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Autonomous long-term inspection of tunnel structures with 3D LiDAR measurements

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This study proposes an autonomous long-term inspection method for tunnel structures using a 3D light detection and ranging (LiDAR) measurements deployed on a mobile robot. Numerous tunnel structures are already installed in the world to apply roads, railroads, and the transportation. The importance of tunnel structures suggests that maintenance should be performed to ensure reliability and safety during long-term operation and to mitigate concerns related to accidents and natural disasters. In recent years, various studies were conducted to monitor the structural health of tunnel structures with contact-type sensors. Contact-type sensors which includes fiber-optic and convergence meter sensors measure deformations for a long-term inspection of the outer wall of the tunnel structure. However, inspection method with contact-type sensors is economically infeasible because suggested method requires a lot of sensors and data acquisition systems. To overcome these limitations, the non-contact type sensor which is 3D LiDAR is used to monitor the structural health of tunnel structures with a mobile robot. The proposed inspection system including the 3D LiDAR and the mobile robot is economically feasible rather than the numerous contact-type sensors and data acquisition systems. Moreover, the proposed method evaluates not only deformations but also determine the deformed location of tunnel structures with a high accuracy localization and mapping method. The proposed tunnel structural health monitoring system was designed to be mounted on a variety of mobile robots to inspect novel conditions of the tunnel structure and the system was manufactured with polylactic acid by using a 3D printing technology to enhance the operational time by minimizing the overall weight of the system. The proposed method comprises 3D point cloud maps (PCMs) generation and localization of the mobile robot phase and health indicators (HIs) extraction phase at the same location for the inspection of long-term structural transformation. First, the 3D point cloud data (PCD) and the acceleration and gyration of a mobile robot are measured during the inspection of tunnel structures with the 3D LiDAR and an inertial measurement unit. This information is fused to construct a 3D PCM by addressing FAST-LIO2 which is tightly coupled lidar inertial odometry method. This procedure could be repeated to inspect structure transformation of tunnels at patrol inspection. Then, 3D PCMs measured during period inspection are registered to extract 3D PCD at the same location with respect to the first measurement condition. Hence, an iterative closest point method with edge features is also executed in this phase to register periodic PCD measurements. Second, 3D PCD in predefined locations are extracted at every measurement. These PCD are used to extract features that are highly correlated to the outer wall and ground of the tunnel structure by using the coordinate transformations and the random sample consensus method. Then, features are used to extract five HIs representing a health condition of the outer wall and ground of the structure. These HIs are then employed to evaluate the structural health of the tunnel at a measurement condition and for a long-term periodic condition. Field experiments were conducted to identify the effectiveness of the proposed method in the inspection of tunnel structures by using a 3D LiDAR system deployed on a mobile robot. The accuracy of the proposed localization and mapping method is evaluated for two inside of the building conditions by comparing the blueprints of the building. A systematic analysis on the experimental results also reveals that the proposed method ensures the accuracy and robustness of HIs extraction at the same location. The proposed inspection method for tunnel structures provides a economically feasible and autonomous solution for health monitoring.

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