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LEARNER: A SLAM and Path Planning Middleware Package for Dynamic and Visually Challenging Environments

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Abstract

Autonomous robotic platforms are utilized in increasingly diverse aspects of modern life, from domestic service robots to self-driving vehicles, continuously assuming laborious, repetitive, or tasks of increased risk for human actors. Despite these advancements, several mission-critical applications remain constrained by the inability of current systems to robustly operate under highly dynamic and unpredictable conditions. Aiming to reduce these limitations, this paper presents LEARNER, a middleware package fully compatible with the Robot Operating System (ROS 2), aiming to enhance the perception and navigation capabilities of mobile robots in dynamic environments populated by humans. LEARNER introduces three main pipelines: i) a trainable perception architecture for mapping previously unknown environments under extreme environmental variations, ii) a hybrid map representation that preserves the dynamic and semantic attributes of observed entities, and iii) a socially-aware path planning framework that enables human-centric navigation. The proposed middleware was validated on a Unitree GO2 EDU robotic platform over a real-world experimental setup, simulating the operational conditions of an indoor fire emergency, characterized by power failure, moving obstacles, and active personnel. The obtained results demonstrate our system's capacity to sustain reliable localization, mapping, and socially compliant navigation in complex and visually degraded environments, thereby advancing the state of the art in autonomous robot operation under extreme conditions.

KEYWORDS

SLAM, Path Planning, Map Representation, Action Recognition, Deep Learning

1 | INTRODUCTION

Autonomous robotic systems are rapidly becoming an integral component of modern infrastructure, assuming a wide spectrum of applications that range from domestic services to industrial logistics, precision agriculture, and emergency response [1–3]. Major recent advancements in sensing, control, and Deep Learning (DL) have enabled remarkable progress in robotic autonomy, particularly in Simultaneous Localization and Mapping (SLAM) and Path Planning (PP) systems. However, reliable robot operation in highly dynamic, human-populated, and visually degraded environments still remains an open challenge.

In such scenarios, classical SLAM and PP pipelines often struggle to maintain consistent performance [4], since the majority of existing systems assume a semi-static environment with stable illumination and minimal structural changes. Therefore, they are highly sensitive to conditional changes, such as lighting variation, occlusions, as well as the dynamic nature of human behavior. Moreover, current DL-based SLAM and PP approaches typically depend on extensive labeled datasets, which limits their generalization in conditions not encountered during training.

In order to overcome those challenges, this work presents LEARNER, a SLAM and PP middleware compatible with Robot Operating System (ROS 2), aiming towards reliable robot operation in dynamic and human-centered settings. LEARNER attempts to bridge the gap between traditional geometric methods and contemporary AI-driven perception by utilizing a hybrid model-based and learning-based architecture. Three fundamental elements form the basis of its design. To enable the robot to perceive and map unknown environments in extremely low-light conditions, we first employ a trainable perception module that improves illumination-invariance and local features optimization. Next, a hybrid map representation engine is implemented, capable of capturing the

Abbreviations: SLAM, Simultaneous Localization and Mapping; PP, Path Planning; DL, Deep Learning.

