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Passive Smart Dust: A Versatile Low-Cost Sensor Platform

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Summary:
We present a new approach to detect chemical hazardous substances from a safe distance. In a first step we were able to detect concentrations of dangerous acids and base by using simple paper-based snippets with a chemically modified surface. A significant color change indicates the presence of a chemical hazard and was detected with the help pf a drone and custom software.

Keywords: passive smart dust, drone, chemical sensors, optical detection

Introduction

The remote and autonomous detection of hazardous substances is an important task that can be achieved using remotely operated platforms equipped with dedicated sensors. In recent years a huge variety of methods and vehicles have been used in hazardous conditions for surveillance [1]. The term "smart dust" was initially coined in a work of science fiction and subsequently developed into a research proposal at UC Berkeley, which received funding from the Defense Advanced Research Projects Agency (DARPA). Although the idea attracted attention, it was eventually judged to be excessively intricate for the technology available at the time [2]. With the launch of the passive smart dust project, we reinterpreted the original idea with simple "chemically intelligent" passive sensor particle brought out in the target area in combination with an active sensor on an Unmanned Aerial Vehicle (UAV).

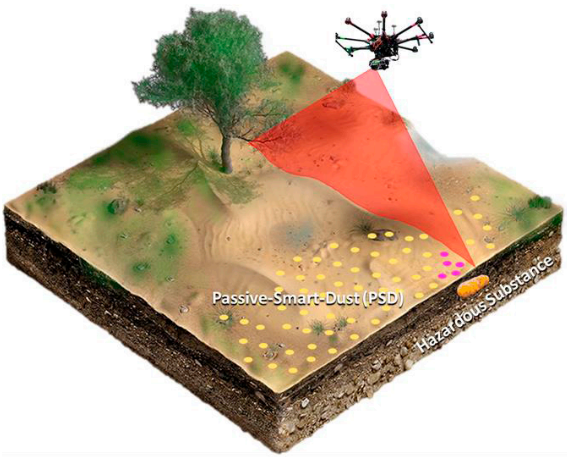

Fig. 1. Schematic presentation of the PSD concept [3].

So, we can circumvent problems of power supplies and communication modules for the smart dust particles that limited older approaches. The surface of the reactive particle can be pre-programmed in the lab to facilitate specific reactions to hazardous substances. The projected applications permit different materials to be used, such as those that can withstand the environment long-term monitoring or that are biodegradable. A frequent scenario of an industrial accident with spoiled acid, as an acute and quickly remediable problem, became the first test setting for our passive smart dust concept [3].

Materials and methodology

Drone platform

The DJI M300 RTK is a commercially available quadrocopter that is suitable to operate in harsh weather conditions. A Real Time Kinematic (RTK) ground station was used for precise determination of localization data. The drone offers maximum flight time of 55 min with a given range of up to 15 km [4]. A payload of up to 2.7 kg can be attached on the platform. In our case the DJI Zenmuse H20T was used for optical measurements. The H20T is gimbal stabilized and contains a zoom capable 20 Megapixel (MP) 1/1.7" Complementary metal-oxide-semiconductor (CMOS) sensor and a 12 MP wide range 1/2.3" CMOS sensor for visible light detection. Moreover, a VOx mircoblometer can measure wavelengths in the near infrared range and a 905 nm class 1M laser provides relevant distance information. An overflight altitude of 20 m was chosen, resulting in a reasonable image resolution and safe distance in which the smart dust is not affected by any rotor downwind.

Sensor particles

For environmental reason, paper-based particles represent the focus of the upcoming work. To be recognized by an optical camera system the used the smart dust particles need to be big enough for being detectable with commercial off-the-shelf camera systems and shall provide a big shift in the emitted light wavelength. At first commercial pH paper [CHEMSOLUTE® universal] was tested within several sizes and heights. In a next step, particles were self-manufactured and optimized.

Macherey-Nagel [MN 617] highly absorbent filtration paper was covered with a mixture of polyethyleneimine (PEI) [Mw~25000, Mn~10000, Sigma-Aldrich, Germany] and 1-Naphtholphthalein [reinst, Carl Roth, Germany] as well as PEI and Thymol blue [ACS 95%, Supelco™, Canada] respectively (Fig. 2).

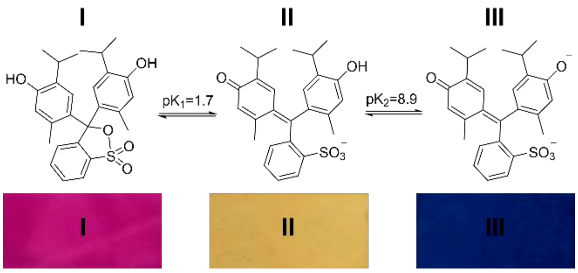

Fig. 2. Different forms of thymol blue combined with pictures of the manufactured test particles at pH value of 1(I), 7(II) and 13(III) respectively.

The used cationic PEI polymer effectively hinders a bleeding of the indicator when exposed to liquids from a time larger than 5 min which is a current problem with commercial test stripes. Both used indicators offer not only one but two color-stages and concurrent detection of strong acids or bases and negative control in the neutral pH range [6].

Evaluation

For an automated localization of contaminated areas, a detection algorithm was developed in Python. The obtained pictures in JPEG format were converted into the Hue Saturation Value (HSV) color space. Subsequently, a filter based on the particle's HUE value was used for particle identification/detection [7]. By using the Exchangeable Image File Format (EXIF) data in combination with distance and angle information from the gimbal, the particles can be localized with an error of under 2 cm. In the presence of a hazard, a warning message is automatically generated, and the identified areas are visualized in Google Earth using its Keyhole Markup Language (KML) file format.

Fig. 3. ROI of red particles indicating the presence of acid (a) After processing hazardous areas are shown on google earth via imported datapoints (b).

Results

Remote sensing of pH paper pieces formed an effective basis for the detection of acids and bases, which could be accurately detected by a camera system from a safe distance. By applying a HSV-filter, which identified the colors of particles that reacted to the presence of acid, all the Regions of Interest (ROI's) were revealed. Additionally, the EXIF data provided the exact location of the hazard. Thanks to the combination with the RTK system of the DJI M300, highly precise location data in centimeter range was obtained. To ensure easy application in the field, the positive test areas were projected onto a widely accessible digital map (Fig. 3).

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