Portable Electronic Embedded System ISFET Based pH Meter Test Kit for *Harumanis* Ripeness Detection

By

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LIST OF ABBREVIATIONS

ADC	Analog to Digital Converter
Ag/AgCl	Argentum/argentum cholide (silver/silver chloride)
Al	Aluminium
Al_2O_3	Aluminium oxide
BOE	Buffered oxide etch
BSC	Back side contact
C/V	Capacitance-voltage
Ca^{2+}	Calcium ion
CAD	Computer aided design
CG	Gas chromatography
ChemFET	Chemical modified field effect transistor
CMOS	Complementary metal oxide semiconductor
DAC	Digital to Analog Converter
DC	Direct Current
DIW	Deionised Water
DUT	Device Under Test
E-Nose	Electronic nose
FET	Field Effect Transistor
GUI	Graphical Using Interface
H^+	Hydrogen ions
Hg	Mercury
Hg_2Cl_2	Mercury chloride
I/V	Current-Voltage

IC	Integrated Circuit
IGFETs	Insulated Gate Field Effect Transistor
ISFET	Ionic Sensitive Field Effect Transistor
K^+	Kalium ion
LCD	Liquid crystal display
ISE	Ion selective electrodes
MIS	Metal insulator semiconductor
MNOS	Metal-nitride-oxide semiconductor
MOSFET	Metal oxide semiconductor field effect transistor
MR	Magnetic resonance
MRI	Magnetic resonance imaging
MS	Mass spectroscopy
mV	Millivolt
Na^+	Natrium ion
NIR	Near Infrared Reflectance
NMOS	n-channel MOSFET
O_2	Oxygen
PCB	Printed circuit board
pCO2	Power of carbon dioxide
PECVD	Plasma enhanced chemical vapor deposition
pH	Power of hydrogen
PIC	Peripheral interface controller
PMOS	p-channel MOSFET
PVD	physical vapor deposition
RE	Reference electrode

RMSECV	Root mean square error of cross validation
RS232	Standard serial communication interface
SCE	Saturated calomel electrode
SCS	Semiconductor characterization system
Si	Silicon
Si_3N_4	Silicon nitride
SiO_2	Silicon dioxide
SnO_2	Stanum oxide
SPA	Semiconductor parameter analyzer
SPICE	Simulation program with integrated circuit emphasis
SSC	Soluble solids content
Ta_2O_5	Tantalum oxide
TAT	Turn-around-time
TCAD	Technology Computer Aided Design

LIST OF SYMBOLS

Symbol	Description	Unit
I_D	Drain current	A
V_D	Drain voltage	V
V_G	Gate voltage	V
V_{TH}	Threshold voltage	V
b	Width of Area	µm
L	Length of Area	µm
μ_n	Electron mobility in a channel	
C_o	Oxide capacitance per unit area	F/m^2
V_{DSAT}	Drain voltage at saturation	V
S	Sensitivity	mV/pH

Alat Ujian Mudah Alih Sistem Terbenam Elektronik ISFET pH Meter untuk Pengesanan Keranuman Harumanis

ABSTRAK

Pengukuran pH dengan menggunakan Transistor Pengesan Medan Ion (ISFET) dan disepadukan dengan sistem terbenam elektronik adalah penting dalam aplikasi dan proses pertanian terutama sekali dalam proses-proses pengawalan keranuman buah, analisis pH dan kawalan penyakit buah. Projek penyelidikan ini ialah satu alternatif atau kaedah pilihan untuk menentukan tahap keranuman atau kematangan buah-buahan yang akan melibatkan penggunaan teknologi ISFET. Idea untuk melaksanakan penyelidikan ini adalah berdasarkan kepada konsep kajian pengukuran pH untuk buah dengan menggunakan alat ujian pH meter gelas konvensional. Eksperimen menunjukkan sampel buah ini menyimpan ion-ion sensitif dalam bentuk isyarat elektrik. Hasil pengujian alat ujian pH meter ini juga menunjukkan yang buah-buahan ini mempunyai nilai analog dan penggunaan sistem terbenam elektronik akan menukar nilai analog ini untuk dipaparkan sebagai nilai digital di paparan LCD. Hal ini membuktikan bahawa terdapat satu hubung kait antara ciri-ciri pH ujian ini dan kematangan buah. Pelbagai sampel harumanis yang berbeza tahap kematangan telah diuji dengan menggunakan alat ujian pH meter ini di mana ianya dikaitkan kepada satu sistem terbenam elektronik. Alat ujian pH meter ini mengandungi satu alat penderia ISFET yang dihubungkan kepada satu elektrod rujukan untuk menyelaras tahap kematangan buah ini. Penderia ISFET ini membuktikan dapat mengesan pelbagai tahap kematangan buah ini maka set-set bacaan pH yang diperoleh akan dipaparkan di paparan LCD. Set-set bacaan pH ini dianalisis untuk mengecam tempoh masa kematangan buah ini dan satu graf pH melawan tempoh kematangan akan dihasilkan untuk memudahkan proses penuaian buah ini. ISFET juga menyediakan satu kaedah memantau input analog dari impedans yang disediakan oleh litar pengayun. Bagi tujuan paparan digital, data yang diperoleh akan dihantar kepada sebuah komputer peribadi melalui hubungan bersiri. Ia akan dipamerkan di paparan LCD sebagai data digital setelah isyarat ini diproses. Hasil ujian penderia ISFET telah membuktikan bahawa ia dapat memberi ukuran pH yang tepat dan boleh dipercayai untuk menentukan tahap kematangan buah harumanis. Ia pasti dipilih sebagai peranti ukuran piawai untuk tahap kematangan buah sama ada muda, ranum atau lebih ranum.

Portable Electronic Embedded System ISFET pH Meter Test Kit for *Harumanis* Ripeness Detection

ABSTRACT

Measurement of pH in terms of Ionic Sensitive Field Effect Transistor (ISFET) and integration with the electronic embedded system is essential in agriculture processes especially in fruit ripeness monitoring, pH data analysis and fruit ripeness control applications. This research project is an alternative for determining the states of ripeness or maturity for *harumanis* using ISFET technology. The idea for implementing this research is based on the concept of determination of pH for *harumanis* by using conventional glass pH meter test kit. The kit shows that a sample of *harumanis* stores ions sensitive signal in terms of electrical signal. Therefore, the pH meter indicates that the *harumanis* has analog value and the embedded system converts this analog value to be displayed as digital value on the LCD display. As it turns out, there is a correlation between these pH properties and the maturity of *harumanis*. The pH of different types of *harumanis* maturity has been measured using pH meter test kit which is connected to an embedded system. This pH meter setup consists of ISFET pH sensor with a reference electrode for calibrating different types of *harumanis* sample. The ISFET pH sensor has shown that detection of different types of maturity levels for *harumanis* is feasible hence the sets of pH reading obtained are observed on LCD display. The sets of pH reading are analyzed in identifying time duration for *harumanis* maturity. Therefore a graph of pH for *harumanis* against duration of *harumanis* maturity can be produced, thus the process of harvesting *harumanis* is easier than as expected. ISFET provides a method to view the analog input from the impedance provided by the oscillator circuit. For digital display purpose, the data acquisition is sent to a personal computer via serial link. It displays digital pH meter by processing the digital output signal. Since the ISFET sensor has proved to give accurate and reliable measurements of the pH properties for *harumanis*, it is chosen as the standard measurement device in determining *harumanis* maturity level; under ripe, ripe or over ripe.

CHAPTER 1

RESEARCH BACKGROUND

1.1 Introduction

This chapter starts with a brief explanation on the background of fruit ripeness and its detection issue or trend about fruit ripeness detection. Next, research objective, scope and the problem statements of the project are addressed. After that, the proposed solution concerning detection system for fruit ripeness is discussed. Lastly, the organization of this thesis is explained.

1.2 An Overview of Fruit Ripeness

Fruit ripeness has variable characteristics and is normally detected based on color, smell and shape. Detecting fruit ripeness is essential in agriculture and increasing technology of fruit ripeness detection shows that fruits ripeness detections are really important. Nowadays, the agriculture field is facing some major problems and issues such as poor management of farm inputs, yield loss due to pests and lack of harvesting technology. These major problems will cause high losses of productivity and quality of local fruit. So, ISFET pH technology can bring some important advantages in agriculture where it can give better prediction of crop yield. It is also an efficient technique for prevention of crop disease and deficiency of local fruit. Hence, the productivity and quality of local fruits will be increased so it benefit to our country's economic especially through agriculture field.

The condition of fruit at the time of harvest has an important effect on the consumer's level of satisfaction at consumption. While many consumers use the terms mature and ripe interchangeably to describe the state of a fruit when it is ready for consumption, Reid (2002) notes that fruit producers and postharvest produce technologists consider these terms to have distinct meanings. Reid indicates that the term mature is best described by the Webster's dictionary; Mature: "having completed natural growth and development."

Reid further elaborates that the term mature describes the stage at harvest that will ensure that the fruit's quality will meet or exceed the minimum level acceptable to the consumer at the time it is consumed. In a climacteric fruit, such as mango, the fruit is not considered to be of desired eating quality at the time it initially becomes mature, but requires a ripening period (typically 8 to 10 days at 25 ºC; Lakshminarayana, 1980) before it achieves the taste and texture desired at the time of consumption. In this context the term ripe is best described by the Webster's dictionary; Ripe: "having attained a final or desired state."

Thus it is important to know the stage of maturity for determining when to harvest fruit since fruit harvested at an immature stage will not be able to achieve a level of quality acceptable to consumers. Sorting harvested mangoes according to their maturity stage in the packinghouse can eliminate immature-green mangoes and separate partially-mature from fully-mature green mangoes in order to improve the uniformity of ripening in lots of fruit at destination. It is also important to know the stage of ripeness for determining the optimal postharvest strategy for handling and marketing fruit.

Because the maturity level at harvest is critical to the development of good flavor quality in the fruit when fully ripe (Kader, 2008), it is important for individuals harvesting fruit to have effective methods of determining mango maturity. Unfortunately, the appearance of red color on the skin (in some cultivars) is not a reliable index of maturity. Likewise, the change in skin ground color (the greenest spot on the fruit) from dark-green to light-green or yellow is not reliable because of variations between cultivars. Differences in ground color between immature and mature green mangoes can be subtle. A number of alternative fruits maturity indices have been studied and will be presented in Chapter 2.

Maturity indices for mango include number of days after full bloom, flesh color, fruit shape (the "fullness" of the cheeks or shoulders), fruit size, skin color, soluble solids content, specific gravity (the ratio of the mango density to the density of water), starch content, titratable acidity, and total solids (dry matter) content (Kader, 2008).

1.3 Problem Statement

The maturity or ripeness of a fruit is difficult to determine. Most farmers in Malaysia normally determine the maturity base on physical and the skin color of the fruit. With this method it can bring great lose to farmers and give bad reputation for a company. This situation occurred when the delivery of those mangoes to the imported country are too young or too ripe. Apart from that, there are many scams that occur during the transmission to the middle person. This situation occurs when there are farmers who tried to get more profit and avoid losses.

The automation of fruit ripeness detection may be realized in the near future by having an instrument that is able to provide online pH display and ripeness state measurement. Online measurement eliminates the need for additional instruments or devices for capturing data and images which is complicated and expensive. Previous methods of fruit ripeness measurement such as by using color, shape and smell require calibration each time a new fruit is detected or there is a modification to the size of fruit. This research aims to implement algorithm based fruit ripeness measurement which will not require any calibration constant.

The implementation of this research by using embedded systems results in ISFET pH meter which is small and portable. The overall cost will also be significantly reduced comparing to using standard Data Acquisition System and powerful computers (Pang, 2004). For industrial applications that are only interested in the fruit ripeness measurement, the result can be seen on LCD. The instrument is also capable to visualize the graph by connecting the instrument to a laptop via standard serial communication interface (RS232). The Graphical User Interface installed on the laptop will display the current pH, fruit ripeness measurement or sensor values for data logging or monitoring purpose.

The development of the firmware for the embedded systems was optimized to achieve highest speed possible. Function calls, algorithms implementations and communication between sub systems were all developed with considerations for accuracy and optimum performance. These optimizations are very important as they affect the overall performance considerably.

1.4 Research Objective

The aim of the research is to develop a portable embedded system pH meter test kit by using in-house fabricated ISFET sensor. The system is designed to detect the fruit ripeness stage and it will be classified or categorized as young, ripe or rotten.

1.5 Research Scope

This research is embarked based on these following scopes:

i) To execute masking design and fabrication process of ISFET pH sensor together with its morphological and electrical characterization. The characterization is crucial for the design of ISFET pH test kit embedded system.

ii) To design and simulate the ISFET pH test kit measurement system circuits which consist of power supply circuit, analog readout circuit, digital signal processing circuit, data acquisition circuit and pH measurement circuit. The Proteus ISIS simulation software is used to validate the circuit designs.

iii) To do the programming on microcontroller board circuit and Graphical User Interface (GUI) by using Microchip MPLAB and National Instruments LabVIEW software. An analysis is done in order to obtain the pH measurement value from the capture signal. A GUI is used as the system interface and displays the output result.

iv) To integrate the ISFET pH test kit measurement circuit on a single printed circuit board (PCB). The testing process for circuits of ISFET pH test kit is done frequently to ensure it properly functions.

1.6 Thesis Organization

The contents of this dissertation are organized into seven chapters and each chapter is written to be largely self-contained and complete. Chapter 1 provides an introduction to digital fruit ripeness detection. Next, the research objective and problem statement are defined. The scope of study is also discussed in this chapter.