Bee4Exp: Biological Method (Bees) for Explosives Detection

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Light-emitting organic semiconductors are highly sensitive to trace vapours of explosives at ppb concentration levels and below. However, detecting trace amounts of explosives in field conditions is highly challenging, especially under variable environmental conditions. Preconcentration techniques allow the explosives to sorb and accumulate on a material over time, thus a higher concentration can subsequently be thermally desorbed and detected via a loss of emission from the organic semiconductors. To assess optimal preconcentration materials, different polymers were loaded with 2,4-DNT and their retention and desorption characteristics were measured for a wide range of analyte concentrations, and thermal desorption temperatures. Camera-equipped drones were also used with signal-processing algorithms to monitor trained honeybees swarming around vapour plumes. We demonstrate an end-to-end methodology with promising results for humanitarian demining efforts.

Introduction

Novel technologies for trace chemical detection of explosives have been developed in recent years, with an emphasis on optical sensing[1-4]. The chemical signature emitted from landmines over time has traditionally been detected by dogs, but the drawbacks with dogs including costs of upkeep, animal behaviour, and time allowed on-site per day[5]. Optical chemical sensing can allow comparable sensitivity to dogs, with the added advantage of low-cost, portable instrumentation with no limits on operational time.

Remote Explosive Scent Tracing (REST) is a common technique for sorbing explosives to a mesh material prior to interrogation via sniffer dog. This method can be used in conjunction with optical sensors, which have drawbacks in field conditions, particularly with windy conditions dispersing trace vapour plumes prior to detection. Preconcentration materials have been characterised with a range of explosives, where the explosive molecules sorb to the surface over time which can then be thermally desorbed to deliver several orders of magnitude higher masses of explosives to the sensor element. Many of the polymers investigated and characterised are however very expensive and not suitable for mass use in humanitarian demining. Some chemically similar materials available off the shelf are promising alternative materials, like fluoropolymer Aflas and PBE.

Finally, the use of honeybees provides a method to survey a wide area without risking human life. Honeybees collect material from the environment electrostatically during natural foraging activity. Explosives present in the environment from landmines can be picked up with pollen and brought back to the hive, which can then be analysed and detected.

A complementary active method involves training bees to fly towards a specific odour in a contaminated area. This is achieved by exposing the bees to TNT, for example, when given a food source like sugar solution. The bees associate the smell of TNT with a food reward, and so when released into the field they hover above a vapour plume. Over distances, the bees are followed by using high-definition cameras and thermal cameras mounted on drones. By using three such drones simultaneously the area can be overlaid for higher reliability. From georeferenced high-resolution video, a map of space-time density of trained bees over the suspected area is generated, which allows the determination of the precise location of an explosive device.

We present recent results from the Bee4Exp project, which aims to use honeybees in a passive method to survey wide areas for landmine contamination, with a subsequent active method where the honeybees are trained and followed by a camera-equipped drone to pinpoint landmines in that area. The aspiration is to provide a new tool for safe humanitarian demining.

Experimental

The methodology for sensor fabrication, preconcentrator preparation, and bee colony preparation is outlined in detail in a previous work[6]. Briefly, the fluorescent polymer Super Yellow (Merck) was dissolved in toluene and spin-coated onto clean glass slides. To assess the performance of thin-film preconcentrators, the fluoropolymer Aflas was compared with a phenol-based epoxy polymer (PBE). Each was dissolved in Tetrahydrofuran to deposit thin films.

To assess the affinity of the preconcentration polymers to DNT, and the optimum temperature to induce thermal desorption, a thin film of the sorbent material was loaded with a known concentration of DNT and heated using a hot plate for 3 minutes for each of a series of temperatures starting from 40 °C in steps of 10°C. After each heating step, an absorption measurement using a UV-Vis spectrometer was performed.

For in-situ placement of the preconcentration material in the hive entrance and exit, sheets of poster canvas were blade-coated with polymer solution and cut into squares before being rolled into tubes and inserted in Standard Lexan plates (1 × 1 cm tube) cut into 10 cm lengths and used as a cartridge with 4 channels and inserted into the entrance of the hives. The cartridges containing the preconcentrators were left in place throughout the day to allow bees to return from foraging and deposit any explosive materials (Figure 1).

Figure 1 - Honey bee in cartridge tunnel containing a preconcentrator.

To test the preconcentrators for explosive residue, the canvas square was placed on a heating element near the sensor in a homemade cell. The sensor was excited with a blue laser diode and its photoluminescence measured over 5 minutes. The photoluminescence at room temperature was measured for 30 s, then the heating element turned on for approximately 100 s to heat the sample to 100°C. The loss in light emission was measured. After measurements had been completed the chamber was flushed again with clean nitrogen to clear the chamber of any residual explosive vapours.

The acquisition hardware consists of video capture using a UAV equipped with an ultra-high definition video (UHD) and a thermal camera (TC). UHD video resolution was chosen to cover the largest possible ground in one frame, so each frame contains more than 8 million pixels. The UAV hovers at around 8 to 10 meters and camera is equipped with a 50 mm lens (equivalent to a 35 mm system), and so each honeybee covers the area of around 20 pixels.

The UAV includes a DYS Saga aluminum gimbal suitable for large DSLRs with a net weight of 1.6 kg and capability to carry more than 3 kg of payload, and a 5.8G video transmitter. This system is compatible with Panasonic GH4 and Sony A7 digital cameras. The camera is enclosed in a steel case with two Li-Ion 18650 batteries and a mount for GoPro RGB camera. The camera has a Ulis Pico 640 image sensor with 17 µm pixel size with a 100 mm lens.

Results

The results from loading the Aflas and PBE films with DNT are shown in Figure 2. The use of Aflas as preconcentrator material has been shown to be effective for adsorbing explosive materials for subsequent thermal desorption and detection, and Figure 2a shows desorption at close to ambient temperatures. Better retention in the polymer allows the samples to remain stable with the original mass of deposited explosive on the surface, leading to more

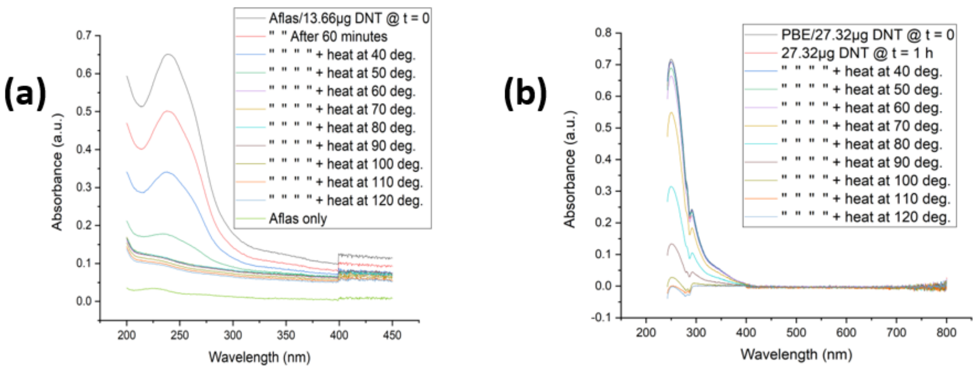

Figure 1 - (a) thermal desorption of DNT from Aflas over 40 ℃ - 120 ℃; (b) thermal desorption of DNT from PBE over 40 ℃ - 120 ℃.

pronounced fluorescence quenching. The polymer PBE shown in Figure 2b exhibits effective loading of DNT, with no desorption noted until heated to 80°C

Results from the camera-equipped drone is shown in Figure 3. The yellow circles show individual bees detected via the algorithm, pointing towards a successful method for identifying honeybees in real time when they swarm above an explosive vapour plume.

Figure 3 - Images of honeybees during a free flight.

Conclusions

Results from a project combining free-flying honeybees for passively sampling explosives materials, and actively trained bees to detect buried explosives with UAV-assisted monitoring, have been presented. Materials Aflas and PBE have been investigated for their affinity to explosives and thermal desorption characteristics. Passive sampling allows for explosives to be collected by foraging honeybees which then deposit the explosives on the surface of a preconcentrator which can then be exposed to an optical sensor for detection; this method is anticipated to be useful for area surveying. The active method is intended to be able to pinpoint individual land mines in an area, with bee swarming over a suspected mine being followed and recorded by a dual camera system mounted on a UAV. Both methods together may provide a robust beginning-to-end procedure for humanitarian demining.

Acknowledgments

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