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3D PRINTED MICROFLUIDICS FOR AGRICULTURAL NUTRIENT DETECTION AND ITS APPLICATIONS TOWARDS LAB-ON-CHIP

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Abstract:

The rapid development of microfluidics technology has promoted innovations in healthcare, biomedical, point of care, food, agriculture, and material science. Precise manipulations of fluids within microscale utilize the same platform for both sample preparation and detection. Soil and plant nutrient management is critical to achieve for agriculture and environmental sustainability. Precision agriculture has recently attracted considerable attention, aiming at realizing efficient and economic nutrient management in crop fields to reduce environmental impacts and increase agricultural productivity and growth. Microfluidics has the potential to influence subject areas from chemical synthesis, biological analysis, optics, and information technology. In this paper prototype and review on miniaturized device for plant and soil study with 3D printed microfluidics sensors for monitoring nutrient to support sustainable agriculture has given. Such integration promises in the future precision agriculture and towards Lab-on-Chip (LOC) devices.

Keywords: Microfluidics, Nutrient sensors, Lab-on-Chip, 3D printing

I. Introduction:

The soil macronutrients, nitrogen (N), phosphorus (P) and potassium (K) are essential for crop growth. The application of N, P and K fertilizers has contributed to increase in yields of agricultural crops; however, excessive use of these fertilizers lead to a source of contamination of surface, ground water and have the major impact on the environment and human health. Precision agriculture is soil and crop management system that measures variability in soil and plant properties to optimize input such as fertilizer based on information obtained from field location [1].

Soil nutrient detection is a management tool that can help accurately to determine the available nutrient status of soil and guide the efficient use of fertilizers. Conventional soil testing methods based on manual or mechanical soil sampling, colorimetric or atomic emission spectroscopy are costly and time consuming. Accurate monitoring of soil nutrient has been limited by the relatively long turn-around time of laboratory analysis. Therefore, quantifying soil nitrate variability requires a fast on-site measurement at high sampling intensity [2].

The time and cost required for the intensive sampling needed in precision agriculture, when using conventional sampling and analysis techniques may be impractical. In this situation on site and miniaturized real time sensors could be useful than manual or laboratory methods. The microfluidics Lab -On –a- Chip (LOC), technology implies those techniques that perform various laboratory operations on a miniaturized scale. LOC is a device, which is capable of scaling the single or multiple laboratory functions down to chip-format. The size of this chip ranges from millimeter to few square centimeters. LOC is the integration of fluidics, electronics, optics and sensors [3].

With recent advances in sensor technology, various techniques have developed to quantify variability in soil nutrients. This paper describes 3D printed microfluidics sensor development and related technologies that are applicable to the detection of soil nutrients in real time for precision agriculture. First various analytical techniques commonly used in soil N, P and K analysis and sensing principle of related laboratory instrument are discussed. Second various types of soil macronutrient sensors reviewed. This paper aims to give a brief overview of most recent development in the field of 3D printed microfluidics for use in the agricultural applications. As a case study, the article discusses an experimentation for 3D printing microfluidics and the related design issue [4].

II. Current Laboratory Methods of Soil Nutrient Analysis:

In standard soil testing laboratory to measure nutrients (N, P and K) various automatic analyzers and extracting solutions have used [5].

III. Nutrient Sensing:

In literature broad review of various types of sensors to measure mechanical, physical and chemical soil properties have taken. In this, reviews focus on sensor for measuring macronutrients (N, P and K) and PH levels in soil. Many sensing techniques are available most of the soil nutrient sensors described in the literature involve one of two measurement methods:

i. Optical sensing that uses reflectance spectroscopy to detect the level of energy absorbed reflected by soil particles and nutrient ions.

ii. Electrochemical sensing that uses ion-selective electrodes, which generates a voltage or current output in response to the activity of selected ions.

Many authors have reported correlation between reflectance techniques and standard methods when using diffuse reflectance spectroscopy in conjunction with various calibration and signal processing methods to estimate soil physical properties. However, result have not satisfactory for soil macronutrients in those ranges where fertilizer application decision must be made for N, P and K. Reflectance spectroscopy can respond to total nutrient concentration in soil, calibration measured by standard soil test is challenge. In general, laboratory tests have shown to be feasible to determine macronutrients in moist soil or soil extracts due to liner relationship to standard methods [6].

Difficulties encountered with current system included a slower than desired and not completely reliable extraction process, electrodes of limited durability and need for frequent recalibration due to signal drift. Effort towards improved extraction systems electrodes and auto-calibration process could increase the potential of such systems. On-site, rapid measurement of soil nutrients is an ideal approach due to variable applications of agricultural fertilizers. Several reviews reported on real- time on the go soil nutrient sensing using soil samplers and ion selective electrodes for sensing nitrate and PH in soil [7].

IV. 3D Printing of Microfluidics Lab-on-a Chip Nutrient Sensing:

Fabrication of Microfluidics devices and 3D printing of macro-mechanical components are two different things, recently brought together by polymers. In early days, glass or silica was only the material for fabrication. Now a day's most of the microfluidics devices are made of polymers like polydimethylsiloxane (PDMS) using soft lithography and various other techniques [3].

Simultaneously 3D printing is becoming a popular technique for macro and micro scale fabrication with more accuracy level at micro and Nano meter scales. This had led researchers to explore it for fabrication of polymers at micro-scale for application like MEMS, Microfluidics lab-on-a chip etc... 3D printing will soon become the future of microfluidics fabrication and bring the microfluidics fabrication out of the clean rooms to maker-spaces. The 3D printing is popular due to quick and simple computer-aided design (CAD) to manufacturing. The 3D printing process includes creating CAD model to be printed, slicing the CAD model using slicing software for additive layer-by-layer manufacturing and creating printing [8].

Fabrication Methods:

The fabrication of microfluidics structure is dependent on the compatibility of the specific fabrication process with the material used for the fabrication [9]. Based on the materials used for fabrication of microfluidics, the fabrications methods can be classified as:

- Conventional Methods
- Modern Methods
- Additive Manufacturing

For the first category, conventional method include deposition, lithography and etching among which lithography is main fabrication techniques uses glass and silica. With this method, only the fabrication of 2D channels is possible. In modern method polymers like PDMS, polyethylene glycol (PEG) used for microfluidics fabrication with soft lithography techniques. However, fabricating 3D structure, varying channel length depth, 3D junction, values, mixers and high aspect ratio structure are still difficult with use of soft lithography. The major limitation of conventional and modern method is the need for costly equipment and also cost of both methods reaches very high because of expensive clean room requirements and need of highly precise and specialized equipment's which make fabrication much expensive and difficult [10] .

The third category additive manufacturing which include 3D printing. The CAD model of the part to be produced is input to slicing software of the 3D printer that converts the CAD file into layer-by-layer toolpath and fabricate the part accordingly. 3D printing is not only low cost, but it is very fast and flexible for microfluidics chip fabrication. 3D printers commonly used for microfluidics are Fused deposition modeling (FDM), Stereolithography (SLA), Digital Light Processing (DLP), Selective Laser Sintering (SLS), Selective laser melting (SLM), Laminated object manufacturing (LOM), Digital Beam Melting (EBM) [11].

V. Case Study:

5.1 Experimental Method:

3D printed microfluidics mixer prototype, which mix two input taken as case study. The CAD file designed with CATIA V5 and Cura 2.1 slicing software used for gcode formation. The Ultimaker 2+ 3D printer with 0.4 Nozzle, PLA material (2.85 mm diameter) and 0.1 layer height (Fig.1). Following characteristic of microfluidics chips observed.

Channel diameter – 1500 µM, Chip Width-73.24mm, Channel Height-1.98mm.

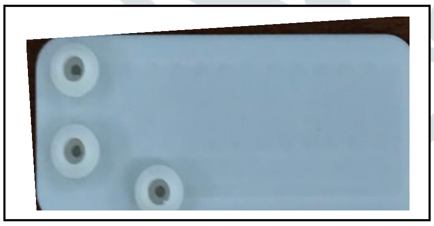

Fig. 1. A Prototype of 3D printed microfluidics mixer

In Proposed system, optical detection method combined with smartphone for nutrient detection (Fig. 1). Capable of 3D fabrication flexibility and smartphone compatibility, this work presents a novel detection strategy for precision agricultural.

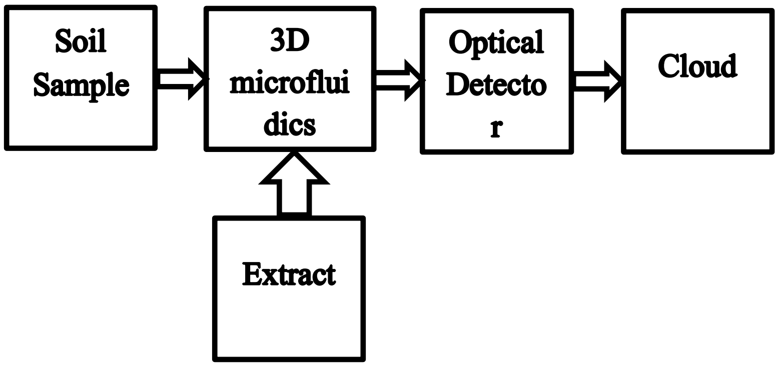

Fig 2. Proposed Nutrient Detection System

VI. Future Trends:

Our research in the field and the investigative of the state-of-the art study that 3D printed microfluidics LOC for nutrient detection have great potential to revolutionize the agriculture field and possess capability to give boost to the effective use of fertilizers in precision agriculture sector. Moreover, this technology can prove to be useful for finding novel way to nutrient detection in precision agriculture.

VII. Conclusions:

In this paper, we have reviewed and presented the development of 3D printed microfluidics a lab-on-a-chip device for soil nutrient sensing.

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