THE EFFECTS OF THE NUMBERS OF FRINGING ELECTRIC FIELD (FEF) FINGERS ON THE PERFORMANCE OF SENSOR FOR WATER CONTENT IN SOIL

BY

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A dissertation submitted in fulfilment of the requirement for
the degree of Master of Science
(Manufacturing Engineering)

Kulliyyah of Engineering
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FEBRUARY 2015

ABSTRACT

The use of fringing electric field electrode as a moisture sensor in low frequency has some limitations such as the measured capacitance value was small and it is hard to differentiate the capacitance value for several moisture level because the capacitance value are so close. Therefore, understanding the effect of the fringing electric field physical design and it working frequency on measured capacitance is needed in order to design a good moisture sensor for automation of water irrigation system. This work focused on identifying the right numbers of fringing electric field electrode finger and operating frequency for optimization. The samples were prepared with five different electrodes which have 5 to 9 electrode fingers and tested with five different moisture level. The supplied signal was within 100 kHz to 2 MHz operating frequency and tested in the room temperature. From the experiment, 6 FEF fingers showed the better result among the other at 900 kHz. The capacitance level has better separation with insulator compared to without it. The work identified that there are two stages where capacitance value are measured and choose the slope where it representing the dielectric of water content as reference. But it requires calibration to set the slope based on the soil type.

ملخص البحث

استخدام تهديب القطب للحقل الكهربائي كجهاز استشعار للرطوبة في الترددات الكهربائية المنخفضة لديها بعض القيود مثل قيمة السعة المقاسة الصغيرة لأنه من الصعب التفريق بين قيمة السعة لعدة من مستويات الرطوبة لتقارب قيمة السعة . ولذلك، فهم تأثير التهديب الكهربائي والتصميم المادي الميداني، وكذلك وتيرة العمل على قياس السعة مطلوب لأجل تصميم أجهزة استشعار الرطوبة الجيدة لأنظمة مياه الري الاتوماتكية . وقد ركز هذا العمل على تحديد أعداد أقطاب تهديب الحقل الكهربائي وتردد التشغيل من أجل التحسين. وقد تم إعداد العينات مع خمسة أقطاب مختلفة التي لديها 5-9 أقطاب واختبارها مع خمسة مستويات للرطوبة. كانت إشارة الموردة خلال 100 كيلو هرتز إلى 2 ميغاهيرتز تردد التشغيل واختبارها في درجة حرارة الغرفة. علاوة على ذلك تم تنفيذ بعض التصاميم الإضافية من الدراسة الأولى لمزيد من التحسين. حدد العمل أن هناك مرحلتين حيث يتم قياس قيمة السعة واختيار المنحدر حيث تمثل عازلة من محتوى الماء كمرجع. لكنها سوف تتطلب معايرة لضبط المنحدر القائم على نوع التربة.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science (Manufacturing Engineering).

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DECLARATION

I hereby declare that this thesis is the result of my own investigations except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at International Islamic University Malaysia or other institutions.

Mohd Farizul Bin Azman

Signature……………………. Date…………………

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ACKNOWLEDGEMENTS

In the name of Allah, The Most Gracious and The Most Merciful. Thankful to Allah, that has gives me strength, healthy body and mind to complete this thesis. Special thanks to my supervisors, Dr Hadi Purwanto for his invaluable advice, guidance, criticism, and their constructive comments, without which I may not meet requirements of Master of Science (Manufacturing Engineering). I am also indebted to my employer, for providing the financial support through MSTAR program. Last but not least to my beloved parents, wife and children for giving a support and understanding while I working hard to complete the work.

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LIST OF ABBREVIATIONS

BD	Bulk Density
CTE	Coefficient of Thermal Expansion
DI Water	Distilled Water
DRC	Design Rule Check
ED	Electrodeposited
FEF	Fringing Electric Field
GND	Ground
IEC	International Electrotechnical Commission
MAFC	Malaysian Agrifood Corporation
MUT	Material Under Test
NDT	Non-Destructive Test
NEMA	National Electrical Manufacturers Association
PCB	Printed Circuit Board
PN	Part Numbers
PPC	Parallel Plate Capacitor
PTFE	Polytetrafluoroethylene
T_d	Temperature of Decomposition
T_g	Glass Transition Temperature
UL	Underwriters Laboratories
USDA	United State Department of Agriculture
VWC	Volumetric Water Content

LIST OF SYMBOLS

A	Ampere
cm^3	Cubic centimetre
°C	Degree Celsius
GHz	Giga hertz
g/cm^{-3}	Gram per cubic centimetre
g/m^2	Gram per square metre
Hz	Hertz
MΩ	Mega Ohm
MPa	Mega Pascal
mm	Millimetre
µF	Micro Farad
µm	Micrometre
Oz	Ounce
Oz/ft^2	Ounce per square foot
%	Percent
cm^2/g	Square centimetre per gram
V	Volt
VWC	Volumetric Water Content

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

In agricultural, plant need to be protected from unfavorable climate condition such as wind, cold, extreme temperature, excessive radiation, precipitation, insect and diseases (Alexandra & Jose , 2005). Recently, there are a lot of farmer use green house to create such controlled environment. To record the climate condition, several sensors are used to collect the data such as temperature sensor, ambient sensor, chemical sensor and moisture sensor. A modern farmer should analyze the collected data to make decision whether to add fertilizer, water and others. There is a need to have an accurate sensor to avoid a wrong data that finally will damage the plant from growing properly. This work will study the moisture sensor design using capacitive effect of fringing electric filed (FEF) type electrode for non-destructive test (NDT) application.

1.2 PROBLEM STATEMENT AND ITS SIGNIFICANCE

The output from FEF electrode sensor is very small (in micro farad with 1A and 1V LCR meter setup). The value is so small and makes it hard to differentiate several moisture level data in capacitance value. Furthermore, the electrode are printed on printed circuit board (PCB) that can absorb some amount of moisture that can affect the reading of the capacitance value that reflex to the moisture level in soil. The challenge of this study is to design the sensor with enough capacitance value to clearly differentiate the moisture level and to find a method that able to prevent moisture entering the PCB material. The material should have a strong structure to make it strong enough to be inserted into soil, less water absorption rate, low cost and very low wrapping ratio. For this purpose, a better design of PCB stack-up planning, copper distribution and fabrication process should be investigated. And the soil preparation method should be defined to ensure the target moisture level of soil can be prepared before tested to have an accurate measurement.

1.3 RESEARCH OBJECTIVES

The main objective of this research is to design a prototype of FEF sensor and preparing the test soil to:

1) Investigate the effect of the numbers of FEF fingers on the measured capacitance value in soil.
2) Investigate the effect of operation frequency on the measured capacitance value in soil.
3) Examine the effect of covered FEF element on the measured capacitance value in soil.

1.4 RESEARCH METHODOLOGY

The first step deals with the physical design of FEF element. Based on the given outline, the electrode width, separation and length is selected to have an optimum capacitance value. From the literature study, the capacitance value will be higher when the electrode width and length are increase and the separations need to be reduced. The second step involves the consideration of PCB fabrication which involves the selection of material, stack-up design and copper distribution. Next step involves the preparation of soil with the target moisture level (in volumetric water

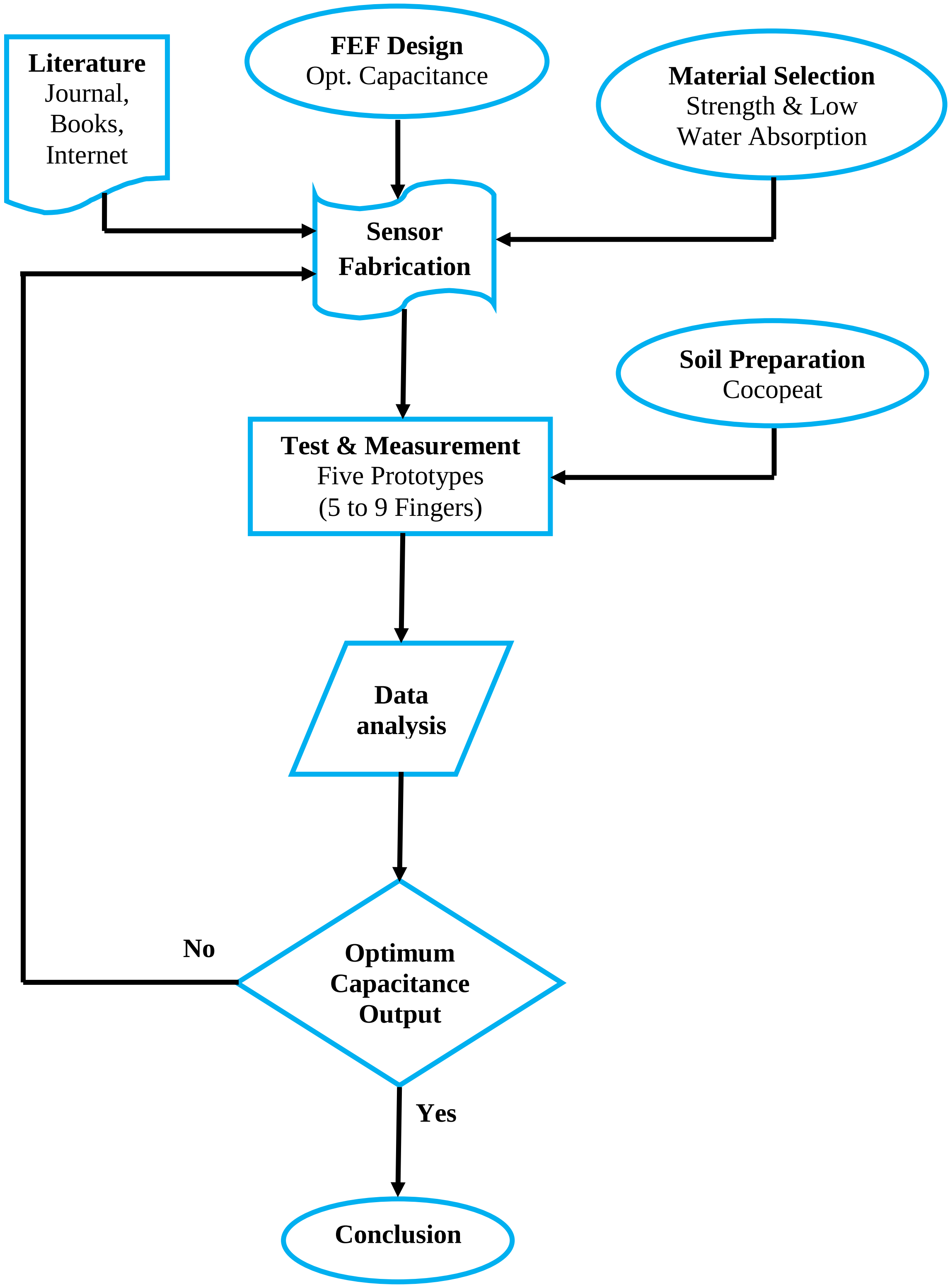


Figure 1.1: Research methodology flow chart.

content, VWC). Finally is the method of experiment that was designed to meet the objective. The flow chart of research methodology is shown in Figure 1.1.

1.5 SCOPE OF RESEARCH

This research is focusing on the investigation of the effect of FEF fingers and its operating frequency with the capacitance value of soil in room temperature. The electrode design of sensor is fabricated on the PCB platform using the Proto-Mat machine where the process does not involve chemical process to make the prototype board. It uses the milling process where the copper being cut off to make the electrode pattern on PCB. The study introduce the method of preparing soil with the target moisture level (0%, 20%, 30%, 40% and 100% VWC) and introduce the method of experiment to analyse the relation of frequency, moisture level and measured capacitance value compared to FEF finger design. The study also introduces some method to optimize the capacitance reading on the good prototype element sensor. Finally, the study introduces the function that generated from the experiment result that can be used to measure the water level of the particular soil type with the good prototype FEF element.

1.6 DISSERTATION OUTLINE

The dissertation is divided into five chapters. Chapter one is an introduction of moisture sensor that are used in the greenhouse to create a controlled environment and discussed on the problem of FEF type moisture sensor that lead to understanding the effect of some parameter on the measured capacitance value that representing the moisture level in soil. Chapter two elaborates the recent literature studies related to this research. Chapter three describes the methodology and procedures of this research. Chapter four discusses on the findings and analyzes the results obtained from the experiment. The detailed discussion is provided in this chapter. Chapter five concludes the findings and summarizes general conclusion and recommendation for future work based on the present findings.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Soil is an element that consists of solid (mineral and organic matter), liquid and gas that exist on the ground. The characteristic was distinguished from the inertial material due to the result of additions, losses, transfer and transformation of energy that has ability to support plan in nature (US Department of Agricultural [USDA], 1999). The soil has a different texture and structure base on the size of mixed particles. This factors effects the soil ability for water retention, absorption and radiation of energy, soil temperature, colour and textual properties. In order to measure soil moisture, the dielectric property of complex soil will be used. When the dielectric property is located in between two electrodes, a conventional parallel plate capacitor (PPC) is formed and the capacitance value can be measured. With this concept, the PPC is open up to provide one sided access to the material (soil) and becoming FEF type electrode as shown in Figure 2.1. This pattern will then fabricate on PCB that will be uses as a moisture sensor. In this chapter, will be discuss the literature study of the FEF type soil moisture sensor.

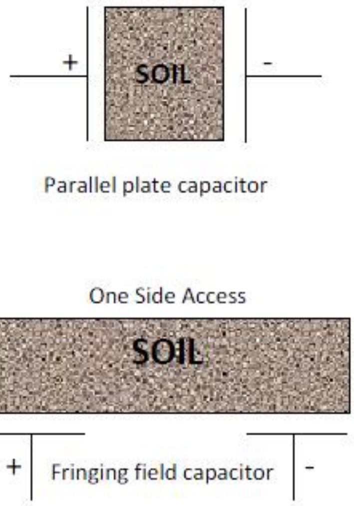


Figure 2.1: Transition from PPC to FEF Capacitor

2.2 PROPERTY OF SOIL

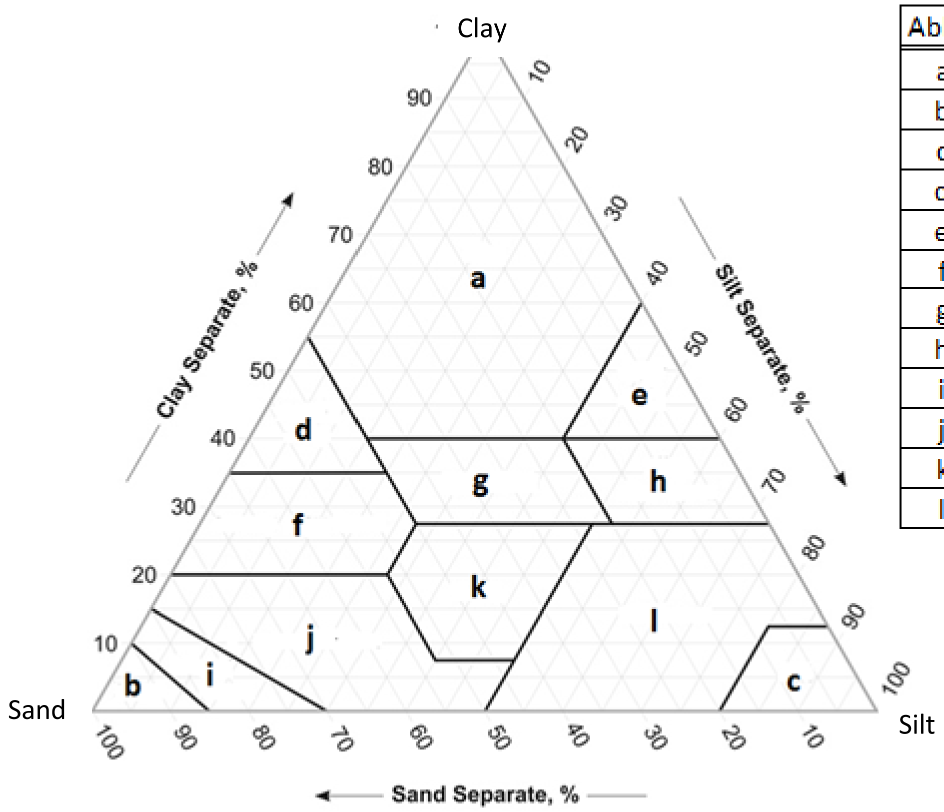
Soil structure is the mixture of several types of soil particles which determines the ability to retain the nutrient, gas and water which is important to sustain the plant life. Soil particle are classified into the soil class name based on the particle sizes and surface as mention in Table 2.1 (Flaschke & Trankler, 1999).

Table 2.1: Particle size classification

Soil Class Name	Particle Size	Specific Surface
Sand	2000 – 20 um	20 – 200 cm^2/g
Silt	20 – 2 um	2000 cm^2/g
Clay	< 2 um	20000 cm^2/g

The combination of those three particles with the weight percentage will create a different soil textural which determined the different type of soil. United State

Department of Agriculture (USDA) classified the soil texture based on the weight percentages as illustrated in triangle diagram shown in Figure 2.2 (USDA, 1987). Each of the corners is representing 100 percentage of sand, silt or clay. Each side of the triangle is divided into 10 percentage portions of sand, silt and clay. The bold lines show the divisions of 12 basic soil textural classes which represented by the small letter alphabets. The textural class of soil are determined by the percentage of each combination which made the total percentage of 100.



Abbr.	Soil Class Name
a	clay
b	sand
c	silt
d	sandy clay
e	silty clay
f	sandy clay loam
g	clay loam
h	silty clay loam
i	loamy sand
j	sandy loam
k	loam
l	silt loam

Figure 2.2: USDA Textural Classes

The complex mixture of soil as per discussion above can be quantified by bulk density (BD). BD is a volume of soil particle and the volume of pores among particle which is calculated by dry weight of soil divided by its volume. It is being express as gram per cubic centimetre (g/cm^{-3}). Bulk density is important because it reflects the soil ability for the structural support, nutrient and water retention, solute movement and soil aeration (Behari, 2005). Soil with loose and porous will have low bulk density while the soil that is compact will have high value of bulk density. The bulk density calculation will be used when preparing the target moisture level or the VWC of soil for experiment.

The knowledge of soil electrical properties such as conduction and displacement current is very important in this study. Conduction current in soil is controlled by the electrical conductivity (affected by soil salinity) and the strength of electric field. While the displacement current is controlled by the dielectric permittivity and the time rate change of the electric field (Curtis, 2001). This can be replaced by a complex relative dielectric permittivity

$$\varepsilon = \varepsilon' + j\,\varepsilon'' \qquad (2.1)$$

Soil moisture sensor based on the dielectric properties is not stable because of the influence of soil texture and structure. It has a great influence on the soil dielectric properties in low and medium frequency but almost no effect in the high frequency. To improve the accuracy of the sensor, the selection of the optimal frequency is important according to the soil texture (Xing, Zheng, Shen, Yang, & Sun, 2010).

Liquid water has a large dielectric constant about 81 and it is due to the molecule's ability to align its dipole when applied field. Anything that resists the molecular rotation and tight binding between soil particles will reduce the constant value. For example, the dielectric constant of soil mineral is in between ranges from 4 to 14 (Flaschke & Trankler, 1999). The dry soil has molecule that tightly bound. When water is added at a first stage, the molecules still tightly bounded but introduce a small increase in dielectric constant. As more water added, the molecules are farther away from particle surfaces and this increase the dielectric constant of soil. This shows the effect of soil texture influenced by water behaviour when added to the dry soil (Schmugge, 1983).

2.3 BASIC OF FRINGING ELECTRIC FIELD

From several studies conducted in the past (Li, Larson, Zyuzin, & Mamishev, 2004), (Li, Kato, Zyuzin, & Mamishev, 2004), it is understood that dielectric permittivity can represent the moisture level of soil. When the soil is dry, the dielectric constant values are smaller than the dielectric constant of the soil that is wet to its saturation. When the dielectric constant material are positioned between two plating panel, it will have the structure similar to that of a capacitor. Thus, we can measure the moisture level or volumetric water content of soil by measuring its capacitance values.

The operating principle of a FEF sensor can be understood in terms of the more conventional PPC, which is commonly used to measure dielectric properties of materials. Figure 2.1 shows a gradual transition from the PPC to a fringing field capacitor. The electrodes of the fringing field capacitor are open up to provide one sided access to material under test (MUT). The sensor can be fabricated on PCB and access to soil are one sided. Soil moisture would change the relative permittivity of the capacitor. Therefore, changes in VWC of the soil would change the capacitance of the sensor.

2.3.1 Fringing Electric Field Theory

FEF element design is based on one sided access capacitance design. The MUT are located on the sense side and based on its dielectric constant, the moisture level of the