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Automated Plant Viability System for Early Detection of Plant Disease

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Abstract: This paper reports on the design and implementation of a plant viability sensor system based on micro fabrication and wireless communication technologies. The system consists of a Solid Phase Micro-extraction (SPME) Injector, a gas chromatography column with OV-1 coating, a low power thermal conductivity sensor, and a circuit design. The system uses the SPME injection method which allows injection of small amounts of analytes into the GC system instantly. The column with a 2 dimensional temperature programming provides a better separation of the volatile compounds and the CMOS TCD sensors provides high resolution for detection of a low concentration. A 12 bit microcontroller with a low noise circuit system and a Bluetooth communication technology are implemented for live monitoring of the VOC gases. The documented performance shows that the system is able to detect and transmit the volatile organic compounds of interest to a handheld device.

Keywords: MEMS, SPME, Volatile Organic Compounds (VOC), greenhouse, Automation, TCD, Gas Chromatograph (GC)

1. INTRODUCTION

It is well known that plants respond to stress by producing chemical signatures (Dorothea Tholl 2006), (Niinemets 2009). Detecting and monitoring these chemical signatures can help to prevent further damage to the yield by investigating the effect of pesticides, and by determining the stage of growth of the plants. The chemical detection of volatile organic compounds is a rapid method deployed to determine the natural release of signatures from the plant to attract or respond to an insect infestation (Ülo Niinemets 2013), (Jarmo K. Holopainen). For example, terpenes and hexanol will become elevated in response to abiotic stress on the plant. This approach has been used previously to measure the differential chemical response to the chewing of herbivores compared to sap sucking insects (Niinemets 2013). Emitted VOCs are important communication molecules between plants and are used as a defence mechanism against insects.

There are currently several techniques to monitor plant conditions in the field such as imaging; using video images to indicate the leaf condition of the plant. Infrared sensors measure the solar irradiation in the field, which along with time, humidity, and other data can be used to estimate the soil hydration level (Choudhury 1987). The products of the plant can interact with components in the atmosphere, in particular ozone and aerosol particles which modify the local concentration of VOCS (Niinemets 2013). Hence, concentration levels can fluctuate depending upon the background air composition and the presence of pollution. Fast isoprene sensors, based on chemiluminescene detectors, have been developed with a detection limit in the 4 ppt by volume with response time measured in milli-seconds. These systems are inexpensive and have stand-alone instruments, meanwhile their weakness is that they have a slow response time. Infrared measurement of the ambient VOC's with plants has also been studied (Bacsik 2004), but in addition to their inability to analyze a complex mixture of several compounds, their required instrumentation can be much more expensive than the proposed MEMS-GC.

Gas chromatography is currently used in both plant pathology and microbiological studies of soil flora. Studies include the investigation of plant infections, the effects of pollutants on plants' health and their resistance to infection. Recent interest in plant metabolics also provides a diagnostic marker for early detection of changes in plant health (Niinemets 2013). In addition, localization of the concentrations at leaves and root systems is of potential interest to the researchers. Work on the air cleaning ability of plants, which can actively reduce the level of VOC's from an enclosed environment to improve indoor air quality, has also been an active area of research (Dong Sik Yang 2009) (Cruz 2014). It is evident that introducing a low cost portable system to monitor VOC levels will be very beneficial to all the studies mentioned and are underway.

The goal of this innovative product is to combine the analytical capability for chemical detection of the MEMS-GC system with the flexibility of autonomous robotic solutions. This combination allows for continuous monitoring of farm plant chemical activity when infected by *Phytophthora*. *Phytophthora,* a soil borne oomycete filamentous plant

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pathogen that causes destructive diseases in agriculture horticultural and forestry settings. The damage caused by this disease are mainly below soil level thus not frequently detected. This adds to the difficulty in controlling the pathogen and the lack of methods to eradicate the pathogen without destroying the plant provide a case for further development.

2. System Design

Here, we present an ultra-portable MEMS-GC system which will be capable of recording the chemical signatures at specific locations to determine new information about the health of the plant and the VOC response of the plant to a fungal infection such as *Phytophthora*. Available autonomous control technology in combination with gas sampling techniques can be utilized to allow precise data collection at a close distance from plants. Figure 1 describes the microfluidic connection and operation of the GC system. The VOC gases are concentrated using a SPME and injected into the SPME injector. Helium is the carrier gas which transports the evaporated compounds through the micro valve, GC column, and the TCD detector. The valve position, column temperature, and TCD response are controlled by a 12 bit micro controller.

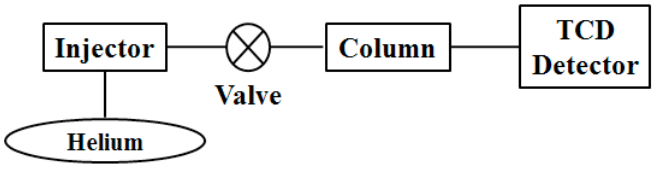

Figure 1. *System architecture and components.*

The overhead space of the plant was collected in a Tedlar® bag. The SPME fiber was connected to the inlet of the Tedlar® bag for 10 mins to collect the volatiles inside the bag. Next the SPME fiber was injected into the system by the SPME injector port. The volatiles desorbed from the SPME were transported by helium (2700 psi gas cartridge, 2.5 g He, 5/8 Zinc-y manufactured by Leland ltd). The helium pressure was set to 30 psi and the flow was measured using Omega pressure sensor. The outlet of the Injector was connected to a 250 µm diameter fused silica (FS) capillary via a NanoPort fitting to the GC column. The outlet of the column was connected to the TCD sensor.

2.1 Injector Stage

For a low concentration of VOCs, solid phase micro extraction (SPME) is an effective extraction method for adsorbing the volatile from the air and has been utilized for standard GC-MS analysis. Fast and repeatable injections of samples into the GC system directly affect the column efficiency; therefore, designing an injector with a small dead volume and thermal mass is necessary to prevent band spreading and poor resolution. Standard GC columns require much smaller samples; hence, a split ratio system has been employed to inject a small amount of sample into the system. The split ratio system injects just a fraction of the mixture into the system and the rest of the mixture is blown away via a bypass line. There has been a substantial amount of work undertaken historically in miniaturizing the injector port to a power-efficient and narrow injection time-width pulse, yet no compatible and effective system is available. SPME utilizes a small diameter fiber coated with the stationary phase of interest for extraction of organic analytes from liquid and gas matrices. The amount of analytes adsorbed by the fiber is proportional to its concentration in the medium. Extracting the compounds from the SPME requires an injector with a high heating rate. This was achieved by reducing the thermal mass of the injector and using resistive heating. The resistance heating is driven by Joule heating, in which heat is generated by flow of electrical current through the layer. 12 V is applied to the heating element to heat the injector to 185 ˚C. The temperature of the injector was set at higher temperature of the uppermost boiling temperature of the compounds to ensure desorption of all the compounds. The SPME fiber used for this experiment is a 30 µm PDMS. ***Figure 2*** shows the integrated system.

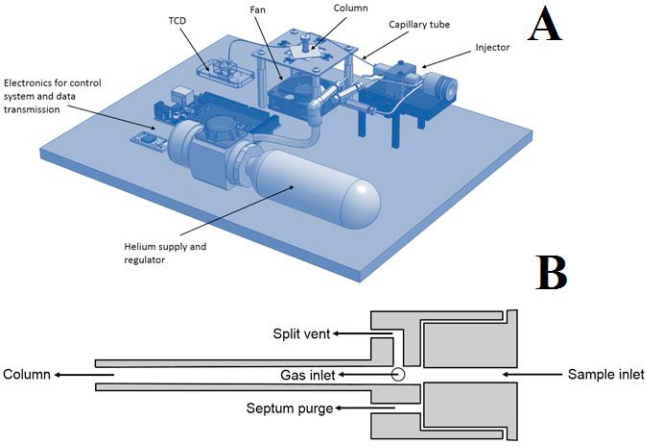

*Figure 2 : (A) Conceptual mockup of experimental setup indicating each major component and the respective location of the component in the experimental system. (**B**) Diagram illustrating approximate locations of GC injector inlet and outlet ports.*

2.2 Separation

GC column is the heart of the system where separation takes place. The most common technique used for the separation of gases is the elution technique, where a stream of inert gases passes through the column and interacts with a stationary phase of choice. In theory, after injecting a mixture of compounds into the mobile phase, the mixture passes through the column while interacting with the stationary phase. Some compounds are retained by the stationary phase; as a result, the compounds are separated based on their retention time. The fabrication of a 3 meter long, 250 µm wide and 350 µm deep column is discussed elsewhere (Navaei 2015).