Design and development of a cost-effective quadcopter for rapid underground mine mapping

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Abstract. Mine surveying and mapping is a time consuming and hazardous task critical in most underground mining activities. The introduction of robotics for underground mine mapping can reduce these safety concerns on humans. This project aims at developing a cost-effective quadcopter, with dedicated sensors capable of performing SLAM (Simultaneous Localisation and Mapping) in GNSS (Global Navigation Satellite System) denied environments, such as underground mine sites. Different localisation and mapping algorithms are compared and tested and the SpectacularAI package proves to provide a computational efficient SLAM method that can be run on the quadcopters on board computer creating dense, detailed point cloud maps.

1. Introduction

Mine surveying is critical for ensuring work safety, efficient resource management and structural integrity monitoring of underground mining operations. By providing precise measurements, project planning and post-extraction assessments can provide important insights including the direction of the stope face, volume of the extracted material and the positions and volumes of underground support pillars [1]. Traditional mine surveying methods, relying on geodetic instruments like total stations and levels, suffer from omission errors due to surface unevenness and tend to be time consuming [2]. Due to severe human safety and health hazards in underground mines, including fires, rock falls, gas leaks and floods [3], robots have recently been employed to aid in surveying, environmental monitoring and exploring. Such robotic platforms include autonomous rovers for underground 3D environment mapping using a rotating lidar sensor [4] and robust platforms, like the rhino, using Lidar and RGB-D Fusing to perform Underground localisation and mapping [5]. Most recent approaches reach further and perform multi-robot exploration, mapping and terrain perception by networking platforms including Quadrupeds, rovers and UAVs (Unmanned Aerial Vehicles) [6]. UAVs specifically are used as rapid exploration means, providing fast data collection and coverage, with most available platforms using expensive lidars to Perform SLAM algorithms [7]. Additionally, they can overcome and navigate through terrain conditions where quadrupeds and rovers struggle, including extreme slopes, water pools, tight spaces and vertical shafts [7]. The aim of this project is to design and develop a cost-effective, small-scale quadcopter performing onboard SLAM in underground mines, to provide a 3D representation of the environment.

1. Methodology and Results

The developed platform, called Void Raven, consists of a custom built 5” quadcopter, where components were specifically chosen focussing on performance and efficiency to maximise the UAVs exploration time. Additionally, the quadcopter is equipped with a Pixhawk 6C Mini Flight Controller, running PX4 to perform the low-level flight control and facilitating processes including position estimate calculations.

Additional components that have been integrated into the platform include a Khadas Vim4, running Ubuntu 22.04 and ROS2 to facilitating all on platform computing, a Here Flow Optical Flow sensor, aiding with position control, due to the lack of GNNS in underground environments and an OAK-D Pro W RGB-D (Red, Green, Blue-Depth) camera, providing depth information and a point cloud to perform SLAM. A RGB-D camera was used instead of the generally seen Lidar, used in most literature, as it comes at significantly lower costs, provides more visual information, including surface texture and colour, and has a lower power consumption. A detailed picture of the platform can be seen in **Figure** 1.

Careful considerations had to be taken into account while looking at SLAM algorithms, due to the limited computational power of the Vim4 and the fact that it is based on an arm64 architecture, where most SLAM algorithms are developed for AMD64 architectures. After careful consideration and testing, it was decided to employ the SpectacularAI package to perform SLAM. This package makes use of HybVIO, which fuses Visual odometry and IMU (Inertial Measurement Unit) data, for tracking the position of the camera [8]. Additionally, it makes use of OpenVSLAM, a re-implementation of ORB-SLAM2, which introduces local bundle adjustment for mapping and pose-graph optimization and global bundle adjustment for global loop closure optimization [9]. **Figure** 2 depicts a point cloud map created by the system, being teleoperated up a flight of stairs, into a foyer, leading into a passageway.

From this map it can be seen that the dense point cloud contains high detail and can thus provide some very important information about the environment. However, a drift in the point cloud can also be seen, which is likely due to unavailable visual odometry at that point, while the UAV was facing a featureless wall while rotating. This performance could be improved by fusing the VIO output into the Flight Controllers extended Kalman filter and using this output as a global position estimate. **(Do I mention how I want to introduce VIO into EKF and use that as position estimate? Or not for now?)**

1. Conclusion

A quadcopter, capable of mapping GNSS denied environments, such as underground mines, was successfully developed using making use of cost effective and energy efficient components. The deployed software suite was tested and prove to provide a point cloud map of its environment containing detailed features. Finally, the platform can further be improved by performing additional sensor fusion and potentially automating it.

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