence perceived precipitation and sensor performance. By combining these complementary datasets, the study evaluates the extent to which controlled climatic chamber conditions can replicate real-world degradation mechanisms in AV sensor perception. Quantitative metrics, including precipitation intensity, particle dynamics, signal attenuation, and perception degradation indicators (e.g., point cloud density and image quality), are analyzed to identify similarities, discrepancies, and scaling considerations between indoor and outdoor environments. The results demonstrate the importance of hybrid testing methodologies for improving the reliability and robustness of autonomous vehicle perception systems in cold climates. This work supports the development of standardized testing protocols and contributes to enhancing the safety and operational performance of AV technologies in winter conditions.

Keywords: Adverse Weather Condition- Autonomous Vehicles- Sensors Perception- Climatic Chamber