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Plant Management by a Gas Chromatograph Installed on a Drone

Ultra-compact, highly sensitive gas chromatograph that can perform "air patrol" of a plant

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Summary

- **The proprietary ultra-compact portable gas chromatograph enables on-site analysis of gases emitted from plants.**
- **During a demonstration at a facility simulating a plant, different types of gases were detected with high sensitivity in a short time (3 minutes).**
- **In addition to plant maintenance and management, the system has a wide range of applications, such as monitoring plant growth and the brewing process in sake breweries.**

A research group led by Kazushi Yamanaka of Ball Wave Inc. has developed a plant management system using their proprietary ultra-compact, portable gas chromatograph "Sylph" mounted on a drone. They succeeded to sensitively detect multiple gases during a short time (3min) in a demonstration at a facility simulating a plant using Sylph with a ball SAW sensor, which is so sensitive that it can detect hydrogen gas in the range of 10ppm to 100%. On-site analysis of smell with Sylph has a wide range of applications, such as plant maintenance and management, monitoring of plant growth, and the brewing process at a sake brewery. The on-site analysis of smell with Sylph throws open the possibility of a wide range of applications.

Details

Plant "air patrol"

In recent years, there has been a trend toward the use of smart technologies such as IoT, AI, and drones in plant security and management. The security and management of petroleum and chemical plants, as well as electric and gas energy plants, is an area where smart technology is highly valuable, not only because of the risk of disaster due to accidents, but also because of the risk of terrorism. The Ministry of Economy, Trade and Industry (METI) is promoting new technologies and regulatory reforms so that smart technologies can be used to strengthen industrial security.

A research group led by Kazushi Yamanaka of Ball Wave Inc., which conducts research and development on sensors, has developed a new plant management system that uses its proprietary ultra-compact, portable gas chromatograph (gas analyzer) “Sylph” mounted on a drone. This management system patrols the air above the plant. It detects hazardous gases emitted from plants and performs “on-site analysis” that can quickly detect the abnormalities in the plant.

Some previous studies have used drones for gas detection, but they were of the “sample return” type, which means that the gas collected by the drone is brought back for analysis. The system developed by us can perform on-site analysis, and hence, the time lag between gas collection and analysis is very low. The advantage is that the analysis data can be used for plant control in real time,” says Yamanaka.

The Sylph ultra-compact portable gas chromatograph, which can be mounted on a drone, weighs only 1/5 to 1/7 of an existing portable type, and 1/40 to 1/50 of a desktop type. And yet, in terms of performance, its sensitivity is same as that of a standard gas chromatograph with "hydrogen flame ionization detector ". Hence, it combines high performance with a revolutionary weight reduction.

Waves traveling on a sphere capture gas molecules

From FY 2019 to FY 2021, the research group conducted research jointly with JAXA (Japan Aerospace Exploration Agency) to study and develop a portable gas chromatograph with a sensitivity of about 1 ppbv (capable of detecting gases with a concentration of about one part per billion) that can identify and quantify volatile substances existing in the atmosphere and surface soil of other planets. It intends to explore the possibility of life activities and resource extraction. The ultra-compact portable gas chromatograph Sylph is the culmination of this research.

The core technology of the ultra-compact portable gas chromatograph Sylph is the "ball SAW sensor (ball Surface Acoustic Wave sensor)”, which is a piezoelectric material consisting of a 3-mm-diameter quartz ball with an interdigital electrode deposited on it, as shown in the photo on the left in Figure 1. SAW is a wave propagating on the surface of a solid. When a gas molecule is adsorbed by a sensitive film, the sound velocity and attenuation of the SAW change. By capturing these changes with an electrode, the gas to be detected can be quantified. A familiar example of device using SAW is the "SAW filter," which improves the sound quality of calls made with smartphones. The SAW filter selects the frequency of radio waves according to the period of the interdigital electrode. Hence, the material and electrode of the SAW filter are similar to those of the ball SAW sensor, although the principle of operation and the flat shape are different.

“The distance over which the waves propagate is a key factor in the development of the sensor. The longer the propagation distance of surface acoustic waves, the easier it is to capture changes caused by gas molecules and the higher the sensitivity. For example, on a finite flat piezoelectric material, the propagation distance of the wave is naturally limited. However, when waves are generated under specific conditions on a spherical piezoelectric body, they form a “naturally collimated beam" (parallel beam) and can travel around a spherical surface many times without being obstructed. The propagation distance of SAW is so long that it is unimaginable according to conventional physics.” (Yamanaka)

The ball SAW sensor is a SAW sensor that maximizes sensitivity by applying a diffraction-free long-range propagation. Yamanaka discovered the principle of the diffraction-free long-range propagation when inspecting flaws on the surface of balls used in ball bearings. At low gas concentrations, the change in propagation time required for one turn is small and difficult to detect, but after 100 turns, this change is amplified 100-fold, making detection easier (Figure 1, right). The ball SAW sensor realized the first single-element, wide-range hydrogen sensor with high sensitivity and a wide detection range, from 10 ppmv (0.001%) to 100% hydrogen gas concentration.

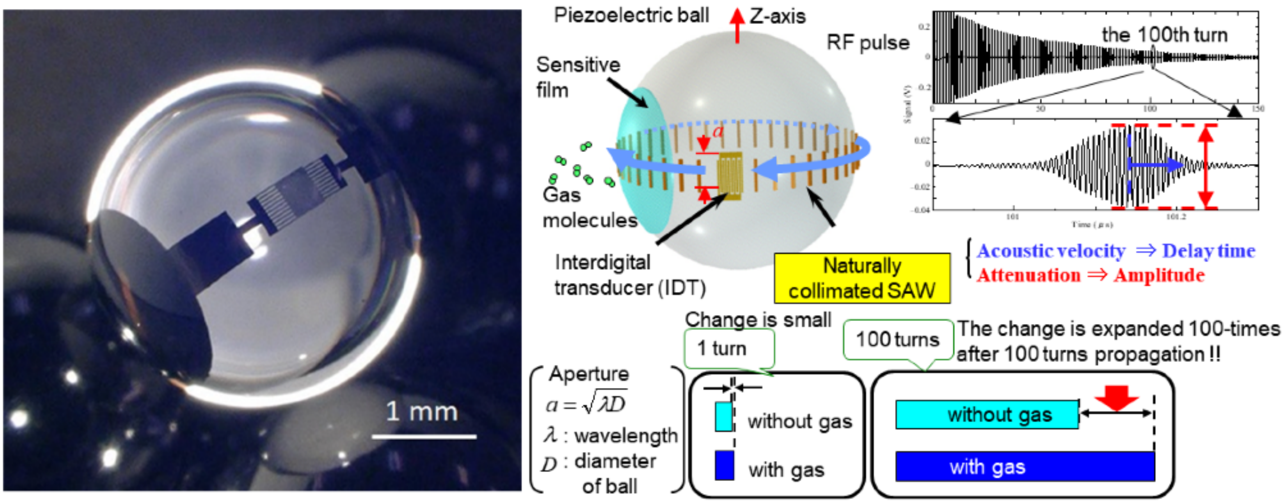

Figure 1 Ball SAW sensor (left: photograph, right: explanation of principle)

Range of applications from monitoring plant growth to monitoring sake breweries

The plant management system equipped with the ultra-compact, portable gas chromatograph Sylph, developed by Yamanaka and his colleagues, was demonstrated at a mockup plant at the Fukushima Robot Test Field. The experiment was conducted by mounting the system on a drone (DJI Matrice 300RTK) with a maximum payload of 2.7 kg (Figure 2). Here, a sampling unit, made of a 3-m-long carbon fiber reinforced plastic pipe, was connected to the gas chromatograph so that the gas to be collected would not be diffused by the airflow caused by the drone's propeller.
In addition, the time taken for the analysis of the plant management must be short. Therefore, the length of the metal solenoid column, the component that separates the gases, was changed from the usual 30 m to 10 m to reduce the analysis time.

During the demonstration in a facility that resembles an actual factory, an equal volume mixture of heptane (C7), octane (C8), and nonane (C9), which are petroleum components normally detected in oil plants, were sprayed using an ultrasonic humidifier through a chimney. Polar liquids such as propylene glycol (P) were vaporized in a smoke generator at the bottom of the chimney to generate white smoke. The drone then approached the chimney and collected these gases for 0.5 minutes and analyzed them (Figure 3 left) during the flight. As a result, all these different types of

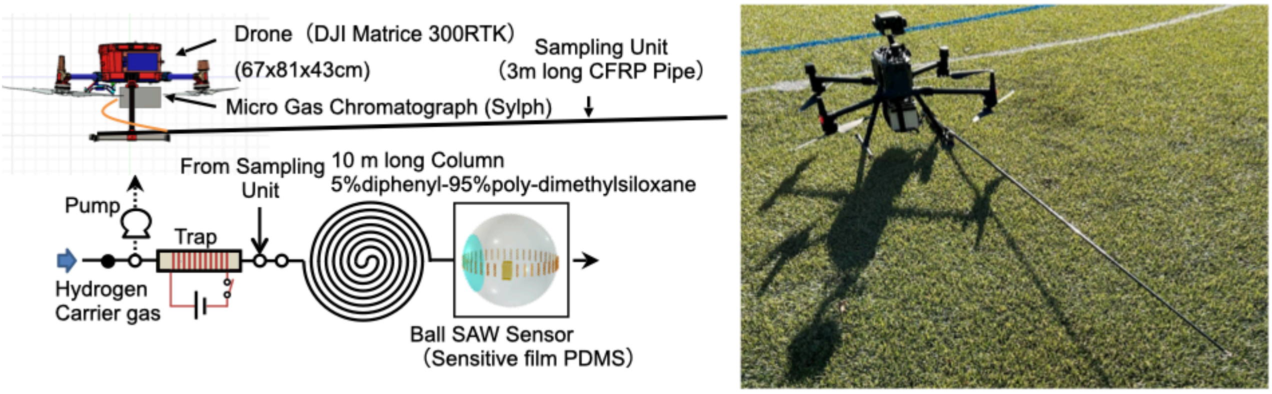

Figure 2: Plant management system used in the experiment. A cylindrical sampling mechanism of approximately 3 m in length was connected to reduce the effect of airflow caused by the drone's propeller.

gases were detected with high sensitivity in a short time (3 minutes). The chromatogram on the right of Figure 3 shows the relative change in SAW propagation time (Delay time) by gas in ppm (parts per million). According to a separately performed calibration, the average concentration of nonane (C9) captured by the sensor was 17 ppmv. Since the noise in the chromatogram is low and the signal to noise ratio (S/N) is greater than 20, the lower detection limit is estimated to be less than 1 ppmv.

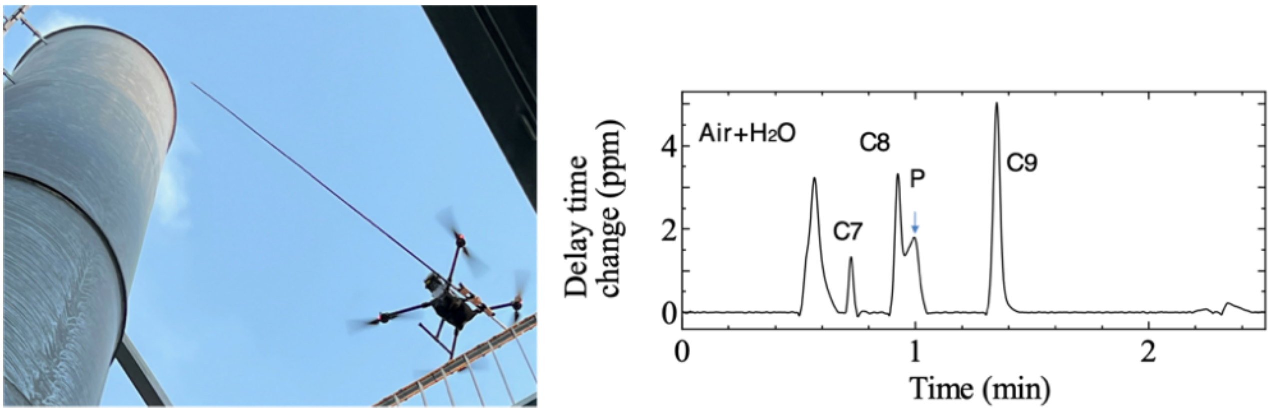

Figure 3: Sampling of gas emitted from the chimney (left) and chromatogram (right). Heptane (C7), octane (C8), nonane (C9) and propylene glycol (P) are detected.

“During the demonstration test, we detected petroleum component gases normally emitted by plants, but it is important to note that propylene glycol (P) was also clearly detected near the octane (C8) peak. The production of this substance requires a special process using a high-performance catalyst and does not occur in plants during their normal operation. Therefore, Figure 3 shows the potential of the developed control system to detect abnormal gases generated by plant malfunctions. In the future, we would like to proceed with research and development of a more practical plant maintenance and management system, which for example, can detect chemical substances specifically as indicators for predicting plant malfunctions," says Yamanaka.

The application of the ultra-compact, portable gas chromatograph Sylph, which allows on-site analysis, is not limited to "air patrol" of plants. It can also be used to detect and analyze sick house gases, measure the local environment by smell, monitor the growth condition of plants, measure the aroma of sake to monitor the brewing process in sake breweries, and obtain brewing control indicators.