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Review Article

MEMS Devices Used in Agriculture - A Review

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Abstract

The development of biological, chemical and medical research had been possible due to implementation of a variety of low-cost, high-performance microscale devices in the consumer electronics and automotive markets through Microelectromechanical systems (MEMS) technology. Despite having huge socio-economic impact, not many studies have been performed in MEMS technology in the area of plant science and technology. In this review, a few examples and applications of our microfluidic devices to overcome this issue. With the help of MEMS devices, multiple model plants can be grown under various biotic and abiotic stress conditions. Through this platform, root and shoot phenotypes along with plant-pathogen interactions at high throughput can be easily monitored. Additionally, this platform provides the base for simultaneous characterization of different genotypes at physiological, biochemical and molecular levels. Large scale use of nitrogen fertilizer has led to various adverse effects on the environment, including loss of biodiversity, pollution of water, reduced crop productivity, and global climate change. There are various microfluidic sensors available which can measure nitrate in soils and quantify nutrient uptake of plants from surrounding environments in a real-time manner. Through the techniques available to measure availability of plant nutrients in soils, it is possible to use fertilizers efficiently, thereby leading to advancement of sustainable agriculture and environment.

Keywords: MEMS; Agriculture; Soil sensors; Environment sensors

Introduction

In 1986, the Micro Electro Mechanical System (MEMS) was first presented. From that time onwards, billions of devices were manufactured and marketed across the globe. Today, multiple devices use MEMS technology such as inkjet printer (printer heads), accelerometers and gyroscopes (modern car airbags, cell phones, drones, game controllers, digital cameras, gadgets, among others), microphones, pressure sensors, media projectors, bio-MEMS application in biomedical transducers health care (Lab-on-Chip) etc. It can be deduced from these examples, consumer goods, material science, electronics, that automotive, and health are the focus areas for MEMS. Also, in agriculture MEMS is used as a supplementary technology (such as drones used to monitor crop growth). However, with the idea of precision agriculture (PA) which states that fields should be managed by zones instead of whole fields to increase profitability and the Internet-of-Things (IOT) has the capability to transform the world we live in; for communication, increasing use of MEMS devices in agriculture will be seen However, the application of technology like IoT in agriculture could have the greatest impact. MEMS will form a significant component of the new information age. MEMS market is forecasted to almost double from $11 billion in year 2014 to $21 billion in 2020 (2-digit annual growth, Figure 1 [1].

Due to availability of better bio-medical, bio-chemical sensors and energy harvesters, MEMS market is forecasted to grow. Apart from other types of MEMS devices, the demand for effective farming and surge in use of IoT devices in agriculture, can lead to development of agriculture-exclusive MEMS sensors.

Main Parameters Used in Agriculture

For ease of understanding, the primary agricultural parameters were grouped into agricultural conditions, which includes environment and soil and agricultural products, which include livestock.

Environment

The group of parameters mentioned above are not exclusive to agriculture. For instance, air temperature and humidity form a significant part of industrial control system and human comfort. Some other parameters include wind directions, velocity and solar radiations. From the whole spectrum of solar radiation, only the most important light sensor (photosynthetically Active Radiations-PAR) will be addressed.

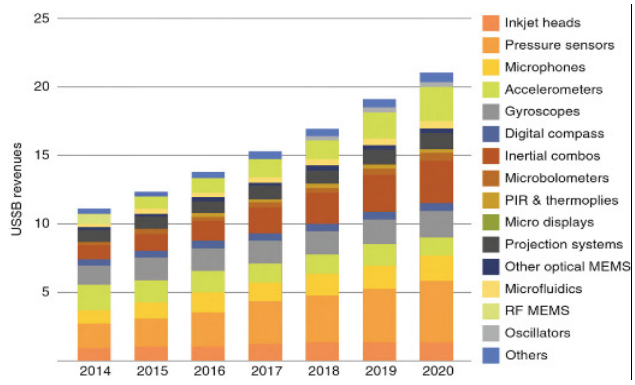

Figure 1: MEMS Sensor market forecast: 2014-2020 value (in B$, adapted from yole Development, April 2015) [1].

MEMS humidity sensor: Presently, majority of humidity sensors have built in electronic system for calibration, temperature compensation and can digitally read measured humidity and temperature values. A fine review of some miniaturized humidity

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sensors [2]. Today, the most popular commercial and industrial application for environment monitoring. Humidity sensors are of two types of sensors are resistive and capacitive humidity sensors. Although the resistive humidity sensors are easily fabrication and the simple readout circuits, the drawbacks of long recovery time and low stability limit their applications (Figure 2) [3,4]. Several advantages of the capacitive humidity sensors such as low power consumption, wide temperature range, and long-term stability, but the readout circuits may be complex for high precision applications [5-7].

Photosynthetically active radiation sensors (PAR): Measure the light needed for growth with the PAR sensor. Plants cannot grow without light in the Photosynthetically Active Radiation (PAR) spectrum. Together with CO_2 and water, PAR is the main factor necessary for photosynthesis. The more PAR a plant receives, the more potential that plant has for growth. Photosynthesis occurs best in the light wavelength range known as photosynthetically active radiation. Photosynthesis process acquire light energy in the optimal range of 400-700 nm (Figure 3) [8]. Multiple photodiodes such as selenium and cadmium sulfide, lead sulfide, silicion (Si), lead selenide and gallium arsenide phosphide (GaAsP) etc. can be used to measure light in the visible range. Amongst these photodiodes, Si (e.g., S1087 Si photodiode [9] and GaAsP are the most valuable. L1-CORE quantum sensor (L1-190 SA or SB) measures photosynthetic active radiation, uses Si photodiode (blue enhanced). Optical fibre is present in all PAR sensors. PAR sensors are developed at low cost.

Measuring soil temperature and moisture using MEMS sensor: The exchange of water and heat energy between the land surface and the atmosphere is controlled by soil moisture and temperature through evaporation and plant transportation. Consequently, an important role is played by soil temperature and moisture in building of weather patterns and the production of precipitation and irrigation. Micromachined MEMS cantilever beams containing a water sensitive nano-polymer and an on-chip piezo resistive temperature sensor form the temperature and moisture MEMS sensors (Figure 4) [10].

MEMS solar radiation sensor: In order to detect photosynthetic active radiation, Si (or GaASP) photodiode with a Fabry-Perrot filter can be made in the range of 400-700 nm or a wider spectrum [11,12].

Soil

Soil moisture content and electrical conductivity are two of the two most important parameters are used in agriculture. There are two major soil Nowadays, soil pH is used more often as a parameter for measuring crop productivity and also used as a tool to identify areas where adequate fertilization has occurred. Single (or dual) probe heat-pulse method (SPHP or DPHP) is one of the methods used for measuring soil volumetric moisture content. Apart from soil moisture, these methods help to read other parameters such as soil temperature, water flux, soil thermal properties (thermal conductivity, thermal diffusivity and specific heat capacity) [13-16]. Electrical conductivity readings can also be read from the same probe (needle like and conductive) [17,18]. Ion-sensitive field effect transistor (ISFET) is normally used for measuring pH in soil. ISFET is made up of an ion-sensitive electrode (in the case of pH) and a FET.

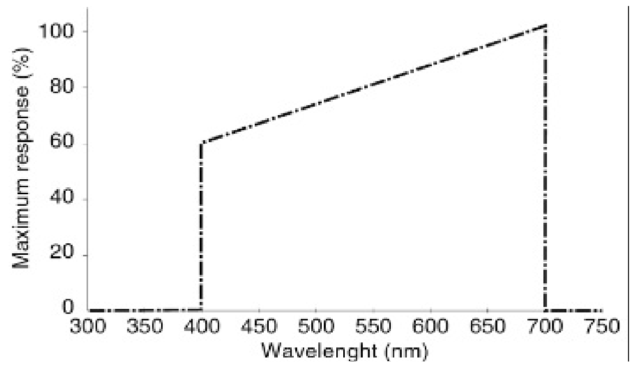

Figure 3: PAR sensor response.

Figure 4: Soil moisture sensor.

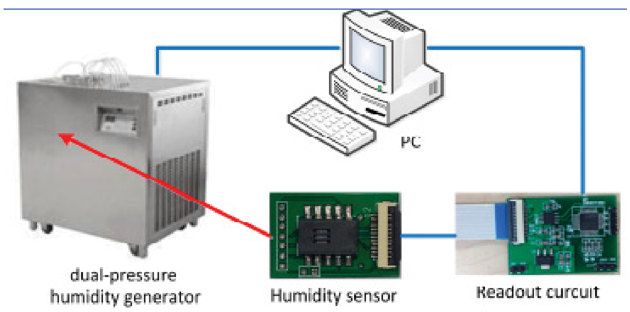

Figure 2: The system of the humidity sensor for static measurement [7].

MEMS soil sensors: MEMS sensors have been developed by some researchers in order to determine soil moisture. In one of the early examples, CMOS devices were built into needles [18] in the order of millimetres, but it cannot be considered as an excellent MEMS device. Some scientists use sensors or methods used for measuring air humidity to measure soil moisture (with different encapsulation-porous medium) [10]. These devices measure soil moisture tension (usually measured with a testiometer) and not soil moisture content. Also, [19] have developed a sensor based on poly (3,4-ethylenedioxythiophene), polystyrene sulfonate (PEDOT-PSS) conductive polymer (Figure 5).

Agricultural crops

In order to achieve optimal plant growth and quantity, plant growers can use automated plant response monitoring which leads to improved climate regulation [20]. For example, sap flow gauges to measure sap flow [21], displacement transducers to measure stem diameter fluctuations also applied to fruit width [22] and detect surface moisture of leaves. There are few MEMS devices based on the inherent dimensions of the device used for the parameters to be measured. These devices measure sap flow (or stem water potential) and leaf wetness.

Stem/fruit width: In order to measure stem or fruit width, sensors measure the mechanical displacement occurred at a cuff placed around stem (E.g. Ecomatik Diameter Dendrometer small-DDS) shown in Figure 5 or the fruit (e.g. Dinamax plant growth sensors [23], shown in Figures 6 and 7. Usually, linear variable, differential transformer (LVDT) is used by these devices for measuring displacements leading to stem or fruit width. A device which measures stem width based on strain gauges [24].

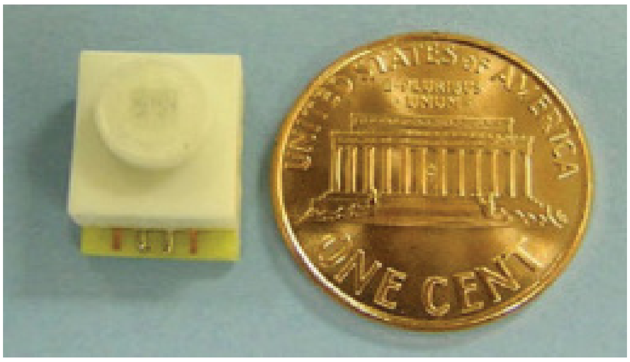

Figure 5: Conductive polymer based on moisture microsensor [19].

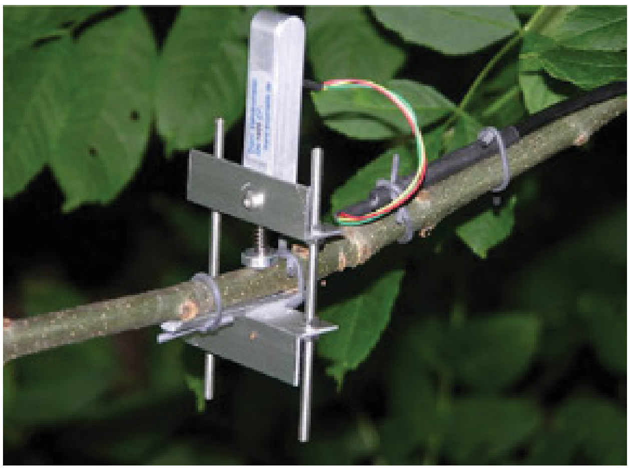

Figure 6: Ecomatik diameter dendrometer.

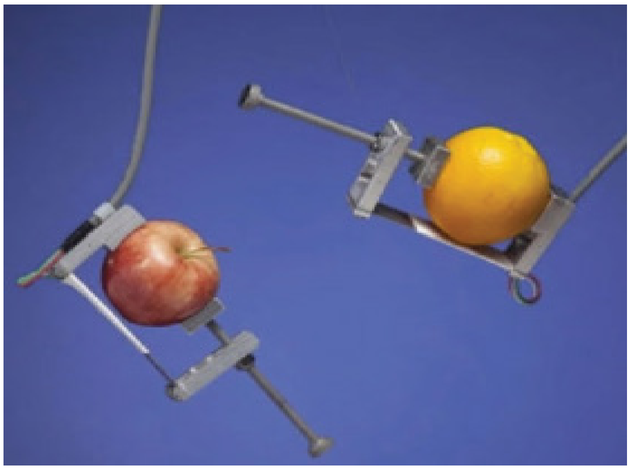

Figure 7: The Dinamax plant growth sensor.

MEMS body temperature: Generally, the body temperature parameter in MEMS device used in livestock is part of multisensory device. This device, which is used for estrus detection. An implantable device has been developed to measure cellulose content in rumen [25].

Other MEMS Devices

Some new MEMS devices have been developed recently in the agriculture area. One such device is a complete weather monitoring system, while other device studies mechanism for root growth.

MEMS to monitor root growth

In order to quantitatively evaluate physical interaction between root and soil, a silicon-based microchannel device combined with force displacement sensors have been developed which simulates a barrier in soil.

MEMS microchip based capillary electrophoresis sensor

Plants provide a defense mechanism against various pathogens or biotic stress through various strategies. Plants respond to fungal invasion by activating defense responses associated with accumulation of pathogenesis related proteins (PRs), which prevent pathogen infection. CE is an important separation and detection of a wide range of analytes ranging from heavy metal ions to detection of phenolic acid in extracts from plant and samples. Analysis of PRs proteins through micro electromechanical systems (MEMS) based capillary electrophoresis (CE) tool in taramira (*Eruca sativa* Mill.) cultivars to pathogen was investigated in 15 and 25 days old plants [26].

Conclusion

This review cited multiple MEMS device used in the agricultural domain. These devices were used as humidity sensor, wind, speed, velocity sensor and solar radiation sensor. Also, the use of MEMS device to sense soil moisture was presented. MEMS devices are used for various purpose in agriculture such as to determine water potential in stem and leaves moisture sensor. Measurement of body temperature is an important parameter when studying livestock stress. It can be deduced from various MEMS device presented in this paper that these devices can be promisingly applied to sense physical parameters commonly used in agriculture, but more work needs to be performed in order to refine them and use their full potential. Currently, most of the MEMS work in agriculture is confined to laboratories. However, transitioning to in situ application seems feasible. Some of the major advantages of using MEMS devices are: small size, large scale economic production, low power consumption and built in electronics (for auto-calibration, digital compensation, self-testing and digital communications).

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