Advancing SLAM in Underground Mines: A Unique Marker-Based Approach for Enhanced Navigation and Mapping

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ABSTRACT

Simultaneous localisation and mapping (SLAM) stands as a pivotal technology empowering autonomous robots to navigate independently while creating detailed real-time maps of their surroundings. This capability is crucial in underground mining settings, where it enhances operational efficiency and significantly strengthens safety in these subterranean environments. SLAM algorithms typically rely on identifying and using distinct geometric features, such as plane and edge features, to understand the spatial layout of the environment and to track how it evolves as the sensor moves through it. In underground roadways, the scarcity of noticeable edge features, coupled with the repetitive nature of walls and corridors, poses a significant challenge, making it difficult for these systems to distinguish one area from another. Furthermore, the absence of global navigation satellite system (GNSS) signals in underground adds more challenges, leading to the accumulation of errors in both the mapping and localisation.

In this workflow, we introduce a robust and precise algorithm designed to address challenges using three sensors: a laser scanner, an inertial measurement unit (IMU), and a camera. To establish the absolute position within the underground space, unique markers are strategically placed and automatically identified. The developed algorithm updates the existing SLAM pipeline to mitigate issues arising from the limited availability of distinct features in underground settings. The system is fully automated, enabling marker identification, georeferencing, localisation, and mapping processes to occur without manual intervention. Advanced image processing techniques are used to detect the positions and identities of the unique markers accurately. Feedback from this workflow adds new features to the factor graph made from the incoming sensor data. Numerical optimisation is carried out to solve the SLAM problem by adjusting the graph to fit the sensor data better, thereby improving the accuracy of localisation and mapping under the constraints of the underground environment. Extensive testing is conducted in underground mines to validate the algorithm's performance, with the results being compared to existing SLAM algorithms in terms of mapping and positioning accuracy.