University of Pittsburgh | School of Computing and Information

Dissertation Defense

Doctor of Philosophy in Information Science

"**Advanced Autonomous Vehicles Analytics for Predicting Navigation Performance**" by
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Abstract:

Autonomous Vehicles (AVs) stand as a monumental leap in modern transportation technology, offering the potential to enhance road safety and optimize transportation efficiency. However, their broad adoption is hindered by uncertainties associated with their sensors that allow for perceiving, interpreting, and interacting with their surroundings. Sensor uncertainties (SUs) arise from various sources, including sensor noise, varying environmental conditions, and inherent limitations in sensor design. SUs undermine the accuracy and reliability of AV navigation, posing substantial risks to AV performance and, by extension, to passenger safety. Considering the high stakes involved, including human lives, traffic flow optimization, and the structural integrity of transportation infrastructures, it is crucial for AVs to operate with minimal SUs. As driving on roads is dynamic with unpredictable elements, like sudden weather changes, AVs must be designed to handle both planned and unforeseen changes with unwavering precision. Failure to account for such uncertainties can cause unsafe driving and culminate in catastrophic outcomes, thereby deteriorating public confidence in autonomous driving technologies.

Common approaches to identifying and handling SUs in AVs involve data fusion and machine learning techniques. Despite their acceptable performance, these techniques are constrained by several critical limitations that hinder their applicability in complex real-world scenarios. For instance, conventional sensor fusion techniques often make overly simplistic assumptions, such as treating uncertainties as independent and normally distributed, which fail to capture the complex interdependencies and nonlinearities present in real sensor data. This simplification leads to suboptimal solutions, especially in challenging environments. Additionally, these techniques lack adaptive mechanisms to respond to changing

environmental conditions, limiting their robustness. On the other hand, machine learning techniques, though capable of processing large volumes of data and uncovering hidden patterns, typically suffer from a lack of interpretability, often referred to as the "black-box" problem. This opacity inhibits a comprehensive understanding of the decision-making processes, complicating efforts to ensure transparency and accountability in AV operations. Furthermore, the extant literature is void in furnishing robust evaluative metrics and tools that could facilitate the systematic analysis of AV sensor performance, both before and after occurrence of incidents.

This thesis addresses these critical gaps by introducing an advanced AV analytics (AVA) framework and making the following contributions. Firstly, it introduces a novel ontology that represents and formalizes major concepts related to SUs in AV navigation. This ontology serves as a conceptual foundation for automated reasoning about navigation safety. Secondly, the thesis formulates a set of tailored performance metrics that provides a more nuanced evaluation of sensor reliability and accuracy under varying operational conditions. Thirdly, the AVA framework incorporates predictive models that not only quantify AV navigation sensor performance but also identify factors contributing to SUs. These models are unique in their multidimensional scope, encompassing environmental variables, and sensor specifications, and are of two types: online and offline. Online models focus on real-time evaluation of uncertainties for immediate decision-making, while offline models, also called forensic models, allow to analyze factors behind any unexpected behaviors. Finally, the thesis introduces a global path planner that integrates AVA's analytical outputs to optimize AV route planning. Unlike commonly used route optimization criteria, such as shortest or fastest routes, this path planner incorporates sensor performance to identify safest routes by avoiding high-risk areas or conditions that could exacerbate SUs. These contributions are thoroughly validated using simulated and real data. The outcomes of the proposed research will help develop AV navigation solutions that are reliable and safe.