Grant: AFC820-69

Title: Autonomous Robotic Early Warning System for Underground Stone Mining Safety

Organization: West Virginia University

Principal Investigators: Ihsan Berk Tulu, Jason N. Gross, Yu Gu, Guilherme A. S. Pereira

Topic: Health and Safety Interventions

Priority Area: Monitoring Systems and Integrated Control Technologies

SYNOPSIS

Problem Statement: In general, underground stone mines have inherently strong rock and experience good ground stability. Also, modern pillar design guidelines developed by National Institute for Occupational Safety and Health (NIOSH) have improved the design of stable layouts for modern limestone mines. However, in these mines, previously mined sections stay open for the life of the mine, which may be many years and subject the pillars to time-dependent degradation, which is not covered in the NIOSH guidelines. Further, these older workings are not typically inspected due to the: 1) impracticality to inspect these vast areas with limited personnel, 2) possible risks to miners who have to inspect these potentially unstable pillars and roof under limited visibility. Also, it is possible that many of these older pillars were designed with older, less sufficient safety factors. In underground stone mines, it is normal for travel ways to working faces to pass through old sections, which puts the abandoned pillars next to active workings. In a recent massive pillar collapse in an old section of the Whitney mine, three miners (outside of the mine) were injured due to an air blast. Further, there are frequent reports of pillar sloughing and roof falls in older sections of other mines. These incidents highlight the potential safety impact on the miners in underground stone mines from unstable abandoned areas. Safety in the stone mines would be improved with a safe and efficient way to monitor these old pillars and provide a long- term stability assessment and/or warn of pillar instability.

Research Approach: This project proposes to develop a methodology for an enhanced monitoring and warning system for old workings in underground stone mines using an autonomous robotic system that is comprised of an Unmanned Aerial Vehicle (UAV) tethered to an Unmanned Ground Vehicle (UGV). This combination of remote vehicles can optimally provide high-resolution 3D maps, which are then used as input for assessment of pillar and roof damage, and long-term stability analysis. Ultimately, this project proposes to develop an early warning system that incorporates time-lapse hazard mapping and time- dependent strength degradation analysis for stone mine pillars from in situ monitoring with the advanced state-of-the-art cooperative robotic system. The research to be accomplished in this project will include:

1. Develop a robotics system specifically for stone mine inspection.
2. Develop a framework for integrating hazard mapping (Stability-Mapping) and boundary element modeling (LaModel) for assessment of pillar damage and long-term stability from remotely obtained 3D mapping.
3. Test and verify the integrated autonomous robotics and Stability-Mapping based underground stone mine hazard detection and early warning system in an active underground stone mine.

Impact of the Research: The proposed autonomous robotic system for monitoring stone mines to facilitate time-lapse hazard mapping will enable rapid response to detected degradations in pillar and roof stability, including actions such as: dispatch support crews to rehabilitate the pillars/roof, warn mining crews to use alternative routes of travel, and, if necessary, to evacuate the mine. The ability to accurately measure volumetric changes of pillars in different time intervals and use this information to update strength degradation in pillar models or empirical equations will allow for an immediate and proactive control response to possibly catastrophic pillar and/or roof failures. Knowledge gained through the use of the integrated robotic monitoring can also be used for the first time in the mining industry to develop true in situ long-term pillar stability data and strength models for hard rock pillars. Successful development

and deployment of these systems, as well as the use of the resulting monitoring results in the development of long-term pillar stability design, is expected to reduce injuries of underground stone mine workers. While the initial problem is associated with long-term pillar stability and design in the underground stone mine industry, the techniques developed in this research would be easily adaptable to the underground coal and metal/nonmetal mining sectors. The autonomous robotics mapping ability would also be adaptable to facilitate search and rescue efforts in case of an accident.