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An Experimental Study using Smart Phone for Transient Fluid Testing Based on Image Analysis and Modelling for Capillary Driven Microfluidics Towards Lab-on-Chip Applications in Nutrient Detection

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Abstract: The rapid development of microfluidics technology has promoted innovations and research in healthcare, point of care, biosensor, food and agriculture. Precise manipulations of fluids within microscale utilize the same platform for both sample preparation and detection. Capillary microfluidics can deliver liquids without peripheral equipment by surface tension effect. Soil and plant nutrient management is essential for agriculture and environmental sustainability. Smartphone Technology has now penetrated every aspect of modern life and is ubiquitous. Smartphone have been used as point of care testing device. A similar approach can be extended in precision agriculture to plant sap nutrient analysis. This paper assesses the viability of utilizing smartphones in nutrient analysis with capillary microfluidics. In the present work a technique for capillary rise measurement based on smartphone camera is developed. The technique consists of measuring the displacement experienced by video analysis with time. The technique was tested experimentally validating the experiment with numerical simulation. The results presented show a good fit between experimental measurements and the expected value. The technique in general presents a good level of accuracy. Such integration promises in the future precision agriculture and towards Lab-on-Chip (LOC) devices.

Keywords: Microfluidics, Lab-on-Chip, Point- of-care, Nutrient sensors, precision agriculture

I. Introduction

The use of sensor technology in agriculture is mainly focused on soil, water and nutrient analysis. The soil macronutrients like Nitrogen (N), Phosphorus (P) and Potassium (K) are essential for crop growth [1]. In precision agriculture soil and plant testing is a valuable tool for determining the fertilizer needs, growth and maximizing the fertilizer efficiency. Soil test is especially useful early in the growing season when plants are too small to collect tissue samples. Plant tissue test for macronutrients Nitrogen (N), Phosphorus (P) and Potassium (K) levels during the growing season provides information for analysing problems. It is preferred than soil test as the results of which can change quickly by rain or irrigation. Plant sap testing offers advantages over the conventional dry tissue testing being carried out in laboratories. Aside from the lower cost it requires, plant sap testing can be easily done in the field as point of care (POC). The results can be obtained quickly which is important in making decisions [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 point of care and miniaturized real time sensors could be more useful than manual or laboratory methods [3]. The microfluidics Lab -On –a- Chip (LOC), technology implies those techniques that perform various laboratory operations on a miniaturized scale [4]. LOC is a device, which can scale the single or multiple laboratory functions down to chip-format [5]. The size of this chip ranges from millimeter to few square centimeters [6]. LOC is the integration of fluidics, electronics, optics and sensors. With recent advances in sensor technology, various techniques have developed to quantify variability in soil nutrients [7].

Plant Sap is essentially water, mineral and nutrients. The channel which carries water and nutrients from roots to the leaf of are known as xylem and phloem. This process is capillary action in plant [8]. Recently capillary driven flow microfluidics has emerged as an attractive microfluidics-based technology and simple to use. The capabilities of capillary driven flow devices have not been fully exploited in developing POC analysis, especially for plant sap analysis in precision agriculture. Capillary driven flow microfluidics work on the principle of capillary action that allows the movement of fluids in capillaries or microchannels passively [9].

The widespread availability of smartphones and the capabilities they offer in terms of computation and imaging will be transformative to the deployment of lab-on -chip in agriculture [10].

In this context there is a need to develop real time and portable analysis and quantification devices. The contribution offered by the current work is experimental study of capillary action using smartphone camera and its video analysis and modelling with COMSOL Multiphysics (5.6) software.

II. Capillary Action

Capillary action or capillarity is the tendency of a liquid to move up against gravity when confined within a narrow tube (capillary). Capillarity occurs due to Surface tension, adhesion and cohesion. Jurin`s law in case of capillary rise states that,

$$h = 2\gamma\cos\theta/gr\rho \text{ ……………………….(1)}$$

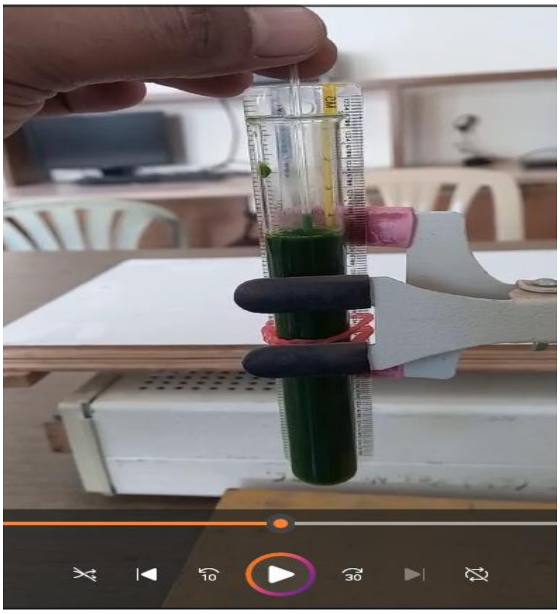
Where, h is the height of liquid column
γ is the liquid -air surface tension
θ is the contact angle between capillary wall and water
g is the acceleration due to gravity
ρ is the density of liquid
r is the radius of capillary tube
Height of fluid is function of radius and the contact angle since the other terms are constants [11][12].

III.Experimental

A. Overall System Design

In this section quantitatively monitored capillary rise level of plant sap and water, we propose a smartphone-based system. To illustrate how capillary rises, we have used Samsung Galaxy A-31 with 48-megapixel camera. Borosil capillary tubes. For water level measuring used glass length scale (Fig.2a-b).

(a)



(b)

Fig. 1 (a) image of video analysis of capillary rise time for Spinach Plant sap (b) image of video analysis of capillary rise time for Sugar cane sap

A. COMSOL Simulation:

COMSOL Multiphysics (5.6) software was used for Capillary flow experiments in a microchannel with width of channel 0.91mm and length 10mm as shown in Fig.2. Simulation of capillary model for water is done in two dimensions as shown in Fig. 3.

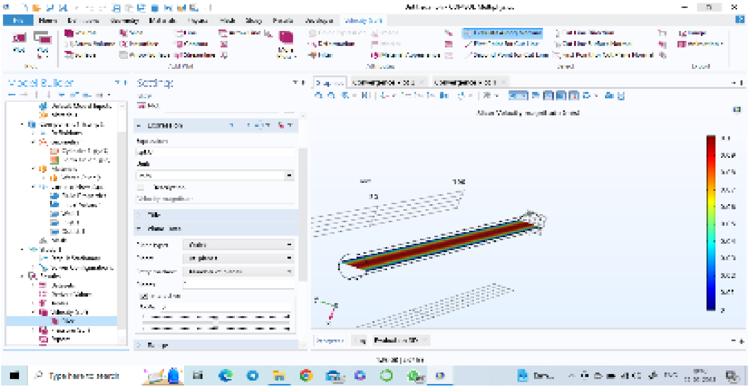


Fig. 2 Capillary 0.91mm model design in COMSOL 5.6 for Water

IV.Results and Discussion

The capillary rise time and rise level were observed with different diameters of capillary for Spinach sap, Sugar cane sap and Water. As shown in Tabel 1 and Tabel 2. Fig. 4 (a) shows the relation between capillary diameter and capillary rise time. Also, fig 4 (b) shows the relation between capillary diameter and capillary rise level.

Table 1 Capillary diameter and Rise time for water

Capillary Diameter in mm	Rise time in Second
0.91	0.01
1	0.01
1.8	0.01
2.5	0.02

Table 2 Capillary diameter Rise level for Water

Capillary Diameter in mm	Rise Level in mm
0.91	10
1	5
1.8	9
2.5	5

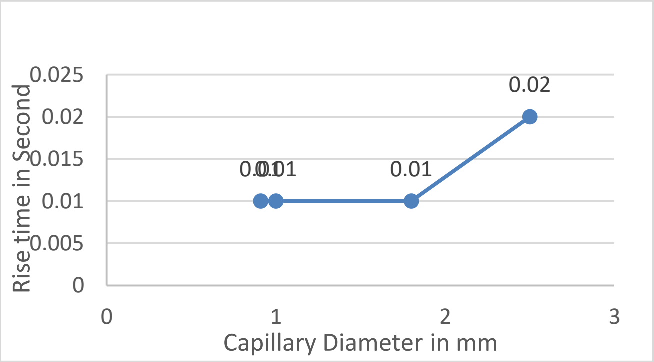
Table 3 Capillary diameter and Rise time for Spinach sap

Capillary Diameter in mm	Rise time in Second
0.91	0.01
1.8	0.02
2.5	0.02

Table 4 Capillary diameter Rise level for Spinach Sap

Capillary Diameter in mm	Rise Level in mm
0.91	11
1.8	8
2.5	6

(a)



(b)

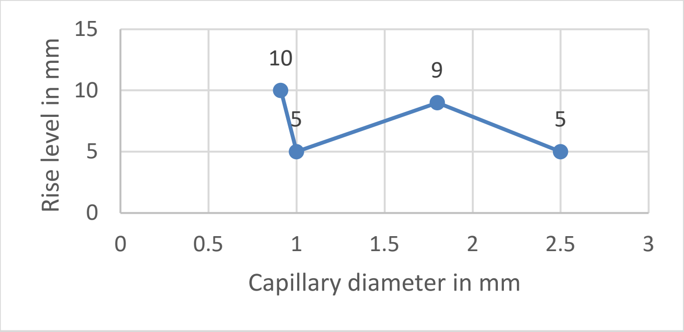
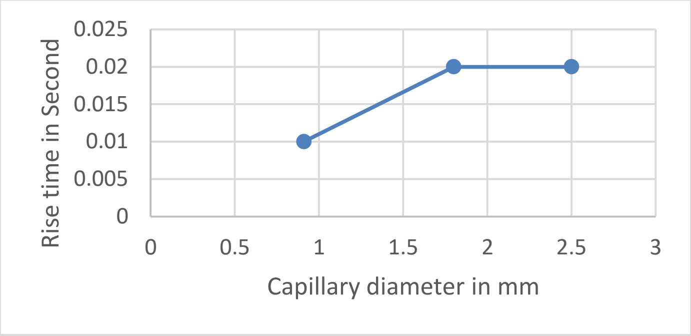


Fig. 4 (a) Capillary rise time response of different capillary diameter for Water (b) Capillary rise level response of different capillary diameter for Water

(a)



(b)

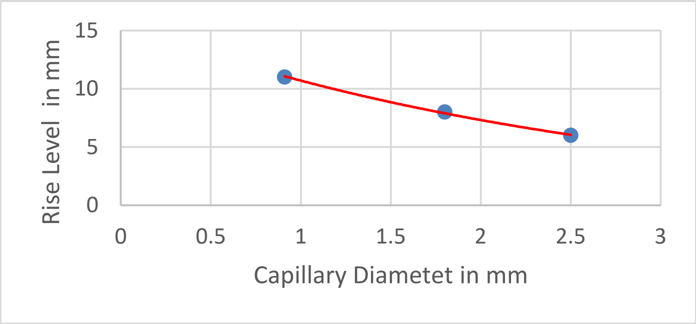


Fig. 4 (a) Capillary rise time response of different capillary diameter for Spinach sap (b) Capillary rise level response of different capillary diameter for Spinach sap

By putting value in Equation (1), we got the relation between capillary height and radius for Spinach sap capillary diameter 1.8mm as:

$$h= 0.0728*\mathrm{Cos}\,(0)/9.81*0.9*1000*10^{3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

$$= 6.67\mathrm{mm}$$

V. Conclusion and outlook

In this paper, we have demonstrated and simulated a method which can be used for measuring capillary rise level and time by capillary action method using smart phone. It shows relationships between capillary rise level and time with respect to capillary diameter. 3D printing features will provide advantages to control capillary flows for autonomous retention actuation of microfluidics devices. This study of capillary action can be useful for plant sap analysis as microfluidics lab on chip in precision agriculture. Our simple model assesses the viability of utilizing smartphones in point of care applications in precision agriculture.

Conflicts of interest

There are no conflicts of interest to declare.

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References

[1] Lin, J.; Wang, M.; Zhang, M.; Zhang, Y.; Chen, L. Electrochemical Sensors for Soil Nutrient Detection: Opportunity and Challenge, Comput. Technol. Agric. 2008, 2, 1349–1353.

[2] Esteves Eduardo, Guilherme Locatelli, Neus Alcon Bou, and Rhuanito Soranz Ferrarezi, "Sap Analysis: A Powerful Tool for Monitoring Plant Nutrition", Horticulturae 7, no. 11: 426. https://doi.org/10.3390/horticulturae7110426.

[3] Shinde S. K., Pol S. R., Buchade P. B., Dongare M. L., Shaligram A. D.,"3D Printed Microfluidics For Agricultural Nutrient Detection and Its Applications Towards Lab-On-Chip", JETIR, April 2023, Volume 10, Issue 4,pp 40-44.

[4] Amreen, K. S., Stefan Haeberlea and Roland Zengerleab , "Microfluidic platforms for lab-on-a-chip applications" 2007 Lab on a Chip, Royal Soceity of Chemistry.

[5] Shinde S. K., Pol S. R., Jadhav B.T., Buchade P. B, Dongare M. L., Shaligram A. D., "Applications Of Microfluidics For Nutrient Detection Towards Lab-On-Chip", 2023, Conference: Interdisciplinary Approach in Chemical and Allied Science (IACAS-2023), ISBN –978-93-5890-998-2.

[6] M. Smolka, Puchberger-Enengl, M. Bipoun A. Klasa, M. Kiczkajlo,W. S miechowski, P. Sowinski C. Krutzler , F. Keplinger, M. J. Vellekoop, "A mobile lab-on-a-chip device for on-site soil nutrient analysis", Springer Precision Agric 2016 DOI 10.1007/s11119-016-9452-y.

[7] Zhen Xu, Xinran Wang, Robert J. Weber, *Fellow, IEEE*, Ratnesh Kumar, *Fellow, IEEE*, and Liang Dong, "Nutrient Sensing Using Chip Scale Electrophoresis and in Situ Soil Solution Extraction, IEEE SENSORS JOURNAL, VOL. 17, NO. 14, JULY 15, 2017.

[8] Mark Denny, "Tree hydraulics: how sap rises", European Journal of Physics, Volume 33, DOI 10.1088/0143-0807/33/1/003.

[9] Hassan Sammer-ul, Aamira Tariq, Zobia Noreen, Ahmed Donia, Syed Z. J. Zaidi, Habib Bokhari, and Xunli Zhang. 2020. "Capillary-Driven Flow Microfluidics Combined with Smartphone Detection: An Emerging Tool for Point-of-Care Diagnostics" *Diagnostics* 10,no.8:509.

[10] Erickson D, O'Dell D, Jiang L, Oncescu V, Gumus A, Lee S, Mancuso M, Mehta S. Smartphone technology can be transformative to the deployment of lab-on-chip diagnostics. Lab Chip. 2014 Sep 7;14(17):3159-64. doi: 10.1039/c4lc00142g. PMID: 24700127; PMCID: PMC4117816.

[11] G.S. Barozzia, D. Angelib , "A note on capillary rise in tubes ", 68th Conference of the Italian Thermal Machines Engineering Association, ATI 2013.

[12] Tamajit Mondal, Sayondeep Choudhury, Ayush Nag, "Transportation of water through capillary action to a certain height without electricity and comparison of the model with a tree", https://www.researchgate.net/publication/343602042.