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Robust Long-Range Optical Tracking for Tunneling Measurement Tasks

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Over the last years, automation for tunnel construction and mining activities increased rapidly. To allow for enhanced tunneling measurement, monitoring of workers and remote control of machines, systems are required that are capable of real-time positioning of several static as well as moving targets. Such a system must provide continuous and precise 3D position estimation in large volumes and must be capable to be installed and work correctly during on-going tunneling or mining tasks.
Tracking systems are a fundamental component of a VR system to determine the 3D-position and orientation of a target in 3D space. Infrared optical tracking systems use infrared light to track several static or moving targets simultaneously with low latency in small tracking volumes. To benefit from the capabilities of infrared optical tracking, a system is proposed to track static as well as moving optical targets in large tracking volumes with a maximum depth extend of 70 meters. Our system needs a minimal hardware setup consisting out of two high quality machine vision cameras, which are mounted on both walls of the tunnel, and a standard (portable) workstation for data processing. Targets are equipped with infrared LEDs and can be either carried by workers or attached to a machine. The two cameras form a stereo rig and face into the measurement volume to allow for continuous tracking. Using image processing techniques, the LEDs of the target(s) are detected in both 2D camera images and are back-projected into 3D using projective reconstruction algorithms. Thereby, the 3D position estimate of the target is determined. Using image filtering techniques, fitting methods based on target's geometric constraints and prediction heuristics, the system allows for unique target identification during calibration and tracking even in environments with heavy interferences such as vibrations, tunnel illumination or machine lights.
We extensively tested the system to (1) determine optimal distances between cameras (baseline) with constraints to a tunnel application scenario, (2) to evaluate robustness of unique target identification and (3) to measure accuracy of estimated 3D position. Our results prove the system's capabilities to continuously track static and moving targets within the whole tracking volume as soon as the target becomes visible to the stereo rig. Thus, preliminary sighting of the target can be omitted. Interferences are filtered and partly occluded targets can be recovered. Up to a distance of 50m with a baseline of 12m, our system provides very high precision of the 3D position estimates with a deviation of 1cm or less along all three spatial axes. At a distance of 70m, our system provides still very high accuracy in the width- and height direction with a deviation of only several millimeters and up to 3cm along the depth axis.
These promising results enable our system to act as measurement and monitoring system in rough indoor environments. Furthermore, it can serve as a reliable wide area user tracking system for future mixed reality applications, e.g. for tunnel simulation, training of engineers, machine control, tunnel data interpretation and inspection.