Mock-up of the Exhaust Shaft Inspection by Dexterous Hexrotor at the DOE WIPP Site

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***Abstract*— This report presents a robotic inspection and cleanup task in a nuclear waste storage facility. In February 2014, the Waste Isolation Pilot Plant (WIPP), a storage facility for high-level nuclear waste located deep underground, experienced a chemically-induced energetic incident within one of its storage containers that resulted in the release of a small amount of radioactive material. This closed the facility for clean-up and the exhaust shaft is the greatest remaining technical challenge. In this report, We introduce the exhaust shaft problem and the proposed solution of using holonomic aerial platforms such as Dexterous Hexrotor and the newly announced platform from CyPhy Works. We present preliminary prototype flight test in a grain silo to mock-up the exhaust shaft inspection task.**

I. INTRODUCTION

On Feb. 14, 2014, an incident occurred at a nuclear waste storage facility in Carlsbad, New Mexico, USA, called the Waste Isolation Pilot Plant (WIPP) [1]. The WIPP is the world's third deep geological repository licensed to permanently dispose of transuranic radioactive waste that is left from the research and production of nuclear weapons. The incident that occurred was a chemically-induced exothermic reaction within an improperly loaded container that caused the container to burst, spewing radioactive smoke through a large portion of the WIPP, indicated in Fig. 1.

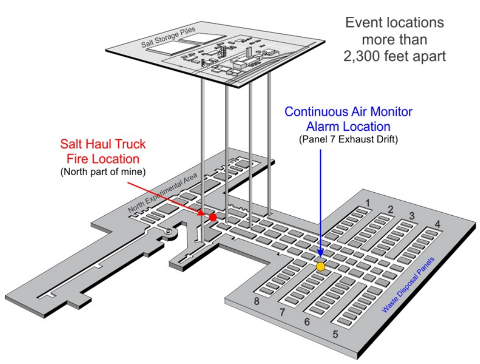

Fig. 1. Spatial layout of the U.S. DOE WIPP site indicating surface buildings with four shafts connecting the main work surface 660 meters below ground. (reprinted from www.wipp.energy.gov

As the cleanup continues, the greatest technical challenge is the inspection and cleaning of the exhaust shaft. The shaft is circular in cross section, 14 feet in diameter, and about 2150 feet long, with 60,000 cubic foot air per minute (CFM) flowing through it. In such a constrained area as a narrow vertical shaft, especially with operations close to the wall of the structure itself, significant turbulence can result due to aerodynamic effects between the downdraft and the wall surface. In addition, as part of the inspection task, there is a requirement of collecting samples from the shaft surface, which means the UAV has to reach out and touch the wall while hovering in a moving air column. In order to survive in the hazardous environment, the ability to resist disturbances and keep position precisely would be essential for UAVs. So we propose with the holonomic aerial platforms such as Dexterous Hexrotor and a commercial product called LVL 1 from CyPhy Works, which can achieve greater precision in turbulence and better control in physical interaction with environment.

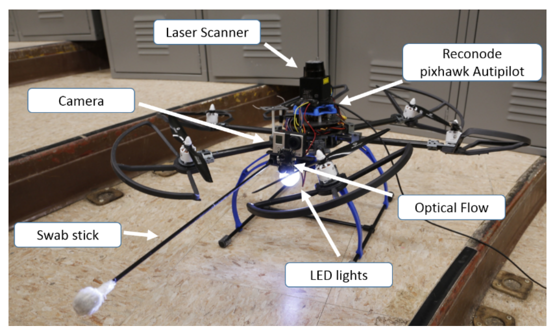

Fig. 2. Prototype of Phase 1, Dexterous Hexrotor with a swab stick.

For initial inspection, we propose to sample periodic areas of the shaft walls with a physical swab that can be analyzed in batch after-the-fact. We propose that the need for precision flight in close proximity to the structure walls and the ability to maintain contact forces at swabbing sites dictates a fully actuated Dexterous Hexrotor configuration that can fly through the shaft and interact with the environment.

II. PROPOSED SOLUTION

During the inspection and sampling task, exhaust air vented to the environment can be reduced from 12,000 cubic meters per minute to only about 1,700 cubic meters per minute, which is about 2 m/s flow of air up the exhaust shaft, more compatible with small UAS.

We propose a multi-phase solution that builds on existing capabilities of the Dexterous Hexrotor with incremental advances. First, we propose sparse sampling of the walls with a swab stick and non-contact radiation detectors to assess

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the magnitude of the problem as shown in Fig. 2. Semi-autonomous control of altitude, based on air pressure, and X-Y localization, based on fitting planar laser scans to a circle, permit quick teleoperated sampling at various altitudes with short, 20-minute, battery-limited flights.

Our goal for phase 1 is 100 samples throughout the bottom half of the shaft. Launched from the bottom exhaust shaft access point in the mine, a 20-minute maximum flight time should allow us to rise to the half-way point (330 meters up), teleoperate the contact-based swab action, and return to the bottom of the shaft. Lower altitudes should permit up to three samples per flight at different altitudes, for an average of 3.5 min per sample. Middle altitude should permit only two samples and high altitude permits only one per flight, for an average of 8 or 20 min per sample. Total time for all samples is 1050 min or 17.5 hrs, plus 4.5 rs of setup/tear down time (22 hrs total, or almost three 8-hour shifts).

The samples collected during Phase 1 will be analyzed with mass spectroscopy to determine isotopes present. Depending on the results of Phjase 1, during which less than 0.001% of the surface is sampled. Phase 2 will employ a reel-to-reel sheet of swabbing material held in contact with the shaft wall using force control of the Dexterous Hexrotor. Figure 3 illustrates the propose mechanism.

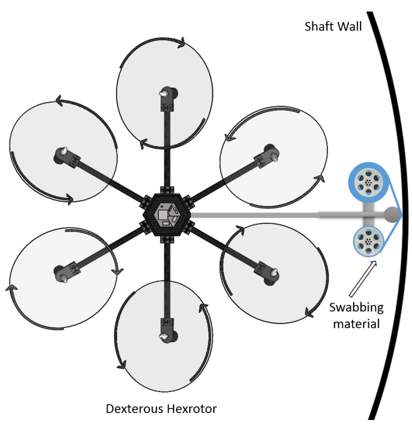

Fig. 3. Proposed mechanism of phase 2, Dexterous Hexrotor with reel-to-reel sheet of swabbing material.

III. Mock-up Flight Test

The flight tests were conducted in a 4.8m diameter and 12m tall grain silo. It has a cylindrical shape inside. We consider it a moderate environment close to the exhaust shaft. Because compared to the length, the diameter of the shaft matters much more due to the ratio of the size. Three preliminary flight tests were conducted, including an inspection task using CyPhy LVL 1, two sampling tasks using Dexterous Hexrotor. The test facility is as shown in Fig. 4.

In this application, a Hokuyo laser range finder would be used to provide precise position information inside the shaft. 9 beams of laser are used to detect UAV's position in the shaft with IMU information. Each beam is converted to range

Fig. 4. flight tests in a silo, including outside look of the silo, CyPhy LVL 1 flying inside doing inspection, Dexterous Hexrotor taking samples, first person view during sampling.

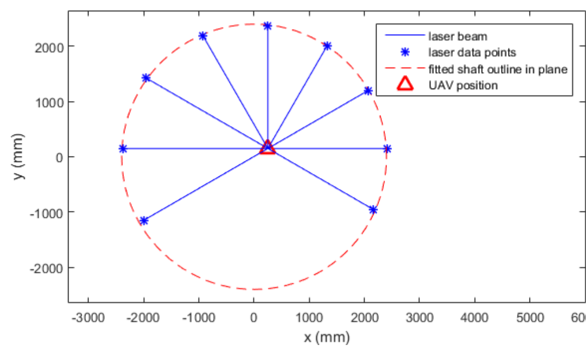

Fig. 5. laser data from Hokuyo URG-04LX-UG01 laser, which gives UAV relative position to center of the shaft.

in plane to give a fitted outline of the cylindrical building as shown in Fig. 5.

IV. Conclusion

Current work presented an initial solution for inspection and simple sampling. Future work would be about full autonomous operation with force control, more adequate sampling mechanism, and possible cleaning robot with water spray.

ACKNOWLEDGMENT

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