



Knowledge brief

Low-weight small Unmanned Aerial Vehicle sampling method for chemical warfare agent detection - a pilot study.

Summary

The timely detection and identification of chemical warfare agents (CWAs) is critical in mitigating the health risks associated with chemical, biological, radiological, and nuclear (CBRN) incidents. Traditional methods often require specialized personnel and typically necessitate close human proximity to hazardous environments for sampling and field detection. This pilot study evaluates the feasibility and effectiveness of using a lightweight small unmanned aerial vehicle (UAV), more specific the DJI Avata 2, for indoor field sampling of CWAs. The UAV was equipped with both MX908 sampling swabs and CWA detection paper, allowing for remote sample collection in indoor environments. Simulants for nerve agents (GB and VX) or solid or liquid aerosols (caffeine) were dispersed above the UAV during separate flights. Results showed successful detection of both solid and liquid aerosolized substances using the MX908 and visual confirmation of simulants on CWA detection paper. The findings indicate that small UAVs, in combination with lightweight sampling tools and handheld analysis devices, offer a practical and reliable method for initial CWA detection particularly in confined hazardous areas. This approach may enhance responder safety and efficiency during the early stages of incident response, although further studies are needed to optimize sampling methods and address limitations such as detection of vapors.

Introduction

In a world where the threat of chemical, biological, radiological, and nuclear (CBRN) incidents has become a serious reality, the ability to detect CBRN agents is crucial for our safety and well-being [1]. This applies both to unexpected disasters, such as incidents at industrial facilities or natural phenomena, and to deliberate attacks involving the use of hazardous substances. The greatest and most immediate danger of CBRN agents is the impact they have on human health: chemicals can be toxic or incapacitating, biological agents can cause lethal infectious diseases, and radiological or nuclear substances can bring deadly levels of radiation [2]. If these substances are not detected in time, they can cause a large number of casualties and result in long-term health damage to the affected population. Detection systems enable first responders to intervene quickly and thus save lives. For the accurate identification of chemical warfare agents (CWA), laboratory equipment such as gas chromatography-mass spectrometry (GC-MS) and/or liquid chromatography-mass spectrometry (LC-MS) systems are often used [3, 4]. However, the use of this equipment requires specially trained personnel and specialized laboratories that are allowed to work with highly toxic substances. Therefore, in the field, first responders use various handheld detection devices to detect potential CWAs, such as Ion Mobility Spectroscopy (IMS), Flame Photometric Detectors (FPDs), Infra-Red (IR)

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Spectroscopy, Raman Spectroscopy, and colorimetric-based detectors such as paper, tubes, and detection kits [5, 6]. Since this detection equipment is handheld, the user must operate in hazardous areas with the appropriate personal protective equipment (PPE).

The development of unmanned vehicles (drones), such as Unmanned Aerial Vehicles (UAV) or Unmanned Ground Vehicles (UGV), has seen tremendous growth across numerous industries in recent years. UAVs are increasingly being deployed during incidents, particularly for imaging purposes [7]. However, UAV applications for detecting hazardous substances are still limited. As already stated, detecting hazardous substances, such as CWAs, presents significant risks for responders. UAVs equipped with sensors and sample equipment make it possible to sample and/or detect these substances remotely. In addition, UAVs are highly efficient. Whereas traditional methods are often labor-intensive and time-consuming, UAV's can be quickly deployed to scan large areas or investigate hard-to-reach locations [8, 9].

UAVs equipped with advanced sensors, such as gas detectors, thermal or infrared cameras, and Light Detection And Ranging (LiDAR) technology, can perform detailed measurements. This helps to locate leaks, determine concentrations of hazardous substances, and map their spread. Additionally, UAV's provide data that can be analyzed and shared in real-time, which aids in faster decision making [10]. A major disadvantage of these sensor technologies is their substantial weight. These payloads often range from several hundreds of grams to several kilograms [11]. Therefore, it is necessary to use large UAVs with a maximum take-off weight (MTOW) of at least 4 kg or more. These large UAVs are needed to transport heavy payloads and still have enough flight time left to perform measurements and/or sampling. For outdoor operations, this is not a problem, but for smaller indoor spaces, large UAVs may not be an option. In these cases, one would ideally use small lightweight UAVs, but these lack payload capacity.

The aim of this pilot study is to assess to what extent lightweight sampling and/or detection tools, mounted onto lightweight small UAVs, that can fly indoors, are effective and reliable for the sampling and instant detection of CWAs. UAV samples are analyzed with handheld equipment for detection of CWAs.

Materials and methods

Materials

UAV

The Avata 2 (DJI, Shenzhen, China) is a compact First Person View (FPV) UAV with a weight of 377 g, which is also its MTOW [12]. The Avata 2 features a 4K ultra-wide camera and an integrated propeller guard design, making this UAV ideal for indoor flights.

MX908 and swabs

The MX908 portable high-pressure mass spectrometry (HPMS) device (908 Devices Inc., Boston, USA) is an advanced portable analysis device specifically designed for the rapid detection of hazardous substances such as toxic chemicals, explosives, drugs, and CWA's [13]. The device uses HPMS, enabling rapid analysis of trace or bulk solid/liquid materials using MX908 swabs (908 Devices Inc.) as well as continuous analysis of gases/vapors and aerosols.

CWA simulants and detection paper

CWA simulants from Ouvry (SIMKIT® Chemical Warfare Agents simulants GB-SIM: dipropylene glycol monomethyl ether and VX-SIM: polypropylene glycol monobutyl ether) were used together with CWA detection paper (CALID-3 Liquid CWA Detection Papers from Oritest). CWA detection paper can be visually assessed by color: red for H-series agents (blister agents), yellow for G-series nerve agents, and green for V-series nerve agents [14].

Caffeine (LGC standard Dr. Ehrenstorfer, product number DRE-C11693000) was used for testing aerosol absorption on the MX908-swabs. Caffeine, as a pure substance, is a white powder and is a mild psychoactive compound with stimulating effects.

Method

UAV Preparation

The Avata UAV is made flight-ready and fitted on the underside with an MX908 swab, which is attached using a piece of duct tape (see photo 1). Over the duct tape, a CWA detection paper is placed and folded over the outside. This way, both test strips are exposed to the downwash from the Avata's rotors.

Photo 1: DJI Avata 2 UAV equipped with MX908-swab and CWA detection paper



Subsequently, tests were conducted by dispersing the CWA simulants and caffeine above the flying UAV. These were dispersed above the UAV using a spray bottle (supplier VWR, Koehler technical products, 10 ml).

Small pre-weighed amounts of caffeine powder were dispersed by blowing the powder off the weighing paper above the UAV to simulate a solid aerosol. To simulate a liquid aerosol, caffeine was dissolved in water to a stock concentration of 4 mg/ml. Using a spray bottle, the caffeine solution was dispersed directly above the flying UAV, thereby simulating a liquid aerosol. The previously mentioned 10 ml spray pump was gravimetrically tested (Sartorius MA 150) for the amount of liquid released per single spray pump, a single spray delivers about 0.13 ml of liquid (0.1256 ± 0.001 (n=5)) as a liquid aerosol. The UAV was sprayed with varying dilutions (with water) of the caffeine stock solution.

The exposed MX908-swabs were immediately analyzed using the MX908 in 'drug hunter trace mode'.

Results

Results of simulant exposure on CWA paper

The CWA simulants were dispersed above the flying UAV using the spray bottle. The mist is drawn in by the rotors and then blown onto the attached CWA paper, which will change color after exposure to the liquid: yellow for GB-SIM and green for VX-SIM. The fine mist of simulants from the spray bottle is therefore visible on the CWA paper. See photos 2 and 3. In photo 2, a pattern of multiple fine green spots is visible on the CWA paper after exposure to VX-SIM.

Photo 2: exposure to VX-SIM



In photo 3, small yellow spots are visible, but not very clearly (at the top part of the paper) after exposure to GB-SIM.

Photo 3: exposure to GB-SIM



Results of caffeine exposure on MX908-swabs

Table 1 shows the results for caffeine dispersed above the UAV as a solid. A weighed amount of caffeine was dispersed above the UAV. The airborne solid particles were drawn in by the Avata's rotors, exposing the MX908-swabs to the substance via the downwash.

Photo 4 is an example that illustrates the typical positive test result as displayed on the MX908.

Table 1: MX908 results solid aerosol dispersing

Amount caffeine (mg)	Result
66	positive
32	positive
17	positive

Photo 4: caffeine positive test result displayed by the MX908 device



Table 2 shows the results for caffeine dispersed above the UAV as a liquid (mist). Repeatability was tested by repeating experiments with the same concentration 5 times (5/5 means 5 positives out of 5 attempts, 4/5 means 4 positives out of 5 attempts, etc.). Table 2 shows that very low concentrations (10.2 ng) can be detected, although with slightly lower repeatability compared to higher concentrations.

Table 2: MX908 results for liquid aerosol dispersing

Concentration (ng/spray)	Result	Repeatability
520	positive	5/5
86.7	positive	4/5
52.0	positive	3/5
10.4	positive	2/5
5.2	No target detected	0/5

During real incidents, the UAV requires a certain amount of flight time to return to its landing pad. Therefore, it is conceivable that aerosol particles could be blown off the swab during the flight. Therefore, it was also investigated whether the sample applied (via the downwash of the UAV rotor blades) could be blown off the swab again. In two experiments with liquid aerosol method (520 ng and 86.7 ng) and one experiment with solid aerosol (17 mg), the spray and powder were sequential applied on different swabs, after which the UAV continued flying for at least 5 minutes before analysis. In all cases, there was a positive result with the MX908, indicating that prolonged UAV rotor downwash does not negatively impact attachment of solid or liquid sample material on the MX908-swab.

Discussion

The results of this pilot study provide proof-of-principle that it is possible to collect CWA samples in the field using a small, lightweight UAV for detection purposes. This low-tech application is particularly interesting for use in the hot zone of an incident where CWA's may have been utilized and airborne aerosols are still present. The results from tables 1 and 2 demonstrate that UAV-based sampling, in combination with analysis using the MX908, is well capable of detecting both solid and liquid aerosols. Especially in the exploratory phase of an incident, it may be valuable to combine UAV camera images with initial chemical analysis using the MX908 and simple CWA detection paper.

It should be noted that, for the various tests with caffeine as a solid and as a liquid, the concentrations used are not an exact measure. Since the spray and dispersed solid passed over the UAV, it is likely that not all of it ended up on the MX908 swab (which probably explains the fluctuations in repeatability, especially at lower concentrations). Nevertheless, based on this proof-of-principle pilot study and the MX908 target list [15], an indication can be given of which substances can potentially be detected with the MX908 in trace mode, and for many substances it is likely to detect them at low nanogram levels.

Most lethal CWA's are mainly available as liquids and will be spread as vapor or liquid aerosol [2]. This means that it is possible to detect these CWA's using CWA detection paper if spread as an aerosol, where the different groups of CWAs can be identified by their specific color (red for blister agents, yellow for G-series nerve agents, and green for V-series nerve agents) [14]. This is likely only possible during actual active dispersal. If there is a significant delay between dispersion and the UAV flight, aerosols may be sedimented and will not be detected with this UAV method. This was not specifically investigated in this pilot study. This should be considered when interpreting a negative result: a potentially hazardous environment where CWAs are present cannot be ruled out. Therefore, this method is not suitable for excluding risks. Another issue to consider is that a drone flying through an aerosol cloud can become contaminated and must be decontaminated or destroyed after use. In addition, after sampling, the drone should remain in the hot zone, and it is important to prevent the drone from flying over sensitive areas such as people or clean zones.

Although aerosol detection appears feasible with this method, it is unlikely that CWA vapors can be detected. A possible UAV-compatible lightweight sampling method for this would be a solid phase microextraction (SPME) fiber/arrows [16]. These fibers/arrows are lightweight and therefore very suitable for small (low MTOW) UAVs. However, this application would require a GC-MS system for the identification of substances bound to the SPME-fiber/arrow.

Conclusion

The results of this pilot-study show that, CWA detection is possible, with sample collection carried out using a lightweight small UAV and subsequent CWA detection performed using handheld equipment and/or CWA detection paper.

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