QUANTUM COMPUTING INC

White paper: Landmine detection using Quantum Photonic Vibrometer

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1 Introduction

Landmines and unexploded ordnance (UXO) detection methods vary widely, each with inherent strengths and weaknesses. Manual detection, involving deminers using metal detectors and prodding tools, is labor-intensive and risky, often leading to frequent false alarms in metal-rich soils. Trained animals, such as dogs and rats, can quickly sniff out explosives but face challenges related to environmental conditions and ethical concerns regarding their safety. Mechanical methods like flails and excavators clear areas rapidly by detonating mines on contact but can miss deeply buried mines and damage the soil structure, making them unsuitable for ecological zones or near civilian structures. Ground-penetrating radar (GPR) offers the ability to detect non-metallic mines but struggles with depth penetration and differentiating between explosives and clutter, particularly in wet or mineral-rich soils. Lastly, drone-based sensors reduce human risk by enabling remote detection, yet they are limited by high costs, operational complexities, and sensitivity to weather conditions.

Vibrometry offers distinct advantages for mine detection, particularly in its sensitivity to minute vibrations indicative of buried ordnance. Unlike traditional metal detectors, vibrometry can detect non-metallic mines, expanding the range of detectable threats. Its ability to precisely measure surface vibrations enables discrimination between harmless objects and potentially hazardous explosives, enhancing operational safety. Traditional vibrometer techniques, like laser Doppler vibrometry (LDV) and MEMS-based systems, face challenges such as susceptibility to environmental noise and limited frequency response. Despite the drawbacks, vibrometry's sensitivity and accuracy are vital for mine detection, enhancing capabilities and reducing risks in hazardous environments.

At QCi, we have developed an innovative technique for remotely detecting land mines that involves the use of acoustic to stimulate the vibrational modes across the terrain, as shown in Figure 1. The presence of a mine under the surface causes a unique vibrational fingerprint due to its distinct material composition and structure. By employing highly sensitive vibration sensors, this technique can detect variations in soil surface vibrations. This allows for a detailed mapping of mine locations, offering a safer and potentially more effective method compared to traditional mine detection methods.

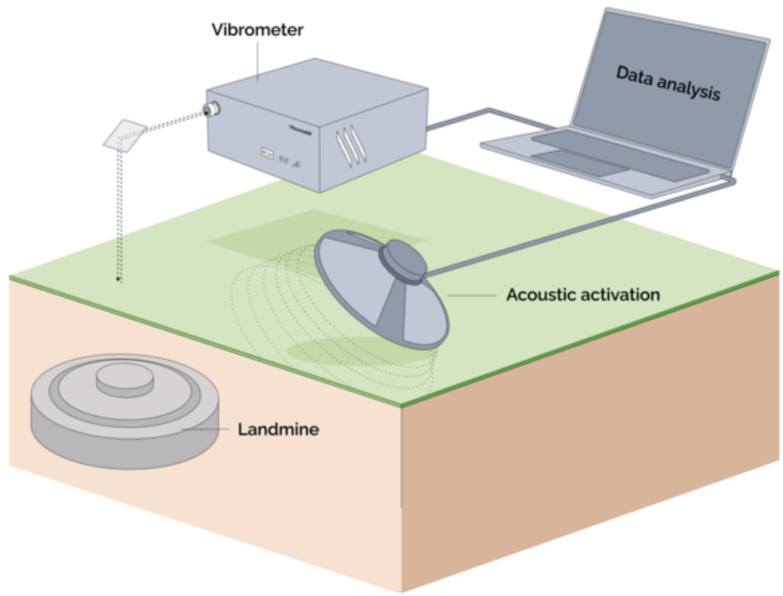

Figure 1: Shows the schematic depicting the mine detection method using vibrometer.

2 Technique

QCI's groundbreaking approach revolutionizes LiDAR by enabling single photon sensitivity in detections of returning signals. This allows for precise interrogation of specific points in the environment through both narrow time gating and frequency filtering. Leveraging quantum measurement, QCI's system surpasses conventional LiDAR limitations, extracting invaluable information from previously inaccessible targets.

Our quantum photonic vibrometer technology employs rapid photon counting to analyze varying backscattering photons from vibrating targets, as depicted in Figure 2. Utilizing an eye-safe infrared laser directed at the target via a circulator, we ensure safety while maximizing efficiency. Spectral filtering of backscattered light eliminates potential interference from solar or environmental radiation, ensuring accuracy in measurements. The use of a time-correlated time-gated single photon detector (SPD) further enhances precision using temporal gating to selectively capture target photons while disregarding those from obstructive objects. This approach enables faithful detection of ultra-low photon levels with an exceptionally high signal-to-noise ratio, providing rich insights even with minimal optical power signals. Remarkably, our methodology remains impervious to pulse interference and surface roughness on the target, enhancing measurement accuracy. As a result, we achieve unparalleled precision in detecting extremely small displacements as low as 100nm, facilitating advanced vibrometry applications with unparalleled sensitivity and accuracy.

3 Laboratory Validation

In preliminary lab testing, we utilized our quantum photonic vibrometer to classify materials simulating mines. Our efforts yielded success as we accurately classified twelve materials, including three wood types, ceramic, and various metals, achieving an impressive accuracy rate of 91%. Currently, we are meticulously analyzing the acquired data to further enhance our capabilities in detecting, classifying, and determining the depth of mines. To expand our database across different sand and soil types and depths, we have acquired a diverse range of inert mines. Additionally, we are leveraging machine learning techniques to extract essential acoustic frequencies, thereby reducing the data acquisition time per mine. Furthermore, we are exploring innovative acoustic activation methods, such as spot audio and acoustic phased array, to concentrate activation on targets and mitigate external noise, thus refining our mine detection processes. These endeavors signify our commitment to advancing the efficacy and precision of mine detection technology through interdisciplinary approaches and cutting-edge methodologies.

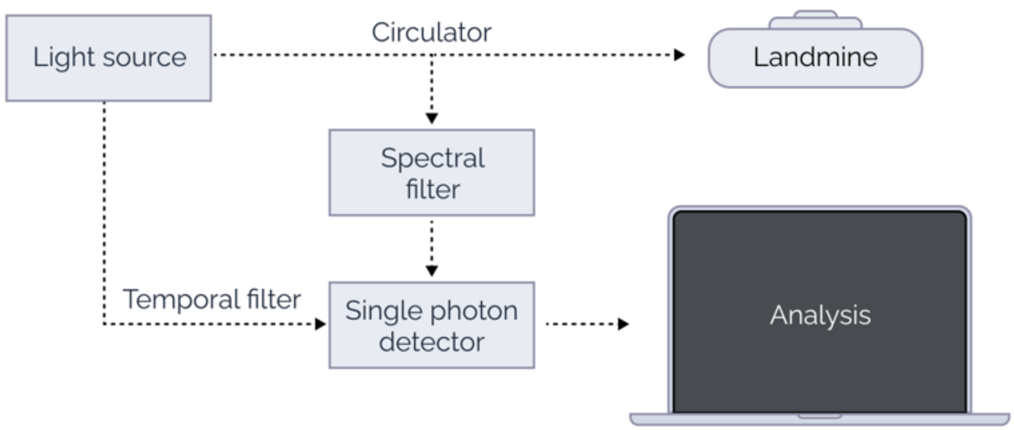

Figure 2: Outlines the vibrometer's internal technology, featuring a laser light source directed by a 3-port circulator. Spectral and temporal filtering enhance signal accuracy before detection by a single photon detector. Analysis occurs on a computer. .

4 Technology Demonstration at Test Facility

Quantum Computing Inc. (QCi) partnered with Worcester Polytechnic Institute's (WPI) robotics department to tackle the intricate challenge of mine detection. Together, we integrated a cutting-edge vibrometer with a robust tracked ground robot, resulting in the development of an advanced integrated system tailored for efficient mine detection operations, even in the most rugged terrains. To ensure seamless functionality in hazardous environments, the collaboration necessitated hardware modifications, such as the design and implementation of custom mounting brackets or adapters. These enhancements not only securely attached the vibrometer to the robot's chassis but also guaranteed stability under varying conditions, as shown in Figure 3. By enabling operators to remotely control the robot, this integration revolutionized the mine detection process, facilitating precise navigation to specific areas of interest and significantly streamlining operations.

The integrated system's effectiveness was demonstrated through its deployment at the Center for Fire and Explosives, Forensic Investigation, Training and Research (CENFEX) range in Oklahoma, where an exhaustive inventory of explosive devices and materials provided critical insights into the complexity of mine warfare. With 143 mines sourced from various countries, including Afghanistan, India, Pakistan, the United States, Germany, Russia, and the United Kingdom, the inventory highlighted the diverse origins and designs of these lethal weapons, underscoring the multifaceted nature of mine threats encountered in conflict zones globally.

Figure 3: portrays the testing range at CENFEX: a) Depicts 143 mine types buried at various depths. b) Shows the range with inert landmines ready for measurement. c) Illustrates the vibrometer integrated with the ground rover.

At this specific location, Unexploded Ordnance (UXO), Improvised Explosive Devices (IEDs), and mines were buried up to 90 cm below the surface. The assortment comprised metal, plastic, 3D printed, and ceramic mines, showcasing the diversity of weaponry in conflict zones. Durable metal mines contrasted with concealable plastic ones, while 3D printed mines reflected modernized warfare. Additionally, ceramic mines, valued for their resilience, added further complexity to the buried ordnance landscape.

In a meticulous testing effort, we buried a grenade 30 inches deep to evaluate the soil surface's mechanical response, providing valuable insights into our system's detection capabilities and advancing mine detection and clearance techniques. Such rigorous testing deepened our understanding of explosive ordnance disposal operations in challenging terrains. Our system has demonstrated remarkable efficacy in detecting the signatures of all buried mines, accurately distinguishing them from the surrounding soil lacking any mines. An exemplary result is provided in Figure 4.

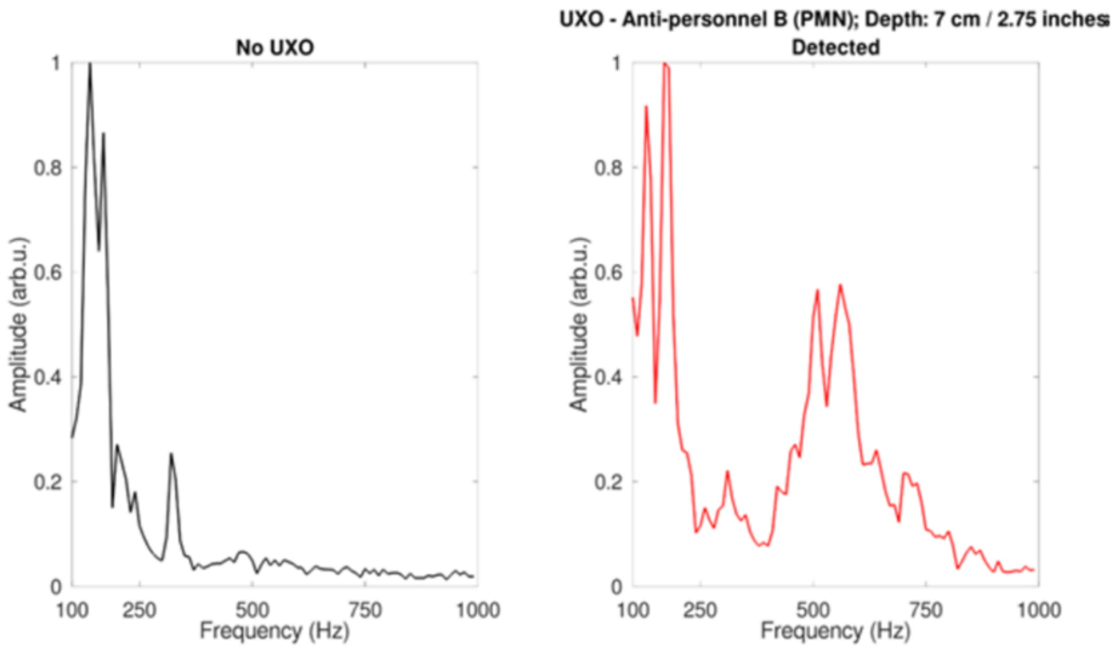

Figure 4: Displays measurement results: left graph shows no mine (black), right graph shows surface measurement of a mine buried 7cm deep (red).

This success underscores the reliability and effectiveness of our detection technology, showcasing its potential to improve safety and efficiency in mine detection operations. By merging expertise in quantum computing and robotics, the partnership achieved significant advancements in remote sensing capabilities. The integration of the vibrometer with the tracked ground robot represents a notable milestone in mine detection, with potential applications beyond this field.

5 Future Capabilities

The development of a single photon vibrometer marks a pioneering step in the practical application of quantum detectors, signaling a new era in this advanced field. The realm of photon detectors is advancing rapidly, driven by ongoing innovations and increasing technological integration. Integrating this technology with a SPAD (Single Photon Avalanche Diode) camera offers significant enhancements, notably in expanding the effective area of detection and reducing the time required for accurate measurements. This combination leverages the high sensitivity and precise timing capabilities of SPAD technology, enhancing the overall performance of vibrometric measurements. By capturing a broader area more efficiently, this hybrid system can dramatically improve operational speed and detection accuracy, making it highly suitable for a variety of applications ranging from industrial monitoring to scientific research where dynamic, minute vibrations are critical. Such advancements not only extend the functionality of quantum detectors but also exemplify the transformative impact of merging different photonic technologies, paving the way for new applications and improvements in both existing and emerging fields.

The single photon vibrometer, beyond its primary application, is a LiDAR device at its base. And this brings the additional benefits of advanced features like 3D imaging, which creates detailed three-dimensional representations of environments. This is instrumental in enabling Simultaneous Localization and Mapping (SLAM) systems. SLAM technology is critical in areas where GPS signals are weak or non-existent, such as indoor environments or densely covered urban areas. It allows devices to accurately navigate and map their surroundings in real-time, relying solely on the LiDAR-generated data. This integration of LiDAR with SLAM is transformative for autonomous vehicles, robotics, and augmented reality systems, providing them with a robust framework for navigation and interaction with their environments without depending on satellite-based positioning systems. The convergence of LiDAR with these sophisticated technologies not only augments its utility in traditional areas but also opens up new possibilities for innovation across various sectors, driving advancements in how machines perceive and interact with the world around them.

6 Summary

In conclusion, the field of landmine and unexploded ordnance (UXO) detection has evolved significantly, incorporating a variety of methods each suited to different challenges and environments. From manual and animal-assisted detection to advanced mechanical and technological approaches, each method contributes uniquely to the goal of safer and more effective mine clearance. QCi's innovative use of vibrometry represents a significant leap forward in this arena, offering a sophisticated solution that enhances detection capabilities through precise vibration sensing. This technology not only promises greater accuracy and safety but also introduces the possibility of further miniaturization and integration with modern robotic and vehicular platforms. QCi's approach, characterized by its SWaPc advantages, is a testament to the ongoing advancements in the field, demonstrating potential to transform mine detection operations, increase efficiency, and ultimately save lives in post-conflict regions.