Position Estimation Using Phase Difference of Electrode Array for Two-Dimensional (2D) Communication System

Supaporn Chantanakorn

Cooperative Education Report submitted in partial fulfilment for the degree of Bachelor of Science Program in Information Technology
Faculty of Information Technology
Thai-Nichi Institute of Technology
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Cooperative Education Report Examination Committee:

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Saprangsit Mruetusatorn, Ph.D.

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Credit	6
Candidate	Miss Supaporn Chantanakorn
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Program	Bachelor of Science Program in Information Technology
Field of study	Information Technology
Faculty	Information Technology
A.D.	2010

Abstract

Company Name	National Institute of Information and Communications Technology (NICT)
Place	Kyoto, Japan
Type of Business	Research Center
Department	New Generation Wireless Communications Research Center
Position	Research Assistant
Supervisor Name	Dr.Bing Zhang

Two-dimensional (2D) communication is a novel communication technology, which uses a sheet of special structure that allows a physical surface to propagate radio signals, and a coupler that is used to input / output radio signal. Furthermore, the 2D communication technology can be applied for energy transmission by using high-power carrier waves, which can easily allocate a lot of sensors on the two dimensional sheet, and gather data from each node with high throughput.

In this report, a position estimation method that uses the phase difference of input electrodes upon receiving pilot signal from device is proposed. The proposed method is described and evaluated by measuring the phase and power level of pilot signal, in which reflection does not occur. The accurate position information of devices can be applied to various location-specific multimedia applications in the 2D communication system. These applications have a very high possibility that people can explore interesting spots or items in more detail. It makes people have more comfortable lives.

Keyword: two-dimensional communication / position estimation / phase difference / pilot signal / carrier wave

Acknowledgement

First and foremost, my utmost gratitude to my supervisor of this project, Dr.Bing Zhang for her sincerity, encouragement and advice to inspire me to complete this project. My sincere thanks go to Dr.Takashi Matsuda for the valuable guidance and support from the initial to the final level enabled me to develop an understanding of the subject. Without his guidance and persistent help this report would not have been possible.

Then I would like to thank my advisor, Dr.Saprangsit Mruetusatorn for unselfish and unfailing support as my report advisor and thank for his help and direction suggested until the completion of the project.

Besides, my sincere gratitude to the National Institute of Information and Communications Technology (NICT) for scholarship of accommodation cost in Japan and provide me with a good environment and facilities to complete this project. In addition I would also like to take this opportunity thanks to my university, Thai-Nichi Institute of Technology (TNI) for allowing me to do the internship at NICT. It gave me an opportunity to participate and learn this subject.

Last but not least, an honorable mention goes to my father and mother who are wonderful parents for their great encouragement, advice and benefactor to support me to complete the project. Without helps and big love of my parents, I would face many difficulties while doing this project. Also thanks NICT research team and my friends who were doing this project with me and sharing ideas. They were helpful that when we combined and discussed together, and had this task done.

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The input electrodes are clipped on the top and bottom and measurement step is 5cm.

The input electrodes are clipped at the 4sides and measurement step is 2.5cm.

Image Contents (Continue)

Image Contents (Continue)

Chapter 1
Introduction

1.1 Work Place Name

1.1.1 Name in English
National Institute of Information and Communications Technology (NICT)

1.1.2 Name in Japanese
独立行政法人 情報通信研究機構

1.2 About NICT

In April 2004, the Communications Research Laboratory (CRL), an incorporated administrative agency, and the Telecommunications Advancement Organization of Japan (TAO), a chartered corporation, were merged and newly launched as the National Institute of Information and Communications Technology (NICT), an incorporated administrative agency.

NICT was established to carry out research and development in the field of information and communications technology, which supports the upcoming ubiquitous network society in an integrated manner from basis to application and also provides comprehensive assistance to the public and private organizations working in this field.

NICT newly started the 5 year medium-term plan in April, 2006. In this important turning point, NICT integrated the contents of research and development already performed up to now into 3 research domains such as "New Generation Network Architecture Technology", "Universal Communications Basic Technology" and "ICT for Safety and Security" and reviewed and very much improved the research organizations to promote these research domains.

Information and Communication Technology (ICT) is the basic engineering field to support all the industrial activities. NICT is making efforts to aim the realization of an ideal society where we can freely communicate one another among the people of all over the world based on Man to Man, and Machine to Machine.

The results of research and development in NICT will be utilized for the international standardization and the technical transfer to the industry, and they are also in broad activities such as the research and development mobilizing the industry and the academia in order to put the technology to practical use, the research commission to universities, companies, etc., the venture support and the advanced support for infrastructures to accelerate the business planning.

In this way, NICT, as the sole national research organization, will continue to make efforts towards realizing a vigorous society and a wealthy life by supporting the national policy as for Information and Communications from the technical side in the field of information and communications.

1.3 NICT Action Principles

1.3.1 Creating Technologies

NICT will undertake research and development by pursuing original technologies, world-leading technologies, and technologies which should benefit society.

1.3.2 Contributions to Society

NICT will try to disseminate the results of our research throughout society by utilizing every means and opportunity.

1.3.3 Devotion to Self-Improvement

NICT will exercise our maximum capacity or ability by acknowledging the importance of our social responsibilities and devoting ourselves to self-improvement with a strong sense of ethics and a spirit of independence.

1.4 NICT Organization Chart

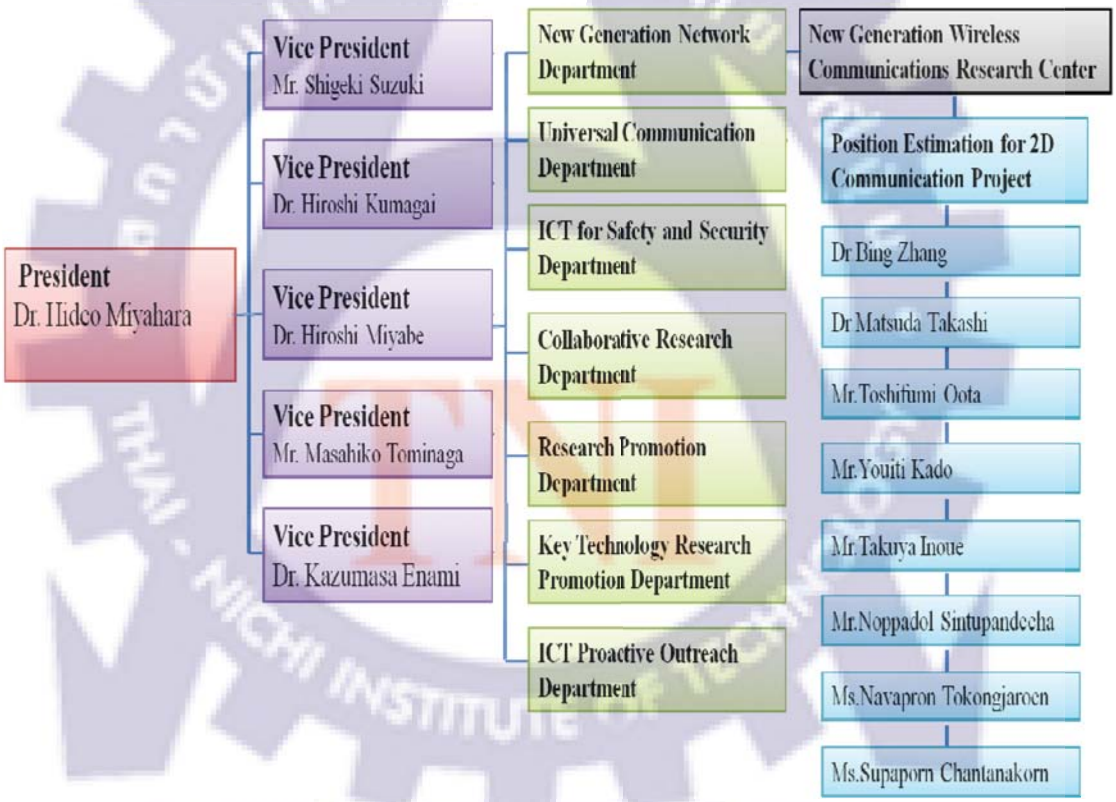

Fig. 1.1 NICT Organization Chart

1.5 Work Place Location

2-2-2 Hikaridai, Keihanna Science City Kyoto Japan ,619-0288

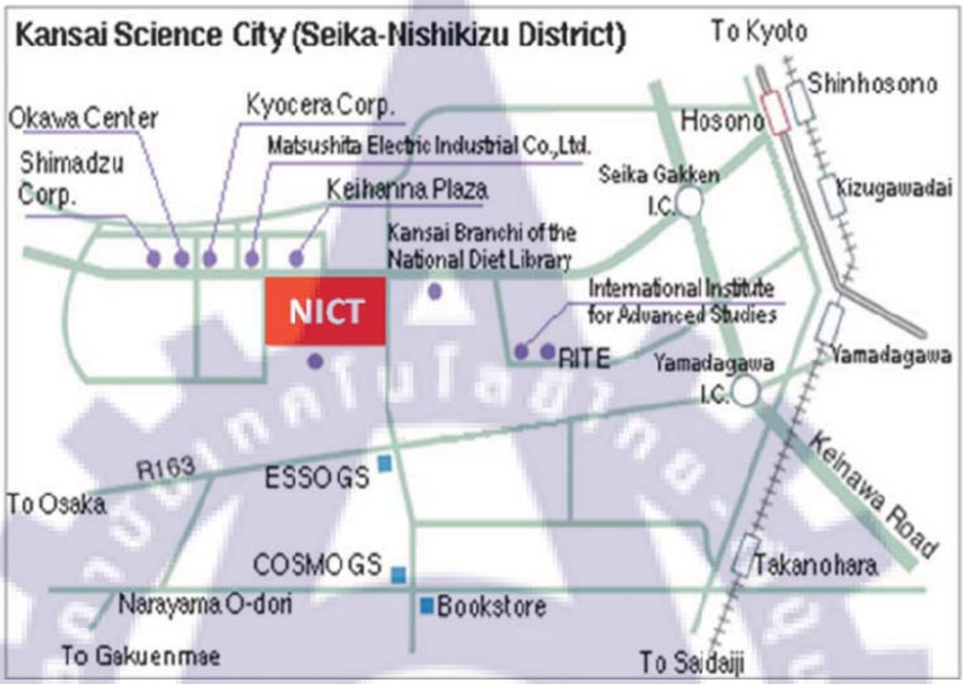

Fig. 1.2 NICT Location

1.6 Work Description

Responsible for supporting the on-going development projects. The general area of focus will be on developing a Position Estimation using phase difference of pilot signal between electrode array for 2 Dimensional Communications System.

1.7 Supervisor

1.7.1 Supervisor Name : Dr.Bing Zhang
1.7.2 Supervisor Position : Senior Researcher

1.8 Period of Work

4 months between 24th May 2010 to 16th September 2010

1.9 Research Objective

The objective of this project is to precisely estimate the position of a device on a Two-Dimensional Communication sheet (2DC sheet) in order to concentrate on providing location-specific for Location-specific Multimedia Services.

1.10 Expected Result

The expected result of this project is we can precisely estimate the position of device that placed on 2DC sheet, expected to estimation position error is within a few centimeters.

Chapter 2
Two-Dimensional Communication System

2.1 Introduction

Improving our daily supports by enhancing the surrounding common tools is a fundamental step to realize the ubiquitous networking society. For example, a table is very common and useful furniture at home. The table can be enhanced by the new technology of epoch-making two-dimensional (2D) communication. The 2D communication technology has both advantageous features of wired and wireless networking. In 2D communication, a two-dimensional communication (2DC) sheet becomes the communication medium to propagate the carrier waves of devices, which are placed on the top of the 2DC sheet. The 2D communication sheet is not just able to establish a communication connection between two devices, but it also can provide other services including high speed transmission, power supply provision, high security, high accurate estimation of the device location, efficient spatial reuse, etc. Further, the 2D communication can also provide energy transmission by using high-powered carrier waves. Therefore, not only the intelligent networking devices, such as laptops, PDAs, and mobile phones, but also any hand-held devices, such as camera, music players, headsets, hand-held game consoles, etc can be wirelessly charges via the 2DC sheet. During working your tasks on the table, 2D communication can identify the position of your laptop and incredibly it can charge your laptop and other devices simultaneously. By this way, 2D communication technology realizes the contextual supports for the need of people.

In this report a prototype system is developed to accurately estimate the position of device that is put on 2D communication sheet. The prototype has eight electrodes array that attached at the one side of the 2DC sheet. Moreover, the proposed method is evaluated in the case that electrodes array are attached at the multiple sides of 2DC sheet. The pilot signals are generated by a client device and sent into 2DC sheet via the coaxial cable. Phase difference of the pilot signal between two neighbors of electrode array are used to estimate the position of the client device which placed on 2DC sheet. The proposed position estimation method to get the accurate position of device that placed on 2DC sheet by using phase difference of electrode array is presented. The proposed method is examined through measuring the phase and power level and discuss the graph results.

2.2 Related Work

The concept of "Network Surface" was first proposed by Scott et al [1]. The network surface are surface which provide network connectivity to specially augmented objects, when these objects are physically placed on top of the surface. When an object (e.g. a notebook computer, PDA) connect, a handshaking protocol assign function such as data or power transmission to the various conducting paths that are established. The surface such as desk or wall etc as Networked, if a suitably augmented object can acquire connectivity to a data and/or power infrastructure, simply by being in physical contact with that surface.

Connectivity is achieved by providing a number of electrically in dependent paths or link between the surface and object, which are allocated to function such as data transmission or power. The difference objects may require different functions and the functions which are available to objects may differ from surface to surface.

The Scott network surface idea, the network surface is composed of cleverly placed tiles. Objects can be connected to the surface through circular pads designed to map with connection points onto the tiles. The drawback of the network has to manage a large number of tiles in the surface, which leads to complex negotiation in between tile's connection points and objects. The network surface can also provide information about position and orientation of objects. The drawback of the network surface is the complexity because the network has to manage a large number of tiles in surface, which leads to complex negotiation in between tile's connection points and objects.

To tackle the mismatching a total problem of network surface, Minamizawa et al [2]. introduces a simple 2DC sheet whereby a proximity connector touches the surface freely without restraint for both power supply and data transmission.

2.3 2D Communication System [3]

The 2DC sheet consists of two components: a sheet and a connector. Figure 2.1 illustrates the basic structure of the 2DC sheet, which composes of four layers: solid conductive (S-) layer, dielectric (D-) layer, mesh conductive (M-) layer and protection (P-) layer. The conductive fabric is usually copper or aluminum, whereas the dielectric material is polystyrene. The purpose of P-layer in Fig. 2.1 is to protect human directly in contact with the M-layer. With this layered composition, an electromagnetic wave can be confined within the 2DC sheet depending on the relative permittivity of D-layer and the mesh size of M-layer. The inter-stripe distance and the stripe width of M-layer are 7 mm and 1 mm for a 2.4 GHz electromagnetic wave. However, the electromagnetic wave still can seep out from the surface of 2DC sheet. We call this phenomenon as "evanescent-wave" as shown in Figure 2.2. The evanescent wave is formed when the electromagnetic wave inside the 2DC sheet is reflected off the surface. The energy flow of evanescent wave is parallel to the input direction of the electromagnetic wave. Meanwhile, the connector is an antenna that an electromagnetic wave is extracted from or inserted into the 2DC sheet.

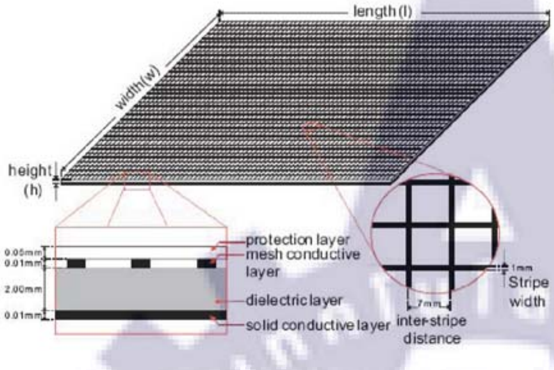

Fig. 2.1 2D sheet construction

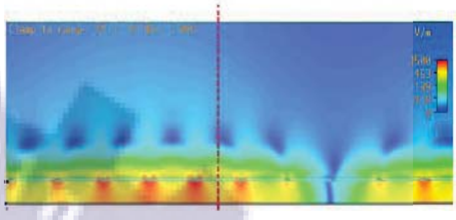

Fig. 2.2 Evanescent wave

Chapter 3
Applied Theories

In the report, both theories, phase difference and path loss, are used for position estimation equation to evaluate the position estimation of device that is placed on 2DC sheet.

3.1 Phase Difference of Multiple Inputs

The phase difference [4,5] or phase shift as it is also called of a sinusoidal waveform (Sine Wave) is the angle Φ (Greek letter Phi) in degrees or radians that the waveform has shifted from a certain reference point along the horizontal zero axis. In other words phase shift is the lateral difference between two or more waveforms along a common axis and sinusoidal waveforms of the same frequency can have a phase difference.

The phase difference, Φ of an alternating waveform can vary from between 0 to its maximum time period, T of the waveform during one complete cycle and this can be anywhere along the horizontal axis between, $\Phi = 0$ to 2π (radians) or $\Phi = 0 \text{ to } 360^{\circ}$ depending upon the angular units used. Figure 3.1 shows example of difference distance between two electrodes and antenna, $\overline{c0p2}$ and $\overline{c0p3}$. Figure 3.2 shows phase difference.

When the device moves, the phase differences of every pair of neighboring plugs are changed. The phase difference of $\overline{c0p2}$ and $\overline{c0p3}$ is presented as follow:

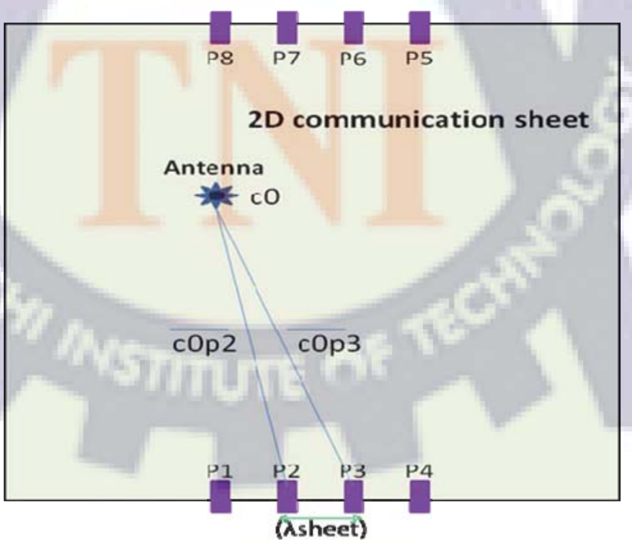

Fig. 3.1 Different distance of two electrodes array

3.1.1 Phase Difference Equation

$$D_{2,3} = \left| \frac{\overline{c0p2}}{\lambda sheet} - \frac{\overline{c0p3}}{\lambda sheet} \right| \tag{1.1}$$

$$\Phi = D \cdot 2\pi \tag{1.2}$$

where λ_{sheet} is the wave length of electromagnetic wave in the 2DC sheet and **Φ** is the phase angle in degrees or radians that the waveform has shifted either left or right from the reference point.

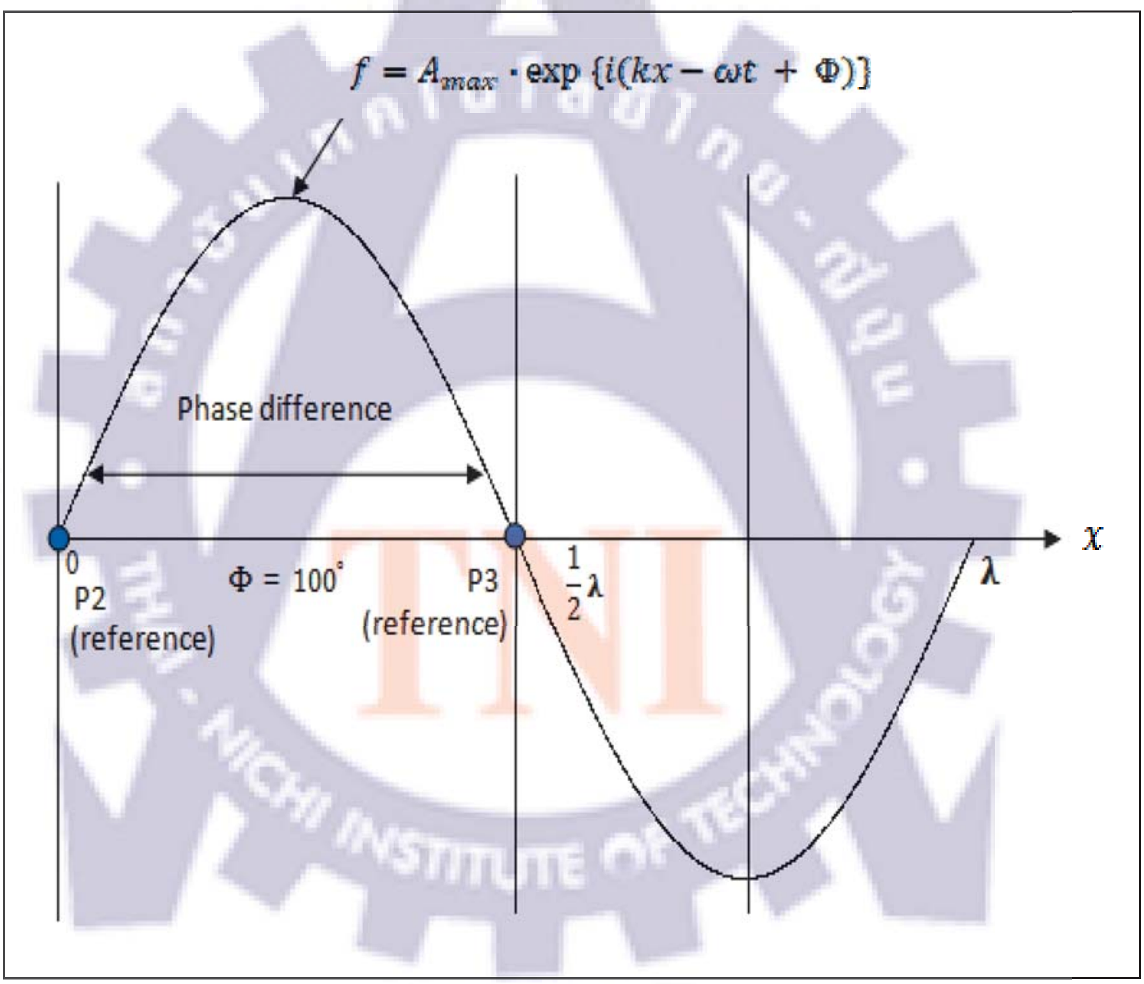

Fig. 3.2 Phase Difference

3.1.2 Wave Function Equation

$$f = A_{max} \cdot \exp\{i(kx - \omega t + \Phi)\} \tag{1.3}$$

where:

A_{max} :	is the amplitude of the waveform.
exp :	is the Exponential Function.
i :	is the complex number.
k :	is wave number (spatial frequency) can be associated with the wavelength by the relation $k = \frac{2\pi}{\lambda}$
x :	is the distance.
ω :	is the angular frequency of the waveform in radian/sec.
t :	is the time.
Φ (phi) :	is the phase angle in degrees or radians that the waveform has shifted either left or right from the reference point.

3.2 Path Loss

Path loss [6] or path attenuation is the reduction in power density (attenuation) of an electromagnetic wave as it propagates through medium like space or 2DC sheet. Path loss is a major component in the analysis and design of a telecommunication system.

This term is commonly used in wireless communications and signal propagation. Path loss may be due to many effects, such as propagation loss, refraction, diffraction, reflection, aperture-medium coupling loss, and absorption. Path loss is also influenced by terrain contours, environment (urban or rural, vegetation and foliage), propagation medium, the distance between the transmitter and the receiver, and the height and location of antennas.

3.3 Position Estimation Equation

In the experimental the three equations, squared, absolute and square root, are proposed to find the accurate position of device. These equations can show the accurate position and error position of device. First the phase and power level information are measured for several points on the 2DC sheet and made a database in advance. Table 3.1-3.2 show the way to gather the database of first time and second time.

Table 3.1 The database of first time

X	Y	D1,2	D2,3	D3,4	D4,5	D5,6	D6,7	D7,8
60	17	A11	A12	A13	A14	A15	A16	A17
65	17	A21	A22	A23	A24	A25	A26	A27
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
90	47	An1	An2	An3	An4	An5	An6	An7

Table 3.2 The database of second time

X	Y	D1,2	D2,3	D3,4	D4,5	D5,6	D6,7	D7,8
60	17	B11	B12	B13	B14	B15	B16	B17
65	17	B21	B22	B23	B24	B25	B26	B27
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
90	47	Bn1	Bn2	Bn3	Bn4	Bn5	Bn6	Bn7

Then the differences of phase and power in database are compared.
The minimum result of these equations are estimated as position estimation.

The formulas show as:

Square Equation = $\sum_{i=1}^{n}(D_{i,i+1} - d_{i,i+1})^2$ (3.1)

Absolute Equation = $\sum_{i=1}^{n} |D_{i,i+1} - d_{i,i+1} |$ (3.2)

Square Root Equation = $\sum_{i=1}^{n} \sqrt{|D_{i,i+1} - d_{i,i+1}|}$ (3.3)

where, $D_{i,i+1}$ is phase difference of electrode i and i+1 from database, and $d_{i,i+1}$ is that from measured value.

For equation (3.1) the distance of device will be exponentiation increase d.

For equation (3.2) the distance of device will be positive value (|d|).

For equation (3.3) the distance of device will be exponentiation decrease d.

Chapter 4
Experimental Evaluation

4.1 Working Plan

Subject	May					June					July					August					September				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
-Study about 2D communication				↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔					
-Measure phase and power of 2DC sheet and Calculate value of phase and power then plot graph					↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔										
-Estimation system consideration										↔	↔	↔	↔	↔	↔	↔	↔	↔	↔	↔					
-Data summary and preparation for presentation														↔	↔	↔	↔	↔	↔	↔	↔	↔	↔		
-Presentation																						↔			

4.1.1 Study about 2D Communication

Subject	May					June					July					August					September				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
-Reading “A Simulation Study for Position Estimation of Multiple Devices in 2D Communication System”				↔	↔																				
-Reading “Sensor Networking based on Two-Dimensional Signal Transmission Technology”				↔	↔																				
-Reading ”An Efficient Wireless Power Transmission System Using Phase Control of Input Electrode Array for Two-dimensional Communication ”												↔	↔												
-Reading ”Digital Scope on 2D Communication Sheet for Location-specific Multimedia Service ”																			↔	↔					

4.1.2 Measure phase and power of 2DC sheet

Subject	May					June					July					August					September				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
-Measuring the position of device every 5cm and 2.5cm interval, that input electrodes are attached on the top of 2DC sheet					←	—	—	—	—	—	—	—	—	—	→										
-Measuring the position of device every 5cm and 2.5cm interval, that input electrodes are attached on the top and right of 2DC sheet					←	—	—	—	—	—	—	—	—	—	→										
-Measuring the position of device every 5cm and 2.5cm interval, that input electrodes are attached on the top and bottom of 2DC sheet					←	—	—	—	—	—	—	—	—	—	→										
-Measuring the position every 5cm and 2.5cm interval, that input electrodes are attached on the 4 sides of 2DC sheet					←	—	—	—	—	—	—	—	—	—	→										

4.2 Work Description

Our work is responsible for supporting the on-going development project. In this project we are responsible to measure the phase and power level information of pilot signal between input electrodes array. There are four experiments that input electrodes are attached at the different locations of edge of 2DC sheet, top, top-right, top-bottom and four sides. For each experiment, positions are measured every 5cm and 2.5cm interval for two times. After that the graphs result are plotted to evaluate the correct position and error position of each experiment and use that result to improve the better position estimation. For every experiment, a report of the experimental result were presented to the research team for discussing the experiment result and evaluating the best way to precisely estimate the position.

4.3 Experimental Setup and Description

Figure 4.1 shows the experiment setup that mainly consists of 2D communication sheet, 8 electrodes, client device, phase angle measuring device, antenna and wave-absorber.

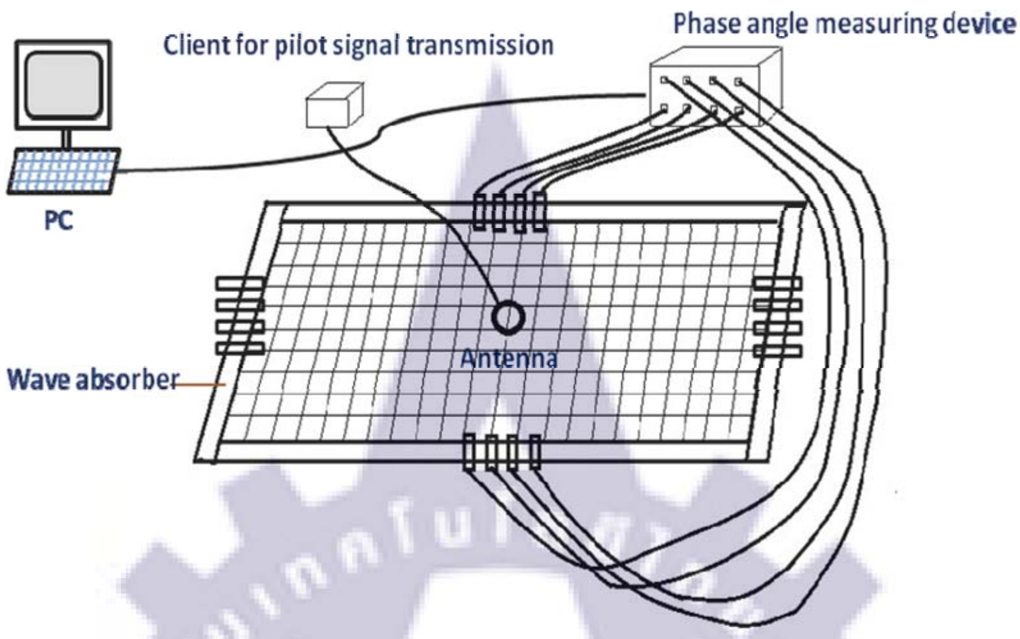

Fig. 4.1 The experimental setup

When the pilot signal transmits to 2DC sheet, the pilot signal is reflected by the edge of 2DC sheet. To absorb the wave reflection, we propose to attach the wave absorber sheet at the edge of 2DC sheet. The wave absorber sheet width is 6 cm, and it is attached around the edge of 2DC sheet. Figure 4.2 shows cross section view of the wave absorber [3] on the edge of 2DC sheet. It is easy to implement the wave absorber by simple structure.

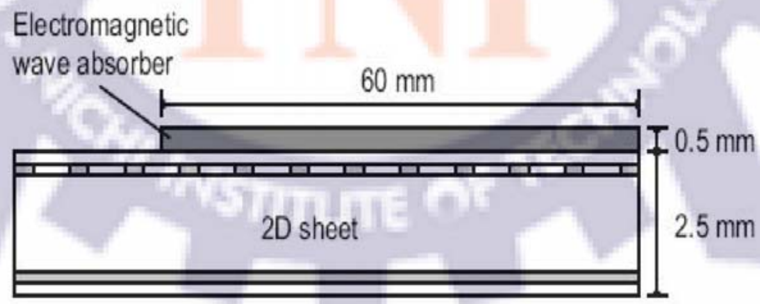

Fig. 4.2 The cross section view of the wave absorber

The size of the 2D communication sheet is 150 cm x 64 cm and measurement area is 30 cm x 30 cm. The measurement position starts at 60 cm to 90 cm of X-axis and 17 cm to 47 cm of Y-axis. In the experiment, each point of 2DC sheet is measured every 5cm and 2.5cm intervals. The total of measurement points is 49 points and 169 points respectively. The pilot signal that frequency is 2.4 GHz. is feeding into the 2DC sheet by the client device for pilot signal transmission as shown in Figure 4.3 via coaxial cable.

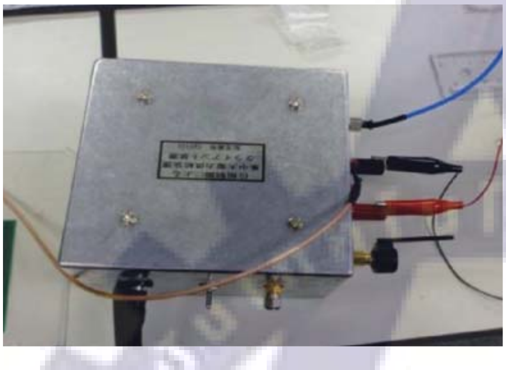

Fig. 4.3 Client device for pilot signal transmission

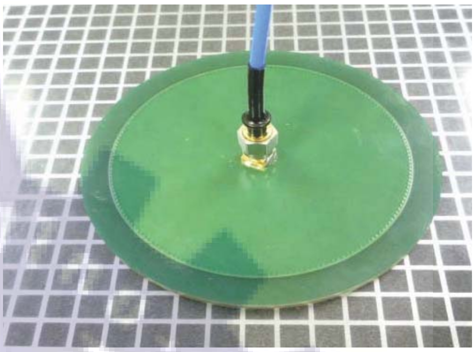

Fig. 4.4 The antenna

The pilot signal that oscillate from an antenna which is 8.5 cm. in diameter spreads throughout the 2D communication sheet and reaches to the electrodes array that are directly attached at multiple side of 2D communication sheet. Figure 4.4 shows the antenna is connected with client device by coaxial cable. The size of each electrode [3] is 12 mm x 47mm as shown in figure 4.5 the interval of electrode array should be less than λsheet that is the wave length of electromagnetic wave in the 2DC sheet. The λsheet calculates as formula :

- λsheet = r × λlight wave

where, r is transmittance ratio.

The pilot signal that are received at 8 electrodes array on the each side of 2DC sheet are sent to phase angle measuring device as shown in Figure 4.6 The phase angle measuring device measures the phase and power level information using electrode array that is connected by coaxial cable. The phase and power level information can be checked on the computer screen. Then the values of the phase and power level are used to calculate and evaluate the position estimation.

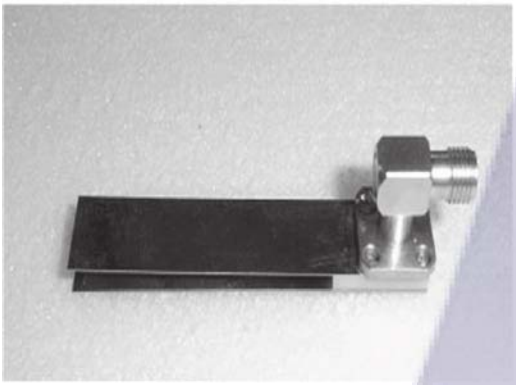

Fig. 4.5 The electrode

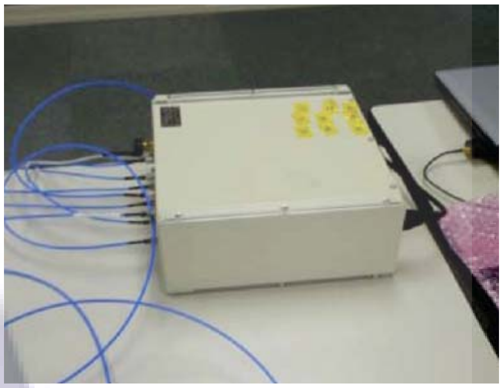

Fig. 4.6 Phase angle measuring device

4.4 Position Estimation Method

As mentioned in the two dimensional communication system section, the prototype is used to describe that 2D communication system can measure the phase and power level via 8 arrayed electrodes attached at the each side of the 2DC sheet. To locate an accurate position of device that placed on the top of 2DC sheet, the proposed 2D communication system measured the phase difference of pilot signal. Figure 4.7 shows the example of arrangement of electrode array.

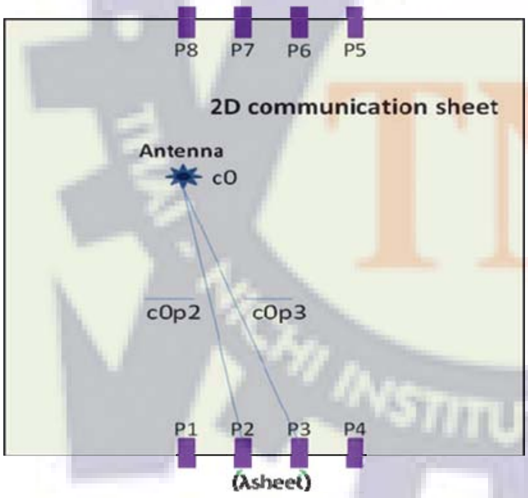

Fig. 4.7 The arrangement of electrode

Fig. 4.8 Phase and Power level information

Technically speaking, the pilot signal that oscillate from an antenna spreads throughout the 2D communication sheet and reaches to the electrode array. The system shows the phase and power level information that use it to calculate the phase difference. Figure 4.8 shows value of phase and power level information of pilot signal which received at the electrode array, in which no wave reflection at the edge. The phase and power level information are used to evaluate the position of the device which is placed on 2DC sheet. Measuring the phase at every electrode, the value of phase difference of each pair of neighboring electrode is obtained. The difference of phase results from that of the propagation delay. Therefore, if there are several electrodes all of the positions on 2DC sheet have unique phase information.

Next position estimation method is described. First, the phase and power level information are measured for several points on the 2DC sheet and made a database in advance. Then the antenna of client device is put on 2DC sheet at random and send the pilot signal. Measuring device measure this pilot signal and compare between the phase and power level difference of database and that of pilot signal by proposed formulas as mentioned in the theory.

The minimum result of these formulas is estimated as position estimation. For example, the phase difference between ‘p2’ and ‘p3’ in fig 4.7 are the resultant from the distance difference of two lengths, $\overline{c0p2}$ and $\overline{c0p3}$. When the device moves, the phase differences of every pair of neighboring plugs are changed. The phase difference of $\overline{c0p2}$ and $\overline{c0p3}$ is presented as mention in theory section which Phase Difference Equation (1.1).

Then a database is created for phase, the differences of power level and position through changing the antenna positions. Table 4.1 shows an example of database.

Table 4.1 The database of phase and power level

Position (cm)	Phase Difference(degree)							Power level(dBm)							
	D1,2	D2,3	D3,4	D4,5	D5,6	D6,7	D7,8	P1	P2	P3	P4	P5	P6	P7	P8
60,17	30	83	113	92	135	139	175	-18.4	-18.6	-20.7	-26.3	-30	-30	-30	-30
60,22	87	5	77	96	108	163	164	-21.1	-18.6	-18.6	-21.5	-24.5	-28.3	-30	-30
60,27	123	57	0	55	93	154	150	-23.5	-20.5	-18.6	-18.5	-20.5	-22.3	-27.9	-30
60,32	134	92	58	16	61	132	117	-28.3	-24.5	-20.7	-20.7	-20.5	-21.1	-24.7	-30
60,37	166	111	98	80	12	99	112	-30	-30	-23.9	-22.3	-20.5	-19.5	-21.5	-25.9
60,42	130	141	91	116	78	28	65	-30	-30	-29.5	-24.7	-21.5	-22.3	-19.5	-23.2
60,47	117	143	165	104	99	46	1	-30	-30	-30	-30	-24.5	-22.3	-21.5	-21.4
65,17	42	63	102	87	115	164	166	-19.5	-20.5	-19.5	-23.9	-26.5	-29.5	-30	-30
65,22	70	1	51	86	91	154	154	-22.3	-19.5	-21.5	-21.5	-23.5	-27.1	-29.5	-30
65,27	105	53	6	40	79	141	142	-23.5	-21.5	-20.7	-21.5	-21.5	-22.3	-27.9	-30
65,32	109	88	46	10	46	121	106	-27.1	-24.5	-23.1	-23.1	-23.5	-22.3	-24.7	-28.6
65,37	137	89	91	61	0	77	94	-30	-28.5	-23.9	-23.1	-23.5	-22.3	-23.1	-25.9

Table 4.1 The database of phase and power level (continue)

Position (cm)	Phase Difference(degree)							Power level(dBm)							
	D1,2	D2,3	D3,4	D4,5	D5,6	D6,7	D7,8	P1	P2	P3	P4	P5	P6	P7	P8
65,42	127	106	87	109	59	25	49	-30	-30	-27.9	-26.3	-24.5	-24.7	-23.1	-24.1
65,47	128	178	146	96	89	33	3	-30	-30	-30	-29.5	-25.5	-24.7	-24.7	-23.2
70,17	20	40	88	98	114	154	148	-22.3	-23.5	-22.3	-24.7	-26.5	-28.3	-30	-30
70,22	64	10	46	77	93	148	136	-23.5	-23.5	-23.1	-23.9	-24.5	-27.1	-29.5	-30
70,27	98	39	10	18	79	134	107	-24.7	-22.5	-23.1	-23.1	-23.5	-22.3	-26.3	-30
70,32	117	73	30	11	27	104	102	-27.1	-23.5	-23.1	-24.7	-24.5	-24.7	-24.7	-27.7
70,37	105	91	71	48	11	69	87	-30	-27.5	-23.1	-23.9	-25.5	-24.7	-23.1	-25
70,42	170	86	76	88	45	21	38	-30	-30	-27.9	-25.5	-25.5	-25.9	-24.7	-25.9
70,47	167	162	97	103	84	17	3	-30	-30	-30	-28.7	-26.5	-25.9	-26.3	-25
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
90,47	129	91	73	73	49	2	6	-30	-30	-28.7	-28.7	-28.5	-28.3	-27.9	-25.9

Next the antenna is put on one of the measured point of database, and the phase and power level of the antenna are measured. Then the phase and power level are compared by using three proposed formulas as mentioned in the theory section which position estimation equation (3.1), (3.2) and (3.3).

4.5 Experimental Method

The experiments in this report are all performed in one test room, using 8 electrodes for four measurement setup that the electrodes are set up at the top, top-bottom, top-right and 4 sides of the edge of 2DC sheet respectively. For each experiment, 5cm and 2.5cm intervals are measured for two times respectively in each measurement step. This section the details of the experimental method is described that the 8 electrodes are clipped on the top edge of 2DC sheet and the positions are measured for every 5 cm interval. Figure 4.9 shows the experimental set up. However, the other experiments that not describe also use the same method. Figure 4.10 shows the measurement condition.

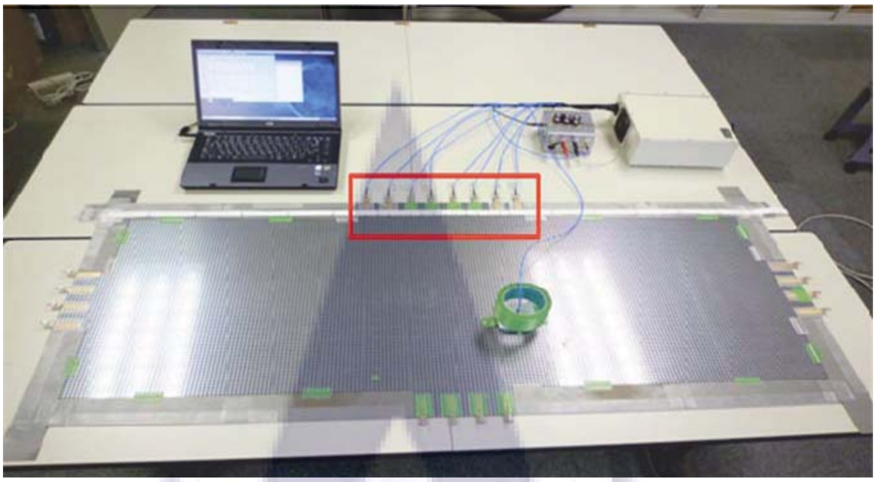

Fig. 4.9 The experiment set up

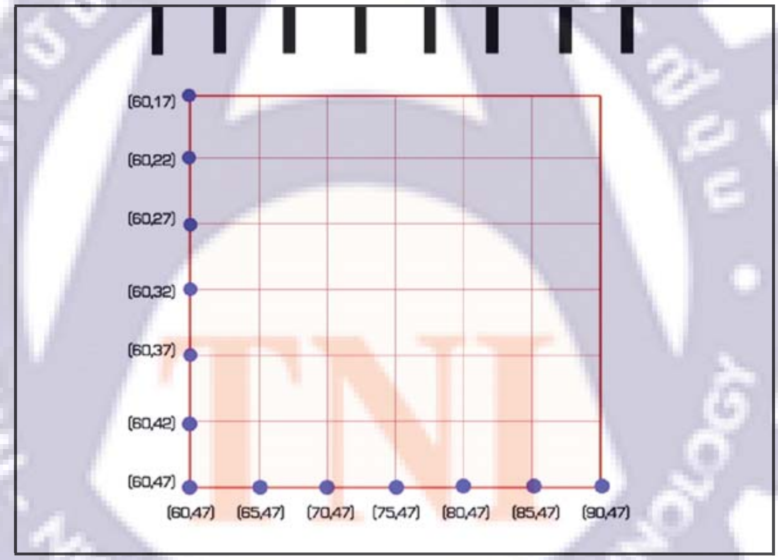

Fig. 4.10 The measurement condition

The measurement area is 30cm x 30cm with starting point is 60 cm to 90 cm of X-axis and 17 cm to 47 cm of Y-axis on 2DC sheet. First, the antenna is put on the 2DC sheet at the starting point (60,17) and the measure button is pressed on the measurement program in PC (phase angle measuring device is connected to a measurement PC via USB cable). This program shows the phase and the power level information of each measured point, the data of each point is gathered by using Microsoft Excel as shown in Figure 4.11.

Figure 4.12 shows the display window of phase and power level information after measured first point.

	CH1	CH2	CH3	CH4	CH5	CH6	CH7	CH8
60,17	19	-15	60	176	-78	49	-108	59
65,17	34	-32	-40	32	132	-125	38	-138
70,17	-82	165	107	115	174	-84	57	-153
75,17	134	10	-94	-152	-170	-105	26	140
80,17	20	-139	111	9	-69	-77	15	115
85,17	-172	12	-123	129	18	-53	-18	41
90,17	80	-83	112	-36	-151	96	46	57
60,22	93	62	121	-138	-39	70	-101	58
65,22	-82	-150	-150	-96	-5	85	-130	40
70,22	-65	-164	144	156	-163	-68	59	-178
75,22	162	52	-33	-81	-97	-49	65	169
80,22	96	-31	-135	138	80	64	151	-116
85,22	-78	112	12	-83	164	110	142	-159

Fig. 4.11 Example of gather data in Microsoft Excel

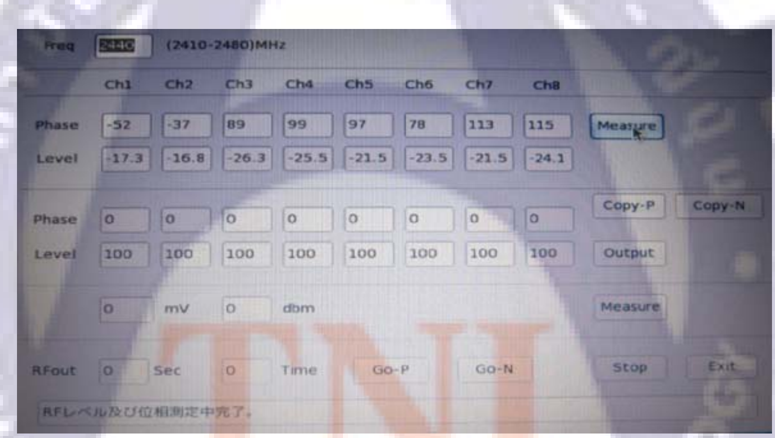

Fig. 4.12 Display window of phase and power level information

After gather the data of the first point, a measurement step still follows 5cm interval for X-axis and Y-axis (e.g. (60,17), (65,22), (70,27), …, (90,47)). This experiment needs two times measurement and a lone period of time (e.g. two hours) for starting a next measurement of the second time.

The longer time of the lone period is better for the experiment because in the short lone period of the second time measurement, it may have had the same condition of first time so we can't get the real result of position estimation. For the second measurement, the same method of the first time measurement is used. After all data are gathered from every point (Both 1st time and 2nd time measurement), the C program is used to calculate the difference phase result. This program use the information of phase and power level of every point to calculate by using 3 formulas which mentioned on the theory section(3.1), (3.2) and (3.3). After we got the phase difference information, the values of phase difference are compared to estimate the position.

Then graphs are plotted to evaluate the correct position and the result is discussed. Figure 4.13 shows an example graph of the result of position estimation. Furthermore, the graphs are plotted to evaluate the correct estimation ratio, average of error distance and maximum error distance of each experiment. Figure 4.14 shows the example of correct estimation ratio.

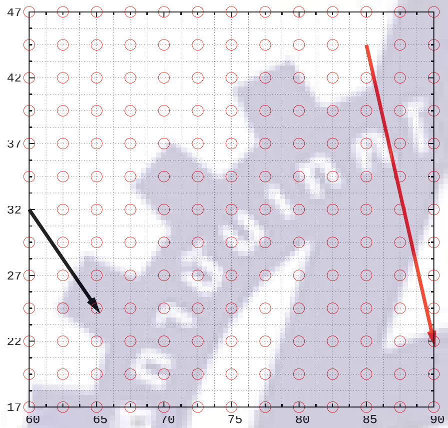

Fig. 4.13 Example of position estimation graph

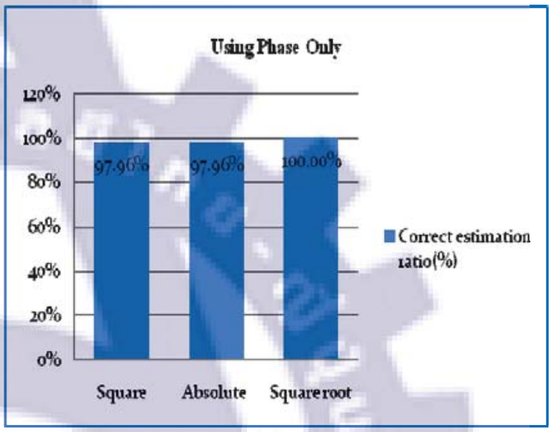

Fig. 4.14 Example of correct estimation ratio graph

4.6 Experimental Results and Discussion

By using the phase and power level information to calculate the phase difference of every pairs of neighboring electrodes array that are attached on the edge of 2DC sheet, then the graphs are plotted for position estimation result to confirm the accurate position of device that placed on the 2DC sheet. The 2 types of graph are plotted to evaluate the position estimation result. The first type is called arrow graph that shows the accurate position and error position of device between first time and second time measurement. The second type is called bar graph that shows the information of correct estimation ratio in percentage, average of error distance and maximum error distance. Both of average of error distance and maximum error distance are in centimeter.

In this section the experimental result of only the experiment which eight electrodes array are attached on the top edge of 2DC sheet and measurement step of 5 cm interval are shown. The other experimental results are not described in this section are used the same method of this result. Those results are shown in the appendix A section as shown in figure a-1-a-74. Furthermore, the comparison tables of the experiment results are shown in table a-1-a-18. The experimental equipments are shown in figures a-75-a-79. In appendix B the C program that is used to plot the graph result is shown. By the way in appendix C, my life styles at NICT are shown in figures a-80-a-88.

Next the graph result of experimental are described that 8 electrodes array are attached on the top edge of 2DC sheet and measurement step is 5 cm interval that starting with arrow graph result. First the arrow graphs are plotted to evaluate the position estimation result by using three equations of square (3.1), absolute (3.2) and square root (3.3) that are mentioned in the theory section. The graph of three equations using three informations separately which phase, power level and summation of phase and power level (x 10). Figure 4.15 shows the result of position estimation using phase information with equations of 3.1, 3.2 and 3.3.

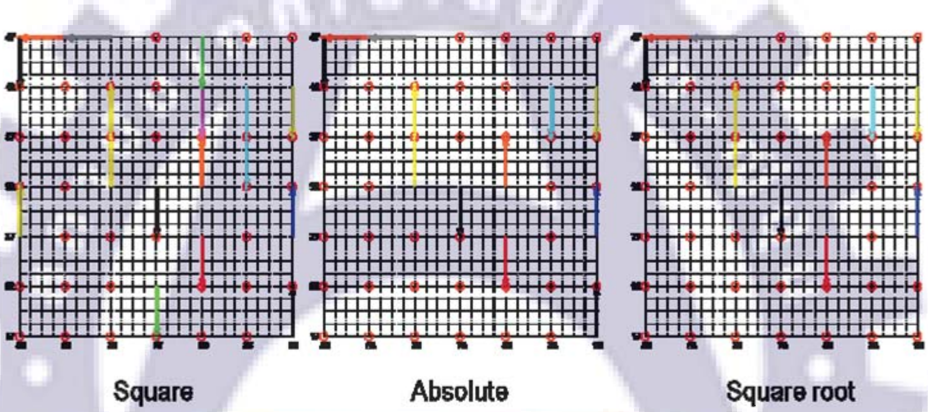

Fig. 4.15 The position estimation using phase information

Figure 4.15 shows the result that the square root equation is the best when using the phase information to evaluate the position estimation. The square root equation can calculate the most of correct positions of device which have 39 points from 49 points. The absolute and square equation are the second and third respectively. The absolute equation can calculate the correct positions have 38 points and the square root equation has 34 points from 49 points. Figure 4.16 shows the result of position estimation using power level information with square, absolute and square root.

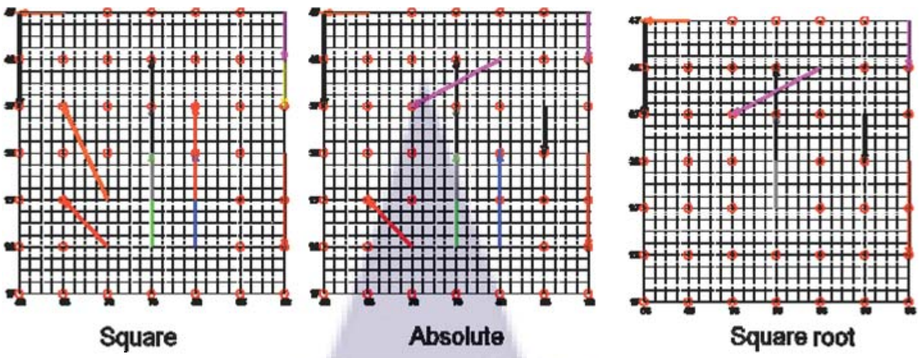

Fig. 4.16 The position estimation using power level information

As the mentioned of the result in figure 4.16, the square root equation is the best equation that can calculate the most of correct position of device when we use the power level to calculate it. The square root equation can calculate the correct positions have 31 points from 49 points. And the absolute and square equation is still the second and third respectively. The absolute equation can calculate the correct estimation has 38 points and the square root equation has 37 points from 49 points. Figure 4.17 shows the result of position estimation using the summation of phase and power level information with three equations.

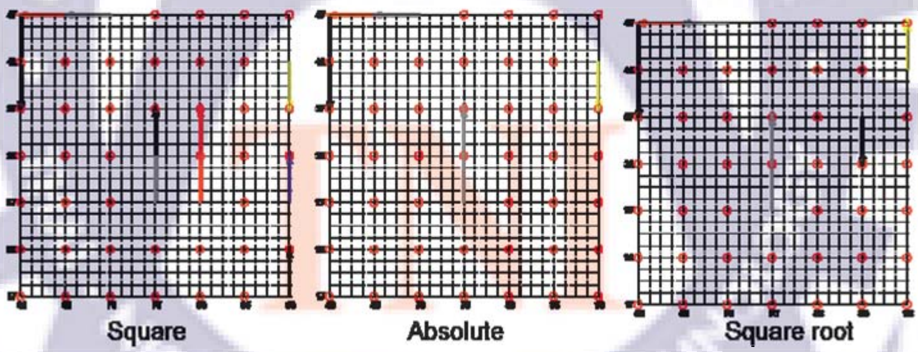

Fig. 4.17 The position estimation using summation of phase and power level(x 10)

In this result the absolute equation is the best equation. It can calculate the correct position has 44 points from 49 points. The second and third are square root and square equation respectively. The square root has 43 points and square equation has 40 points.

Then the arrow graphs are plotted to evaluate the position of device by using phase difference between range of input electrode which array 0-7, array 1-6 and array 2-5 as show in figure 4.18, the only phase information is used to calculate in square equation.

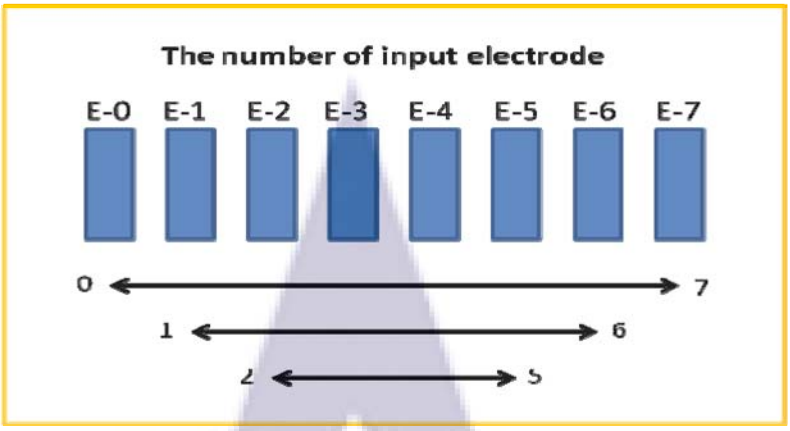

Fig. 4.18 The range of input electrode

Figure 4.19 shows the result using phase information with square formula in three range of input electrode.

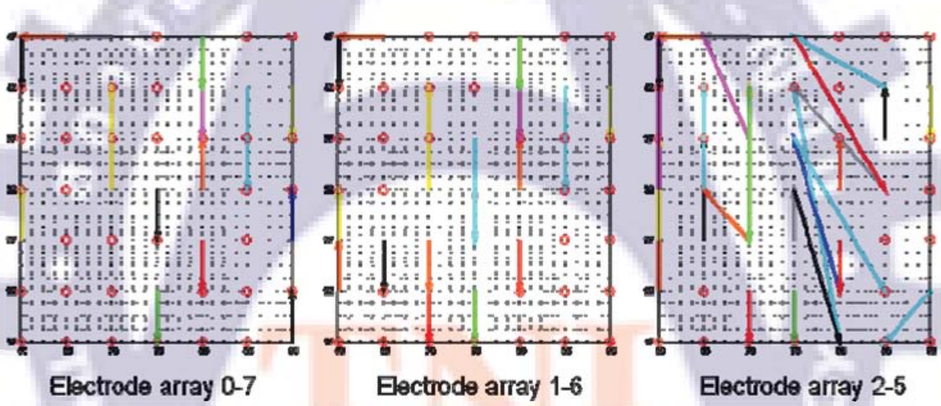

Fig. 4.19 The result using phase and square equation with three patterns of input electrode

This result show the best range of input electrode is between array 0-7. The second is array between array 1-6 and the third is array between 2-5. In array 0-7 can calculate the correct position estimation has 34 correct points from 49 points. The array 1-6 can calculate the correct position estimation has 33 correct points and the array 2-5 has 23 points from 49 points.

After that the arrow graphs are plotted by using the phase and power level information that calculated in square equation. In this result the weight of power level is changed to calculation estimation for 4 patterns. The weights are 1, 2, 5 and 10 respectively.

Figure 4.20 shows the phase result by using square equation with the four weights of level.

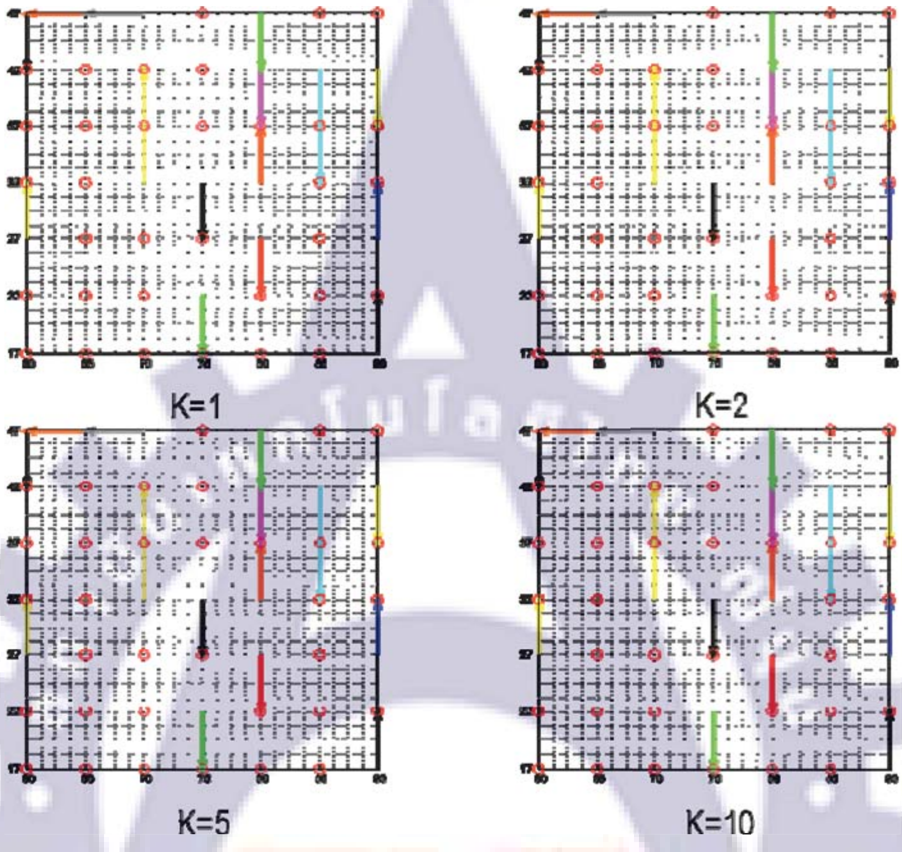

Fig. 4.20 The phase information result with 4 times of k (where k is the weight of level)

Figure 4.20 shows that 4 weights of power level can calculate the correct position equally as well. The weights 1, 2, 5 and 10 can calculate the correct position have 34 points from 49 points.

After the arrow graphs have already plotted, the bar graphs are plotted to evaluate the correct estimation ratio, average of error distance and maximum error distance.

First the correct estimation ratio, average of error distance and maximum error distance are evaluated by using three equations that mentioned in the theory section (3.1, 3.2, 3.3). The graph of three equations using three information which phase, power level and summation of phase and power level(x10) separately. Figures 4.21 and 4.22 show the correction estimation ratio of phase and power level information respectively with equations 3.1, 3.2 and 3.3.

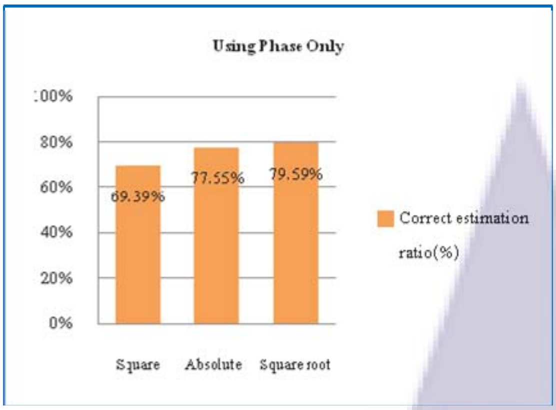

Fig. 4.21 The correct estimation ratio using phase information

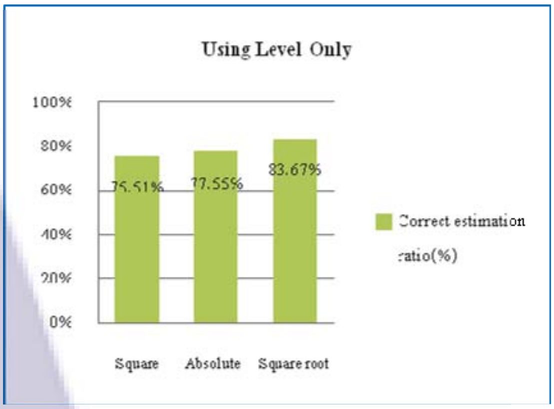

Fig. 4.22 The correct estimation ratio using power level

The results of correct estimation ratio of phase and power level information show the best equation to calculate the position estimation is square root equation. By using the phase information the correct estimation ratio of square root is 79.59%, the absolute equation is 77.55% and square equation is 69.39%. By using the power level information the correct estimation ratio of square root is 83.67%, the absolute equation is 77.55% and square equation is 75.51%. Figure 4.23 shows the correction estimation ratio using summation of phase and power level (x10) with square(3.1), absolute(3.2) and square root(3.3) equation. Figure 4.24 shows the average of error distance using phase information with square(3.1), absolute(3.2) and square root(3.3) equation.

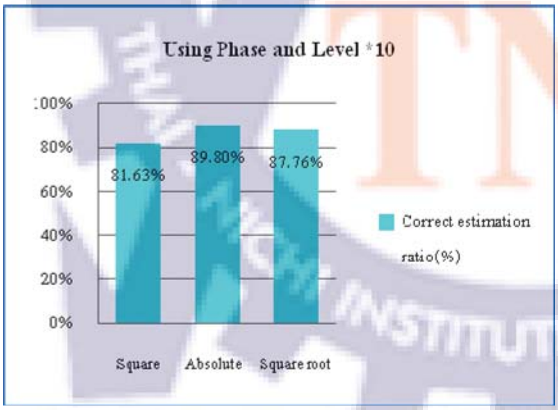

Fig. 4.23 The correct estimation ratio using summation information of phase + (level (x 10))

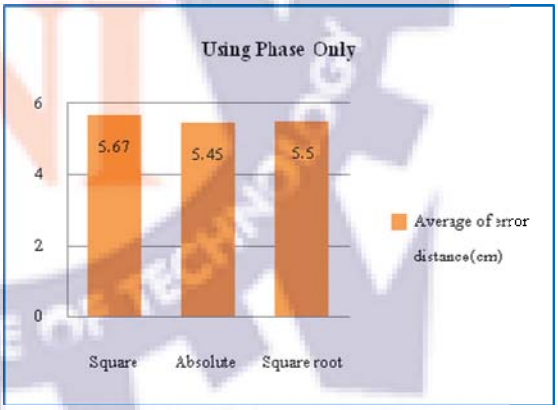

Fig. 4.24 The average of error distance using phase information

The result of the correct estimation ratio using the summation of phase and power level (x10) shows the absolute is the best equation that has the correct estimation ratio is 89.80%. The square root and square has 87.76% and 81.61% of correct estimation ratio respectively. In figure 4.24 the result shows the average of error distance with three equations, the square equation has 5.67 cm, the absolute equation has 5.45 cm and the square root equation has 5.5 cm of the average error distance. Figures 4.25 and 4.26 show the average of error distance using power level information and summation information of phase and power level(x10) respectively with equation 3.1, 3.2 and 3.3.

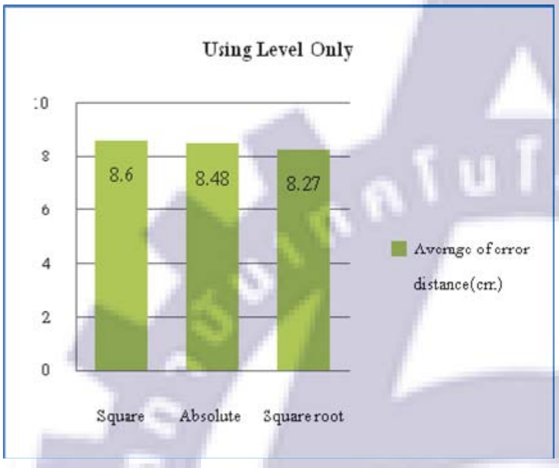

Fig. 4.25 The average of error distance using power level information

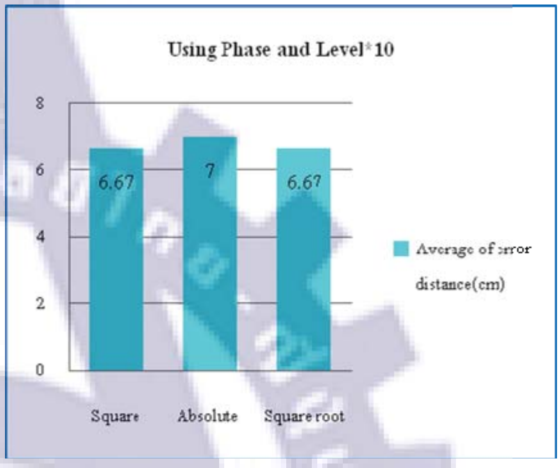

Fig. 4.26 The average of error distance using summation information of phase + (level (x10))

The graph result of the average error distance using power level information shows the square equation has the highest average error distance which 8.6 cm, the absolute equation is 8.48 cm and the square root is 8.27 cm. By using the summation of phase and power level (x10) the average error distance of square is 6.67 cm, the absolute equation is 7 cm and the square root equation is 6.67 cm. Figures 4.27 and 4.28 show the maximum error distance using phase and power level information respectively with equation 3.1, 3.2 and 3.3.

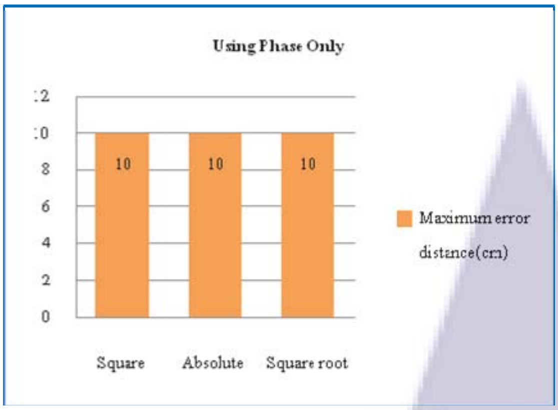

Fig. 4.27 The maximum error distance using phase information

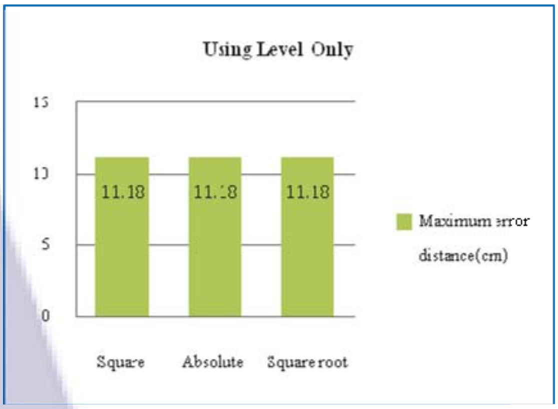

Fig. 4.28 The maximum error distance using power level

In figure 4.27 show the result that square, absolute and square root equation has equally maximum error distance that is 10 cm. The figure 4.28 show result of the maximum error distance using the power level information which the square, absolute and square root equation has equally maximum error distance that is 11.18 cm. Figure 4.29 show the maximum error distance using the summation information of phase and power level(x10) with equation 3.1, 3.2 and 3.3.

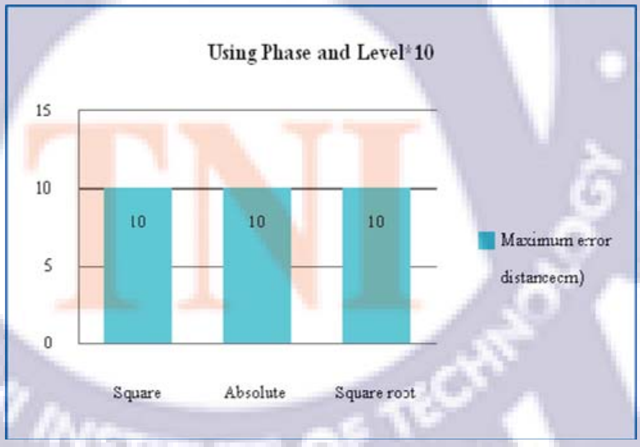

Fig. 4.29 The maximum error distance of phase + (level x 10) information using 3 equations

The graph result of the maximum error distance using the summation of phase and power level (x10) show the square, absolute and square root equation has the equally maximum error distance that is 10 cm.

Next, the bar graphs are plotted to evaluate the correct estimation ratio, average error distance and maximum error distance using three information which phase, power level and summation of phase and power level (x10) separately with three ranges of the input electrode. Figures 4.30 and 4.31 show the correct estimation ratio using phase and power level information with the three ranges of input electrode.

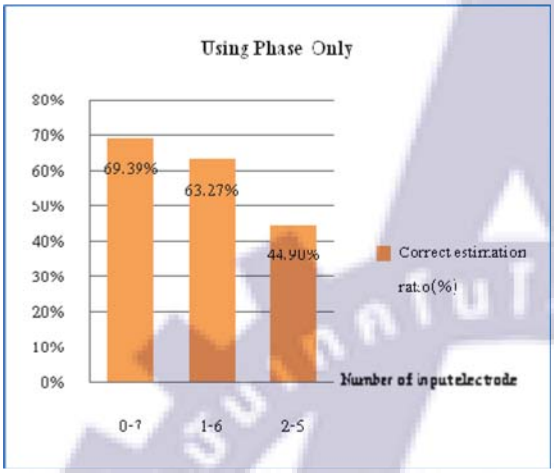

Fig. 4.30 The correct estimation ratio using phase information

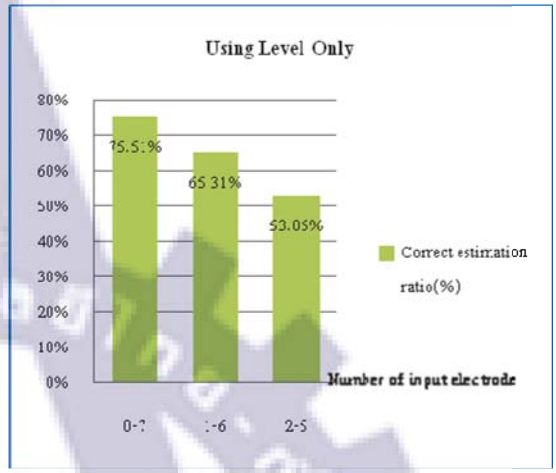

Fig. 4.31 The correct estimation ratio using phase information

In this result, the correct estimation ratio of the phase and power level information in electrode array 0-7 is the best range that has the highest correction ratio. By using the phase information the electrode array 0-7 has the correct estimation ratio is 69.39%. The electrode array 1-6 is 63.27% and electrode array 2-5 is 44.90%. By using the power level the electrode array 0-7 has 75.51% of the correct estimation ratio. The electrode array 1-6 is 65.31% and electrode array 2-5 is 53.06%. Figure 4.32 shows the correct estimation ratio using the summation information of phase and power level(x10) in the input electrode which array0-7, array1-6 and array2-5. Figure 4.33 shows the average of error distance using phase information in range of input electrode which array0-7, array1-6 and array2-5.

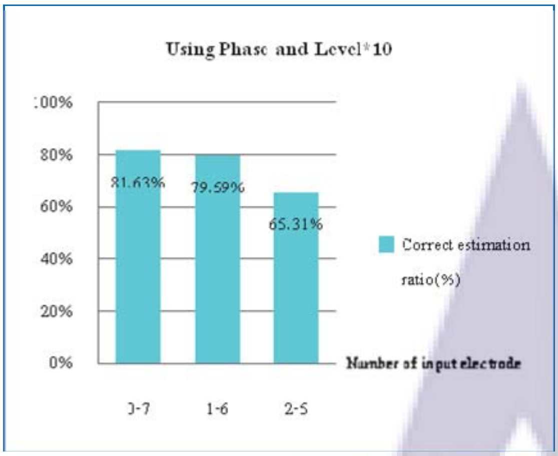

Fig. 4.32 The correct estimation ratio using phase + (level(x10))

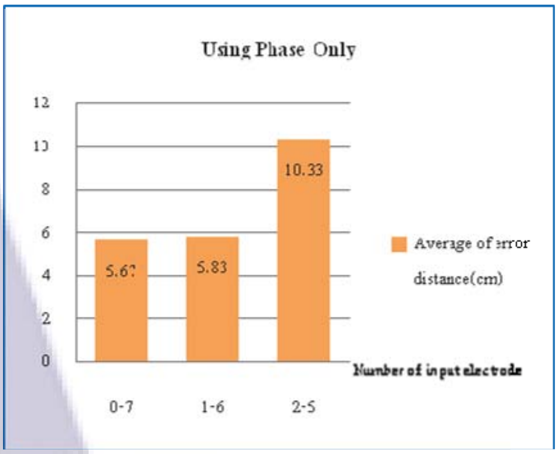

Fig. 4.33 The average of error distance using phase information

In figure 4.32 the graph result show that the correct estimation ratio by using the summation information of phase and power level(x10). The electrode array 0-7 has the highest correct estimation ratio that is 81.63%, the electrode array 1-6 is 79.59% and the electrode array is 65.31%. The graph result in figure 4.33 shows the result average error distance by using the phase information that electrode array 0-7 is 5.67 cm, the electrode array is 5.83 cm and the electrode array 2-5 is 10.33 cm. Figures 4.34 and 4.35 show the average error distance using power level and the summation information of phase and power level(x 10) in range of input electrode which array0-7, array1-6 and array2-5.

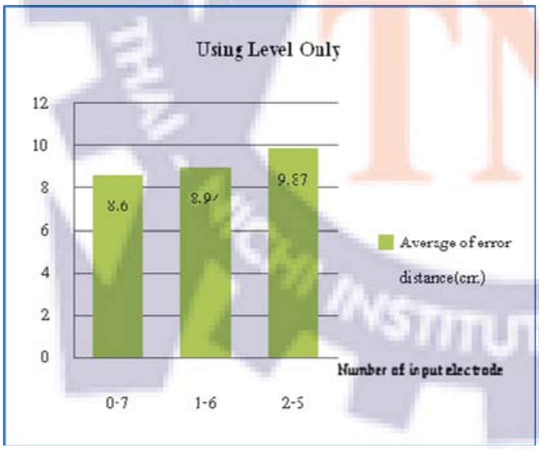

Fig. 4.34 The average error distance using power level

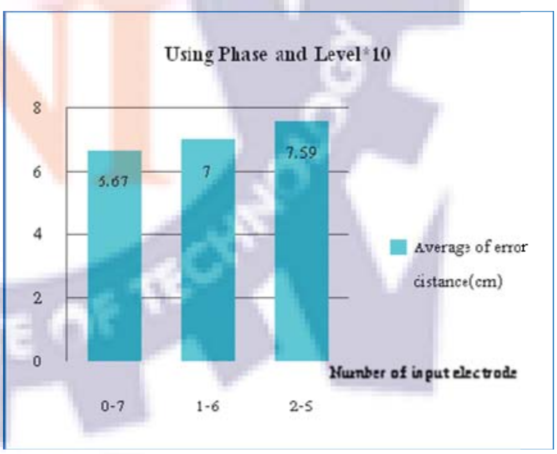

Fig. 4.35 The average error distance using phase + (level(x10))

The graph result of the average error distance using power level and the summation information of phase and power level(x10) shows the range of input electrode array 2-5 has the highest average of error distance which 9.87 cm and 7.59 cm respectively.
By using the phase information, the average of error distance of the electrode array 0-7 is 8.6 cm and the electrode array 1-6 is 8.94 cm. By using the summation of phase and power level(x10) the input electrode array 0-7 is 6.67cm and the input electrode array 1-6 is 7cm. Figures 4.36 and 4.37 show the maximum error distance using phase and power level information in the three range of electrode array respectively.

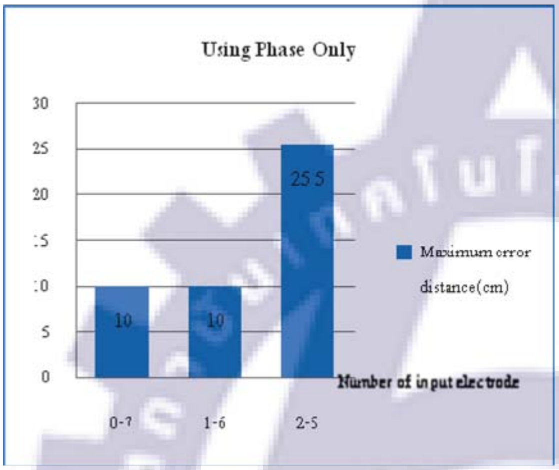

Fig. 4.36 The maximum error distance using phase information

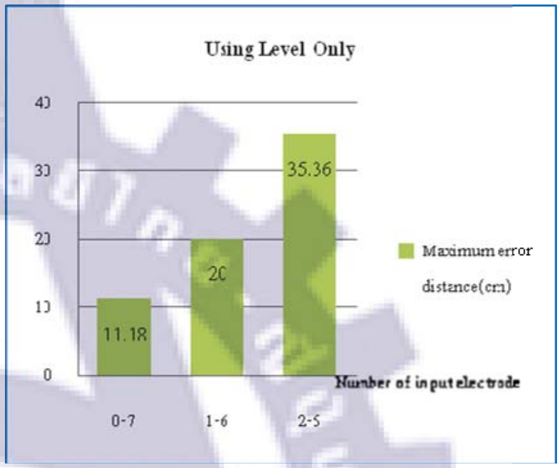

Fig. 4.37 The maximum error distance using power level information

The maximum error distance result using the both information of phase and power level, the input electrode array 2-5 has the highest error distance that is 25.5 cm and 35.36 cm respectively. By using phase information only, the input electrode array 0-7 and 1-6 has equally maximum error distance that is 10 cm. By using power level information, the input electrode array 0-7 has the maximum error distance is 11.18 cm and input electrode array 1-6 is 20 cm. Figure 4.38 shows the maximum error distance using the summation information of phase and power level(x10) in the three ranges of input electrode which array0-7, array1-6 and array2-5.

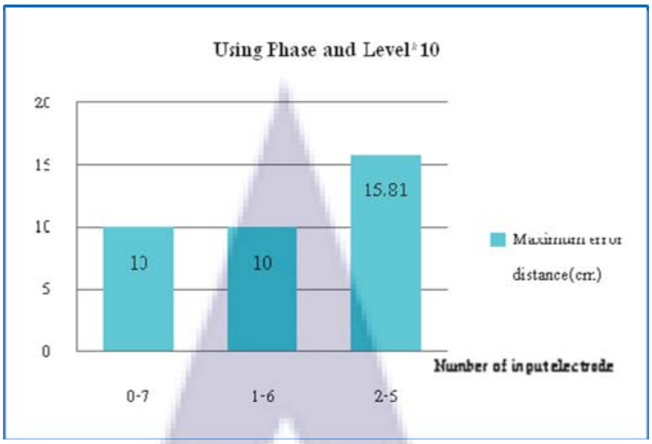

Fig. 4.38 The maximum error distance using phase+(power level(x 10))

In this graph result, the input electrode array 2-5 has the highest error distance that is 15.81 cm. The input electrode array 0-7 and 1-6 has the equally maximum error distance that is 10 cm.

The last result of the bar graph is the graph to evaluate the correct estimation, average of error distance and maximum error distance of equations 3.1, 3.2 and 3.3 separately by using the information of phase, power level and four weight of power level which k=1, k=2, k=5 and k=10. Figures 4.39 and 4.40 show the correct estimation ratio and the average error distance of square equation respectively.

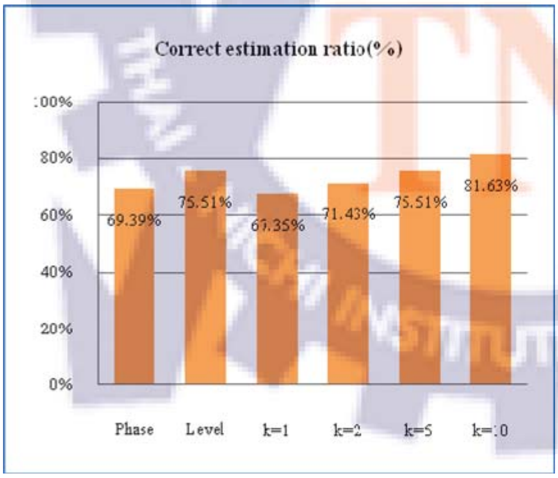

Fig. 4.39 The correct estimation ratio of square equation

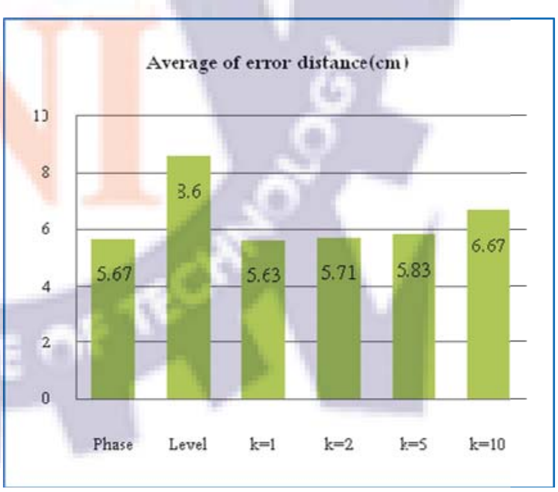

Fig. 4.40 The average of error distance of square equation

In the graph result of figure 4.39, the weight of power level that k=10 has the highest correct estimation ratio that is 81.63%. The second is the level and the weight that k=5 has the equally correct estimation ratio that is 75.51%. The correct estimation using phase is 69.39%, the weight is k=1 is 67.35% and k=2 is 71.43%. The graph result in figure 4.40, power level has the highest average error distance that is 8.6 cm. The average error distance using phase is 5.67 cm, the weight that k=1 is 5.63cm, k=2 is 5.71cm, k=5 is 5.83cm and k=10 is 6.67 cm. Figure 4.41 shows the maximum error distance of square equation. Figure 4.42 shows the correct estimation ratio of absolute equation.

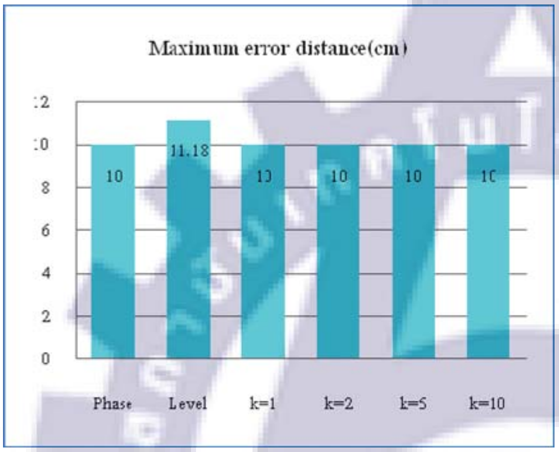

Fig. 4.41 The maximum error distance of square equation

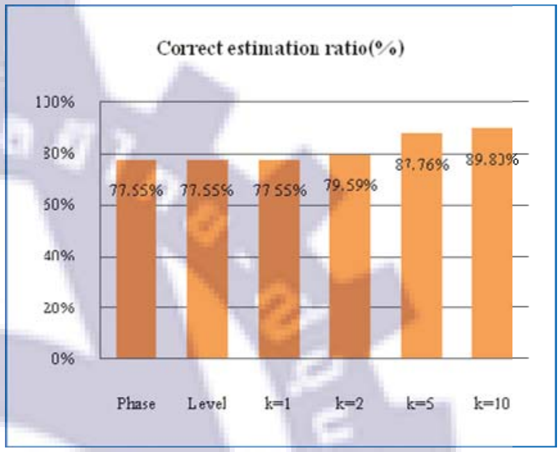

Fig. 4.42 The correct estimation ratio of absolute equation

The graph result of figure 4.41 shows the maximum error distance of the square equation that the power level has the highest error distance that is 11.18 cm. The phase, the weight that k=1, k=2, k=5 and k=10 has the equally maximum of error distance that is 10 cm. The graph result in figure 4.42 show the correct estimation ratio of the absolute equation which the weight that k=10 has the highest correct estimation ratio that is 89.80%. The phase, power level and weight that k=1 has the equally correct estimation ratio that is 77.55%. The weight that k=2 has the correct ratio is 79.59 and k=5 is 87.76%. Figures 4.43 and 4.44 show the average error distance and maximum error distance of absolute equation respectively.

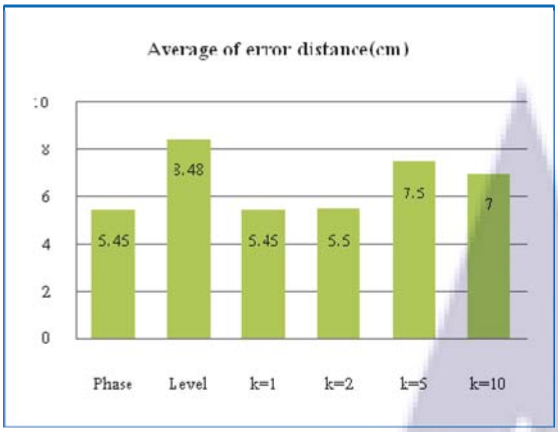

Fig. 4.43 The average error distance of absolute equation

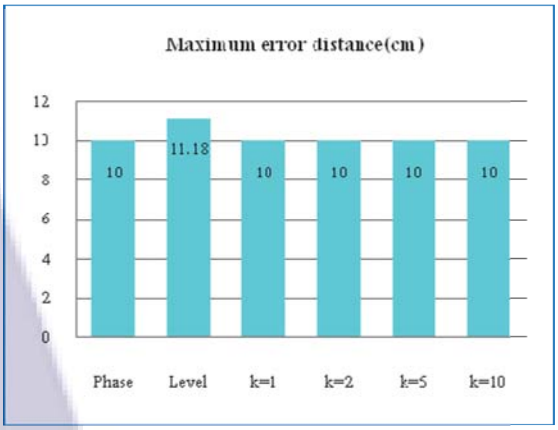

Fig. 4.44 The maximum error distance of absolute equation

The result of average error distance using absolute equation, the power level has the highest average error distance that is 8.48 cm. The phase and weight that k=1 has the equally average of error distance that is 5.45 cm. The average error distance of weight that k=2 is 5.5cm, k=5 is 7.5cm and k=10 is 7cm. Figures 4.45 and 4.46 show the correct estimation ratio and average error distance using square root equation.

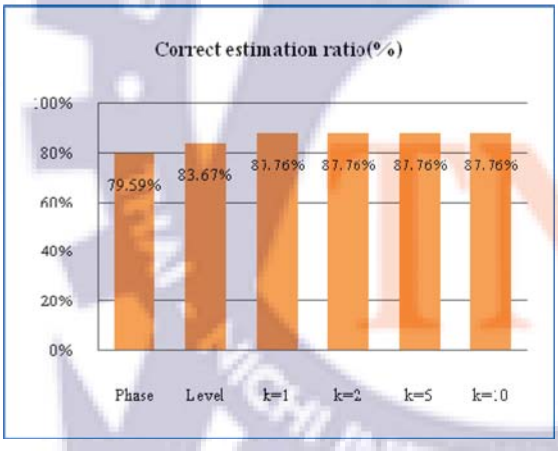

Fig. 4.45 The correct estimation ratio of square root equation

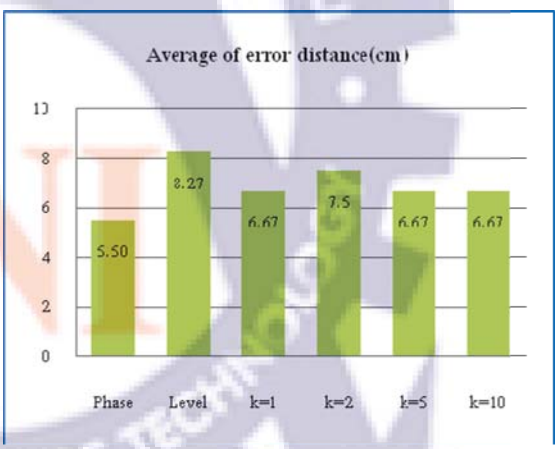

Fig. 4.46 The average of error distance of square root equation

The graph result of the correct estimation ratio using square root equation in figure 4.45, the weight that k=1, k=2, k=5 and k=10 has the equally of correct estimation ratio that is 87.76%. The correct estimation ratio of phase is 79.59% and power level is 83.67%. The graph result in figure 4.46 show the average error distance of square root equation

that the power level has the highest average error distance that is 8.27 cm. The average error distance of phase is 5.50 cm, the k=2 is 7.5 cm and the weight that k=1, k=5 and k=10 has the equally average error distance that is 6.67 cm.
Figure 4.47 shows the maximum error distance of square root equation.

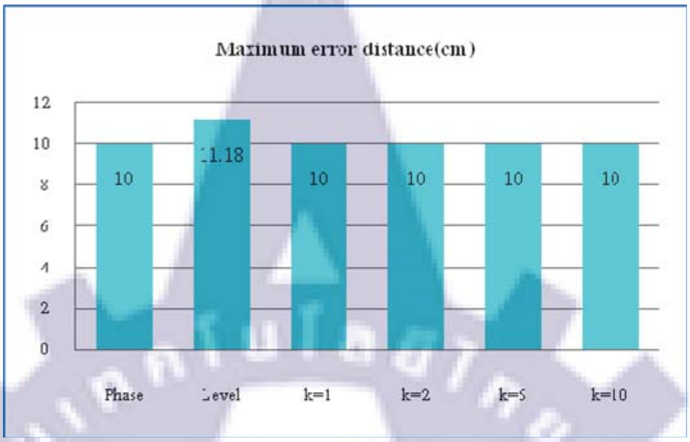

Fig. 4.47 The maximum error distance of square root

The graph result of maximum error distance using square root equation, the power level has the highest maximum error distance that is 11.18cm but the information of phase, the weight that k=1, k=2, k=5 and k=10 has equally maximum error distance that is 10 cm.

Chapter 5
Experimental Conclusion

5.1 Concluding Remarks

In this report, the position estimation is developed by using the phase difference of upon receiving pilot signal between input electrodes in two-dimensional communication. The developed system aims to precisely estimate the position of device placed on the 2DC sheet. The experimental result revealed that 80% position points can be estimated without error for any situations by using the summation of phase and power level(x10) with square equation which is the best use to precisely estimate the position of device placed on the 2DC sheet.

5.2 Experimental Conclusion

In the case that input electrodes are clipped on the top of 2DC sheet and measurement step is 5cm, the result revealed that 70% position point can be estimated without error by using the summation of phase and power level(x10) with square root equation. In the case of number of input electrode array, the result revealed that 80% position points can be estimated without error by using the summation of phase and power level (x10) and the number of input array is 0-7.

5.3 Recommendations

- This experiment needs a long lone period of time between the first measurement and second measurement. The more time of the lone period is better for the experiment because in the short lone period, it maybe have the same condition of first time so we can't get the real result of position estimation.
- While measuring it should be made sure that an antenna and electrode must come in contact with the 2DC sheet.
- Measuring method for every experiment should be same.
- There must be nothing placed on the 2DC sheet except antenna.

Chapter 6
Possible Applications

6.1 Introduction

The position estimation using phase difference of electrode array for two-dimensional (2D) communication system can be applied to new communication technology for digital-specific multimedia service [7]. In recent years, multimedia data have explosively increased in the web environment for education, investigation and exploration. At the same time, augment reality research has paid a great attention to providing views and contents in a real setting to enhance the perception of environments and spaces. A basic function position aware display is demanded in such system for many application.

Position indexing has been realized on normal computer screen by reading various input devices. However, such systems are not sufficient for indexing detail from a large map or hierarchical maps.

To develop a new communication technology, the researchers [7] construct a platform on which users can watch details just as a magnificent by touching a special sheet. The new communication technology that complements wired and wireless communications, a special physical medium has been developed to perform both data and power transmission inside 2DC sheet. Through a connector put on the top of 2DC sheet, an electromagnetic proximity connection is obtained to receive and send the electromagnetic signals, while moving the connector mounted device away from the sheet disconnects the transmission. The signal transmission covers a wide surface or on partitioned surfaces to facilitate information transmission and visualization. The system are designed and built, can enlarge details at a location or show related media data without directing viewer's focus to separated screens or windows. The system has a function of magnifier or scope to pin-point locations with a small display on surface. By placing a small high-resolution LCD on the sheet, we will be able to see position specific information and media detailed in resolution in contrast to a global map laid on the surface. The platform can look into 2D or even 3D space by touching the surface sheet with a small display.

6.2 Digital Scope System on the Sheet

The Position detection adds another dimension to the platform so that it can work as human-computer interface in a larger space than a computer screen with touch panel. A large and coarse level map is overlaid on the communication sheet or is projected onto it, and the small display device is placed on the sheet. The printed map has no influence on the electromagnetic wave. The map overlaid on the sheet can be an atlas of world, city, convention site, exhibition room, human body, etc. The map can also be a table of item as brief index of categories. Such a map or table can cover a large area or a big collection that a normal PC screen has insufficient resolution to include. For example, a street view can be displayed according to the position and orientation of the scope display on a road map. Moving a scope display along a street in the map will update the street view in it. This setting can benefit virtual navigation in large city, which is not flexible on a normal PC window that displays only a limited part of map and corresponding street view side-by-side.

Fig. 6.1 Digital scope on a 2D communication sheet to view media contents at indicated location in an atlas

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[6] **Pathloss** [Online], Available: http://en.wikipedia.org/wiki/Path_loss [2010 October 08].

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Appendix A

The remaining experimental result that input electrodes are clipped on the top, top-right, top-bottom and 4 sides of the 2DC sheet and measurement step are 2.5cm and 5cm interval.

First, the experimental result that eight input electrodes are clipped on the top of 2DC sheet and the measurement step of 2.5 cm are shown.

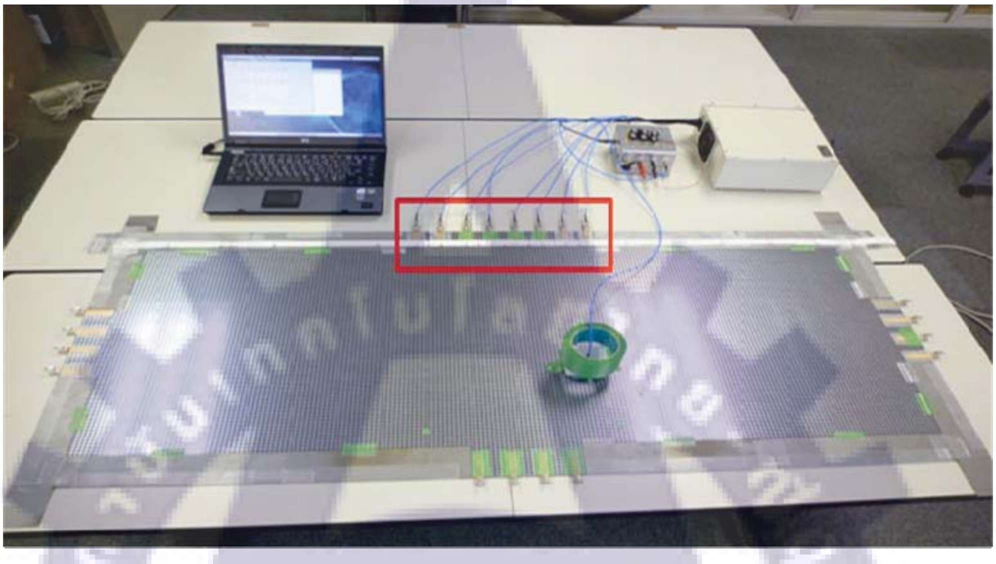

Figure a-1 The experiment set up

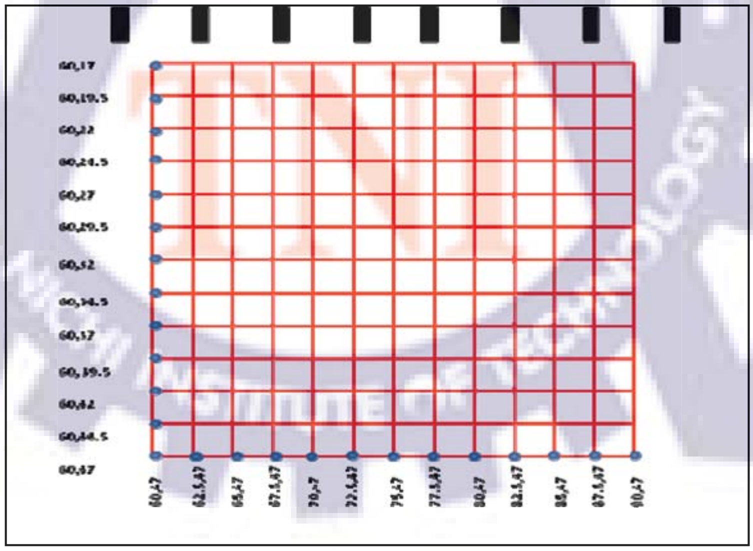

Figure a-2 The measurement condition and measurement step is 2.5 cm interval

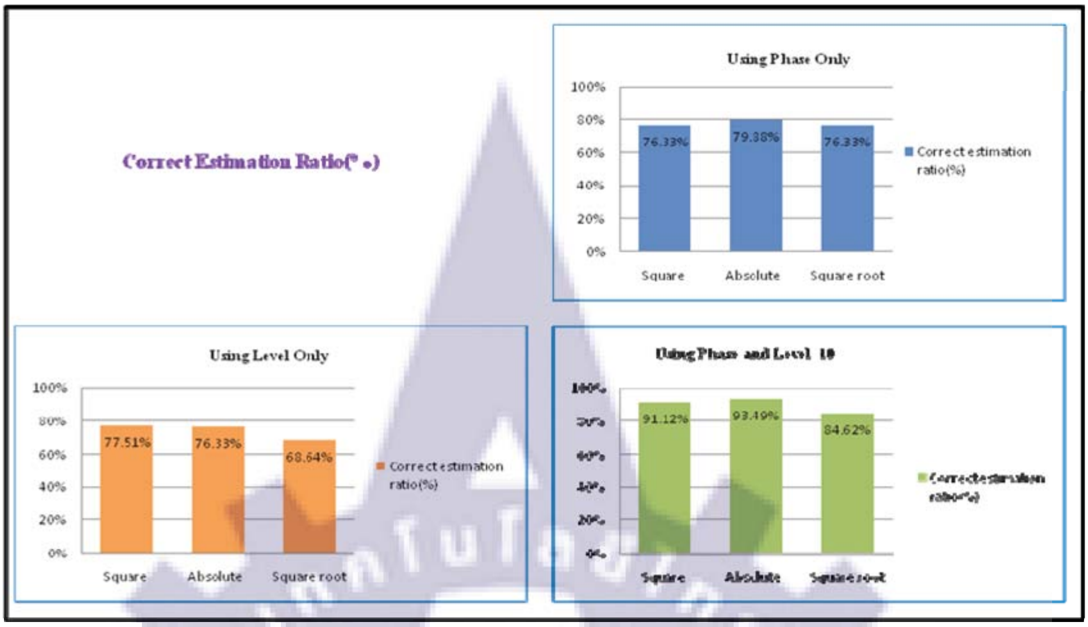

Figure a-3 The correction estimation ratio of phase, power level and summation of phase and power level(x10) information with equations 3.1, 3.2 and 3.3

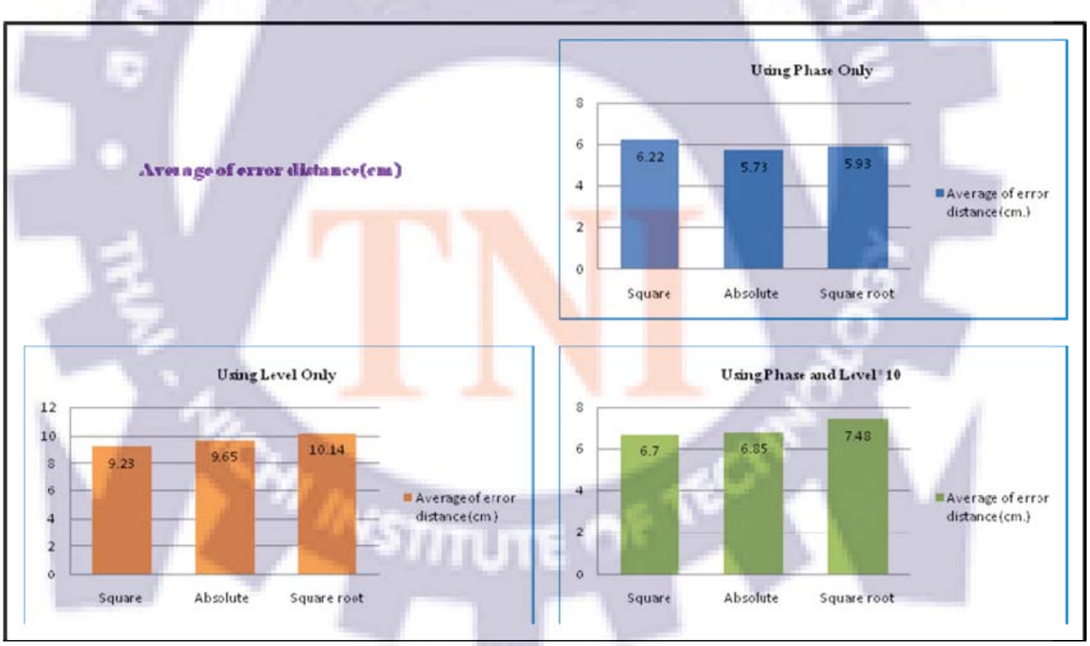

Figure a-4 The average error distance of phase, power level and summation of phase and power level(x10) information with equations 3.1, 3.2 and 3.3

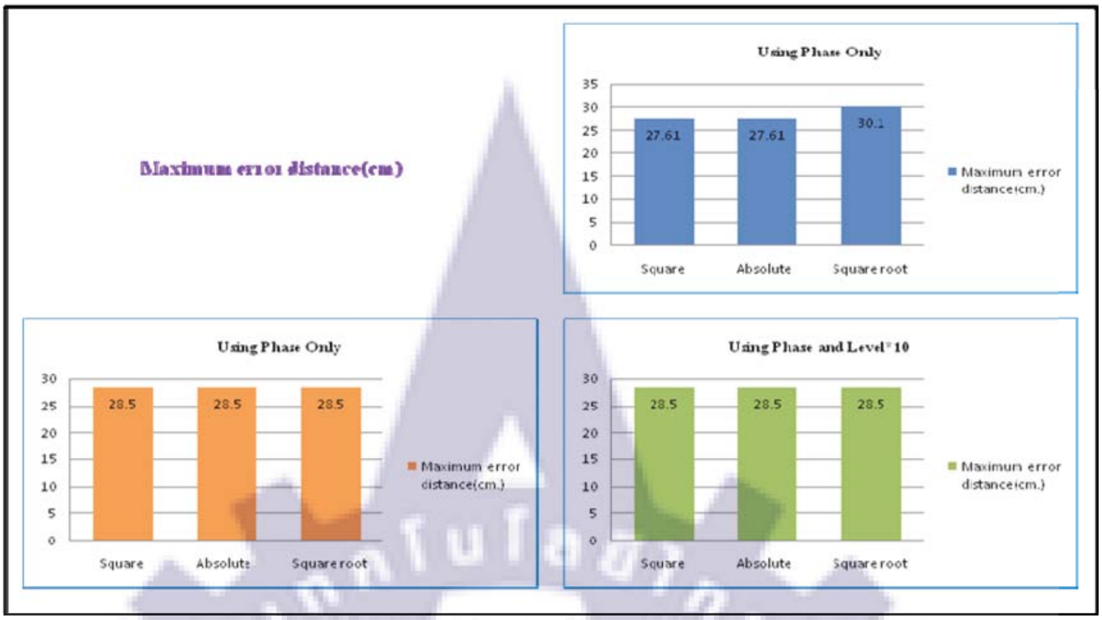

Figure a-5 The maximum error distance of phase, power level and summation of phase and power level(x10) information with equations 3.1, 3.2 and 3.3

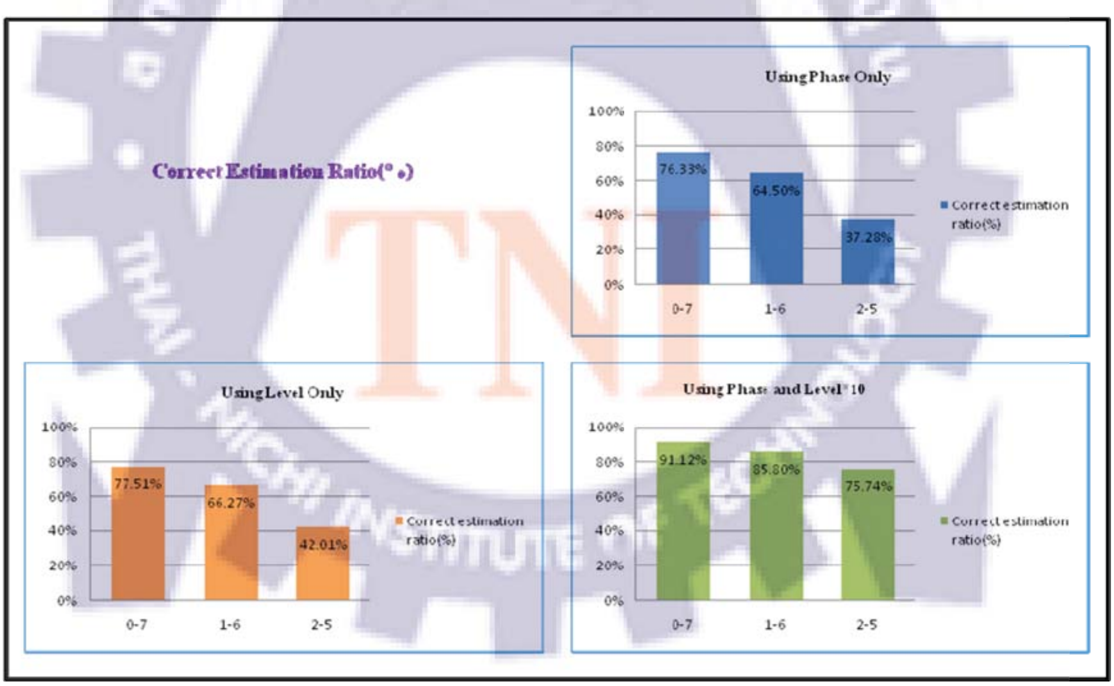

Figure a-6 The correct estimation of phase, power level and summation of phase and power level(x10) information in the three ranges of the input electrode

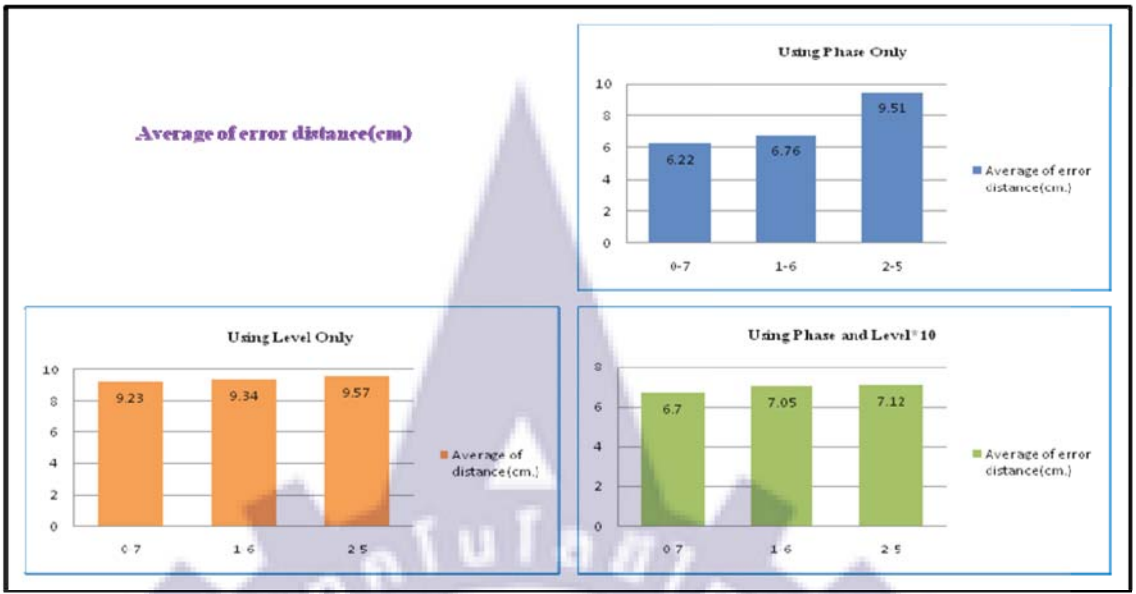

Figure a-7 The average error distance of phase, power level and summation of phase and power level(x10) information in the three ranges of the input electrode

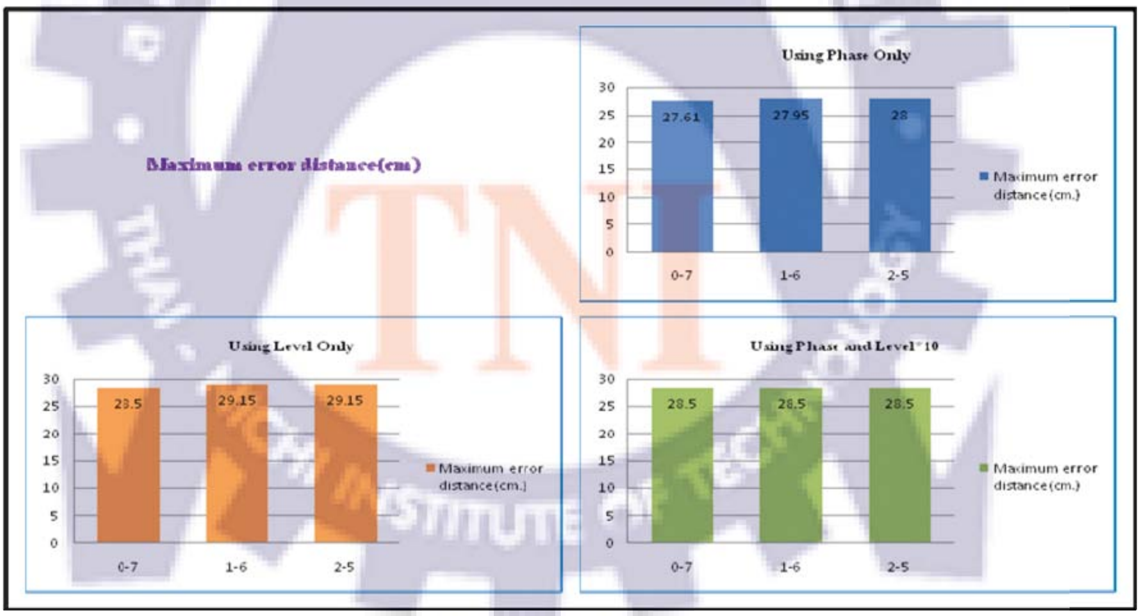

Figure a-8 The maximum error distance of phase, power level and summation of phase and power level(x10) information in the three ranges of the input electrode

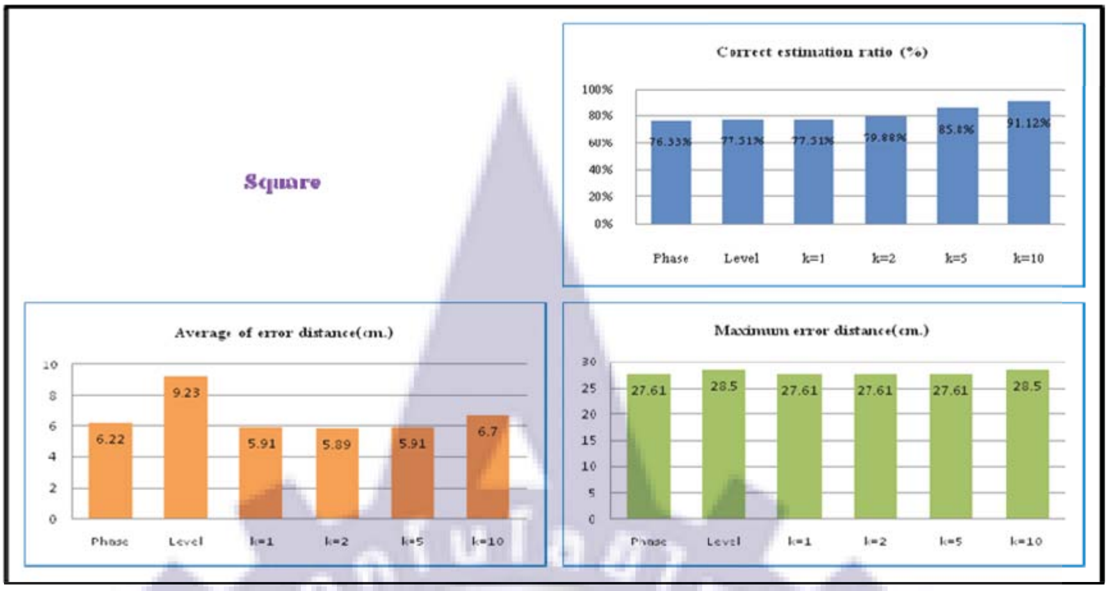

Figure a-9 The correct estimation ratio, average of error distance and maximum error distance of square equation by using the information of phase, power level and four weight of power level which k=1, k=2, k=5 and k=10

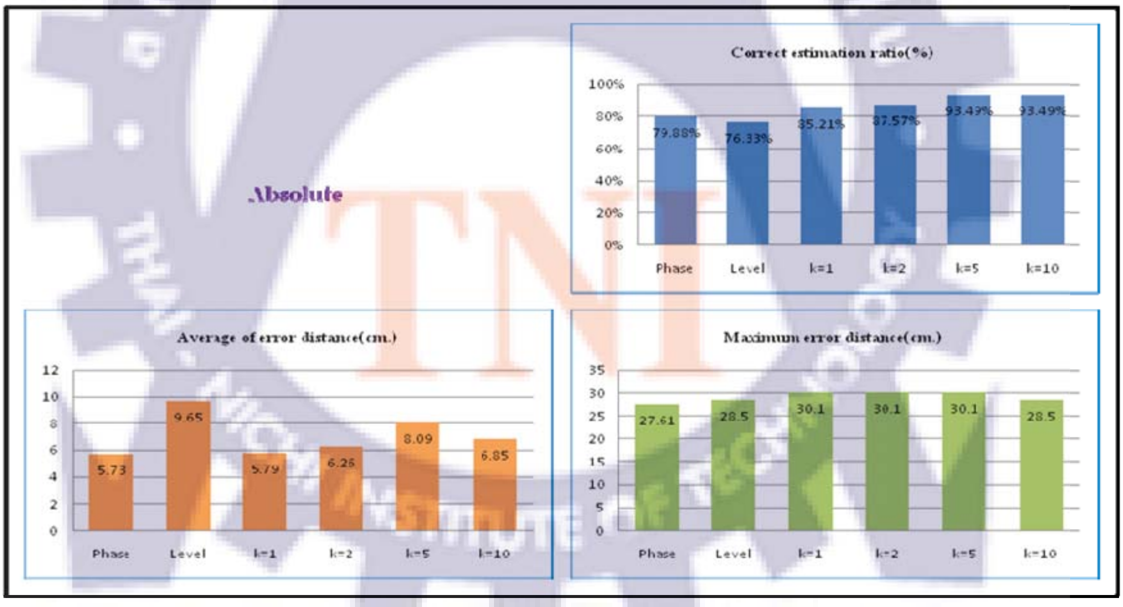

Figure a-10 The correct estimation ratio, average of error distance and maximum error distance of absolute equation by using the information of phase, power level and four weight of power level which k=1, k=2, k=5 and k=10

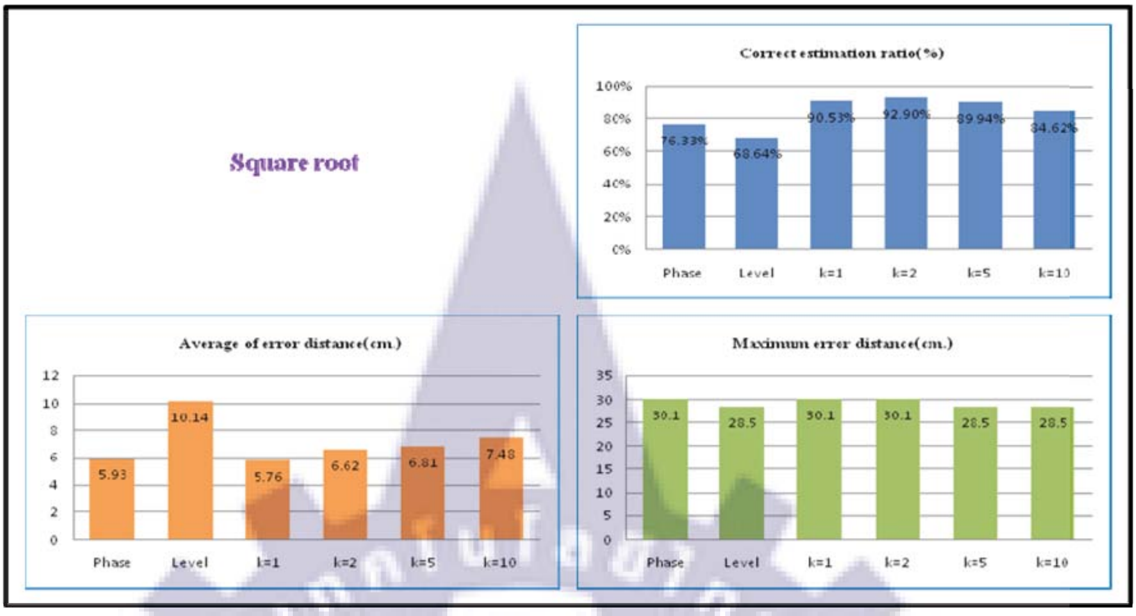

Figure a-11 The correct estimation ratio, average of error distance and maximum error distance of square root equation by using the information of phase, power level and four weight of power level which k=1, k=2, k=5 and k=10

Next, the experimental result that input electrodes are clipped on the top and right of 2DC sheet and the measurement step of 2.5cm and 5cm respectively are shown. It is starting with experimental result of 2.5cm interval.

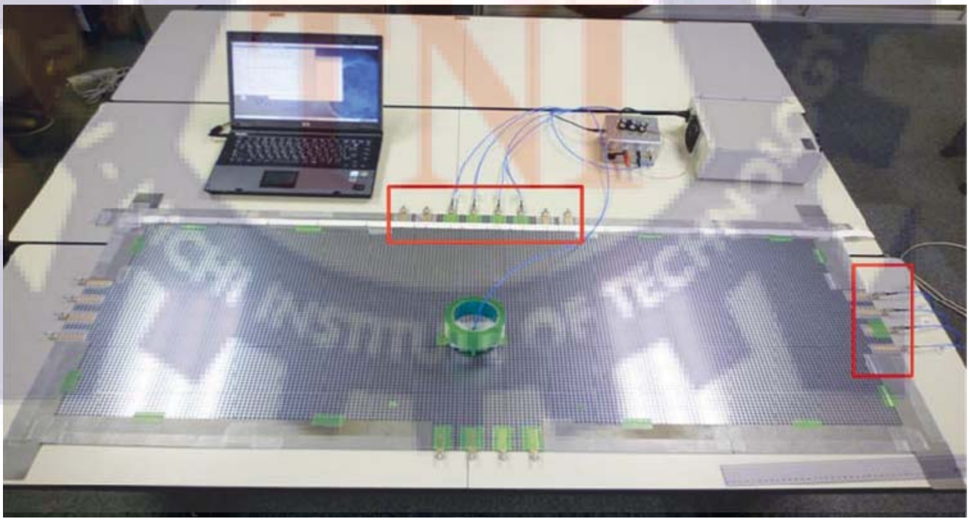

Figure a-12 The experiment set up

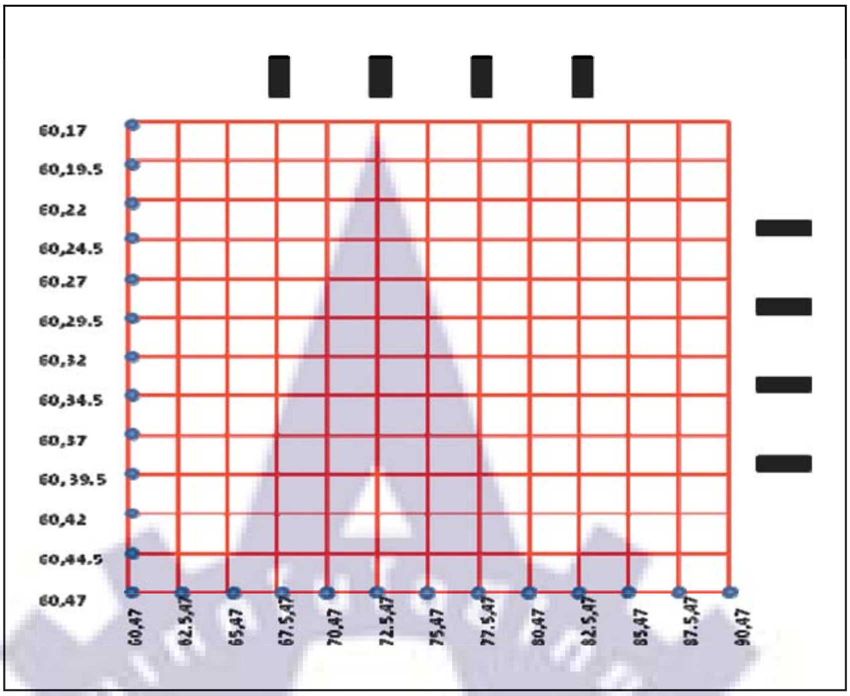

Figure a-13 The measurement condition and measurement step is 2.5 cm interval

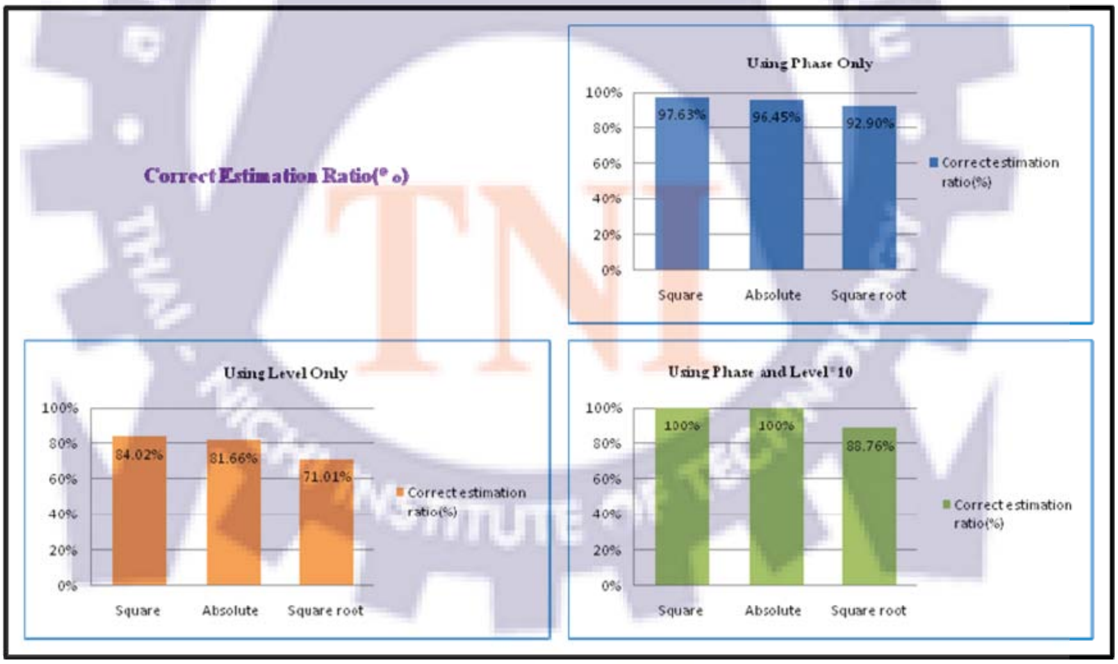

Figure a-14 The correction estimation ratio of phase, power level and summation of phase and power level(x10) information with equations 3.1, 3.2 and 3.3

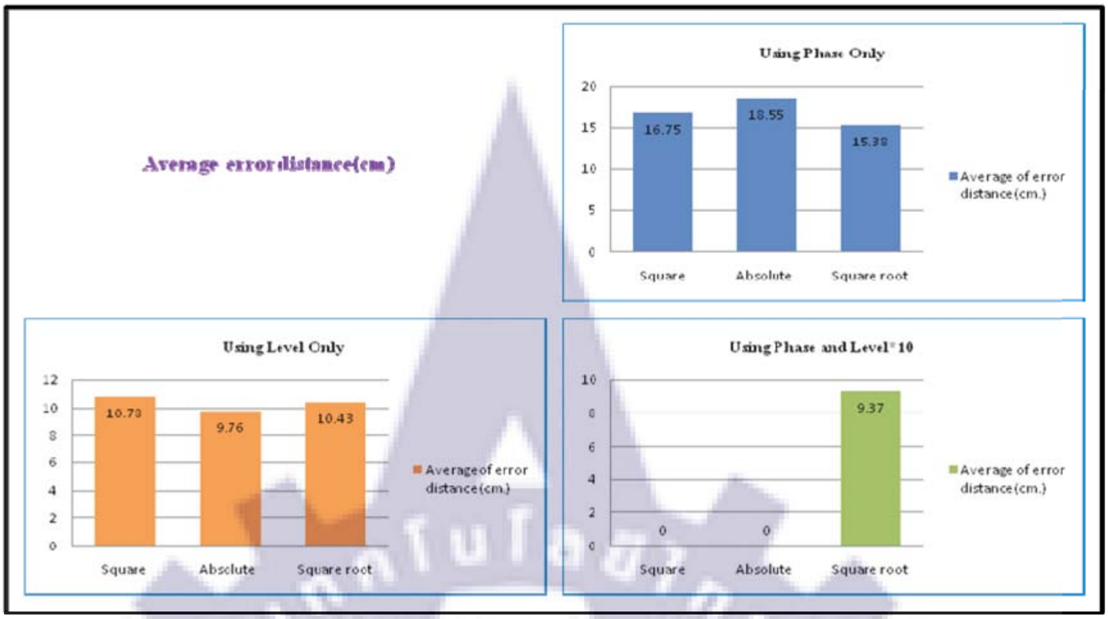

Figure a-15 The average error distance of phase, power level and summation of phase and power level(x10) information with equations 3.1, 3.2 and 3.3

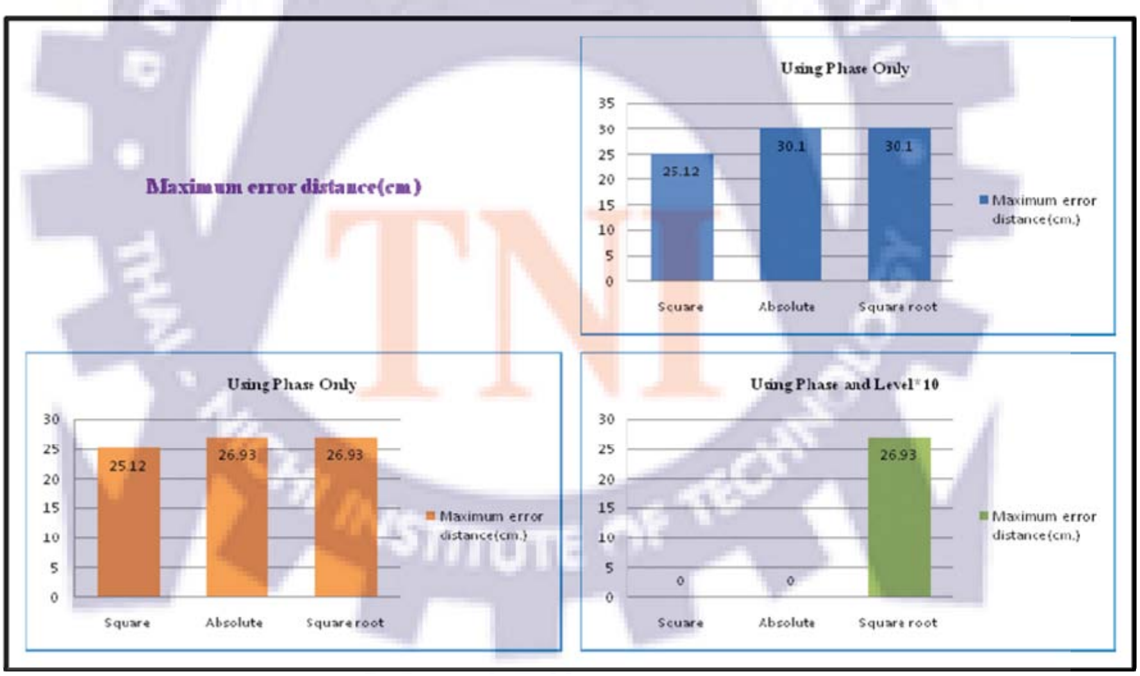

Figure a-16 The maximum error distance of phase, power level and summation of phase and power level(x10) information with equations 3.1, 3.2 and 3.3

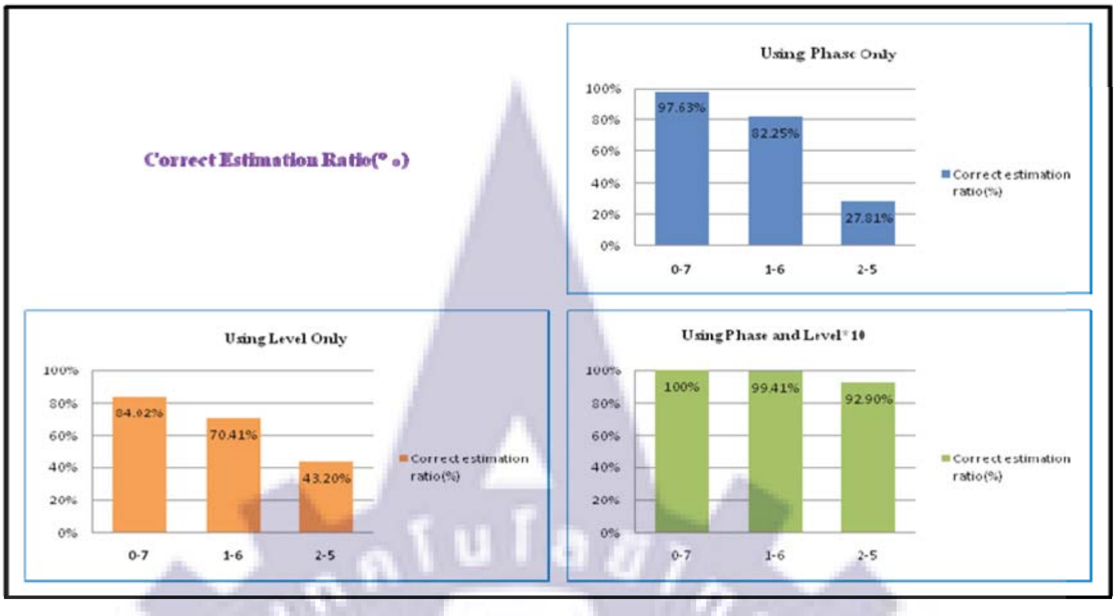

Figure a-17 The correct estimation of phase, power level and summation of phase and power level(x10) information in the three ranges of the input electrode

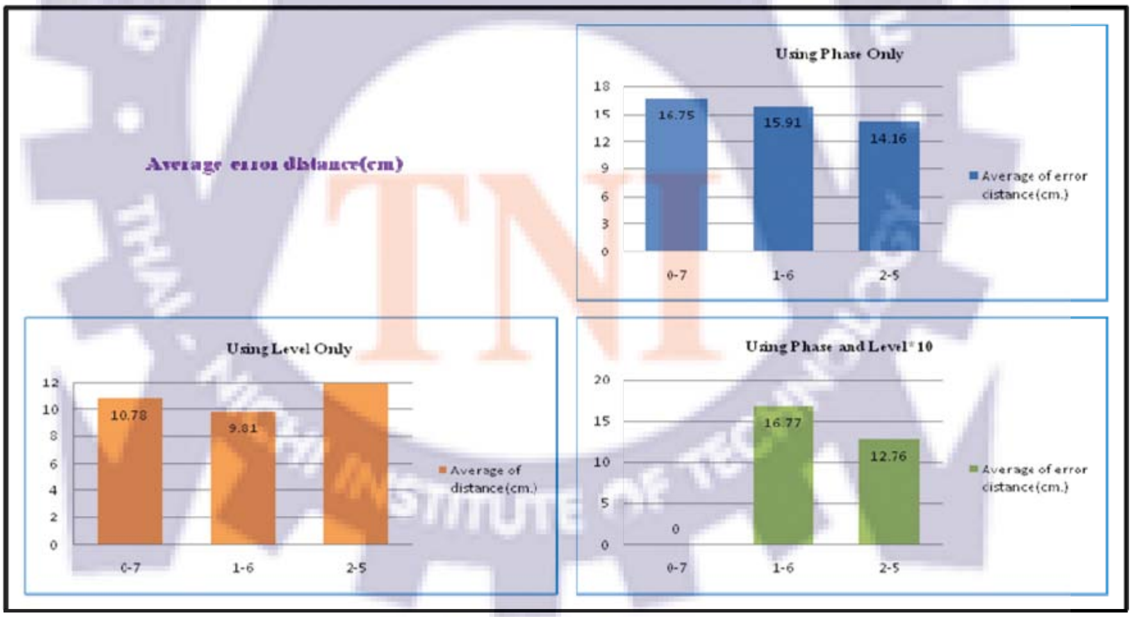

Figure a-18 The average error distance of phase, power level and summation of phase and power level(x10) information in the three ranges of the input electrode

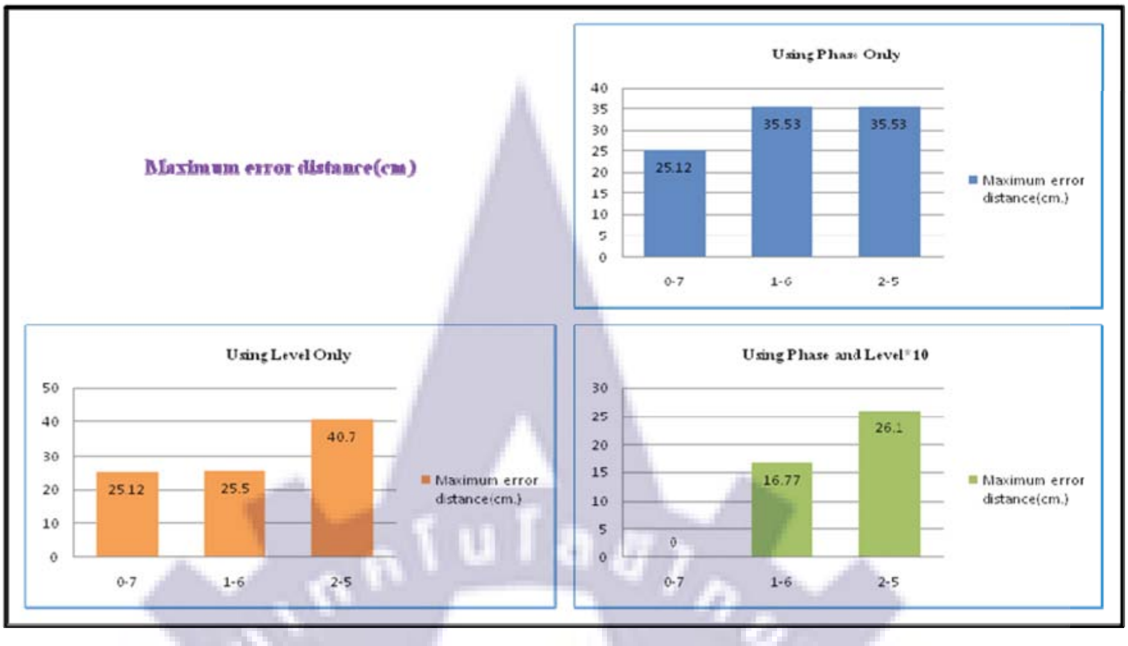

Figure a-19 The maximum error distance of phase, power level and summation of phase and power level(x10) information in the three ranges of the input electrode

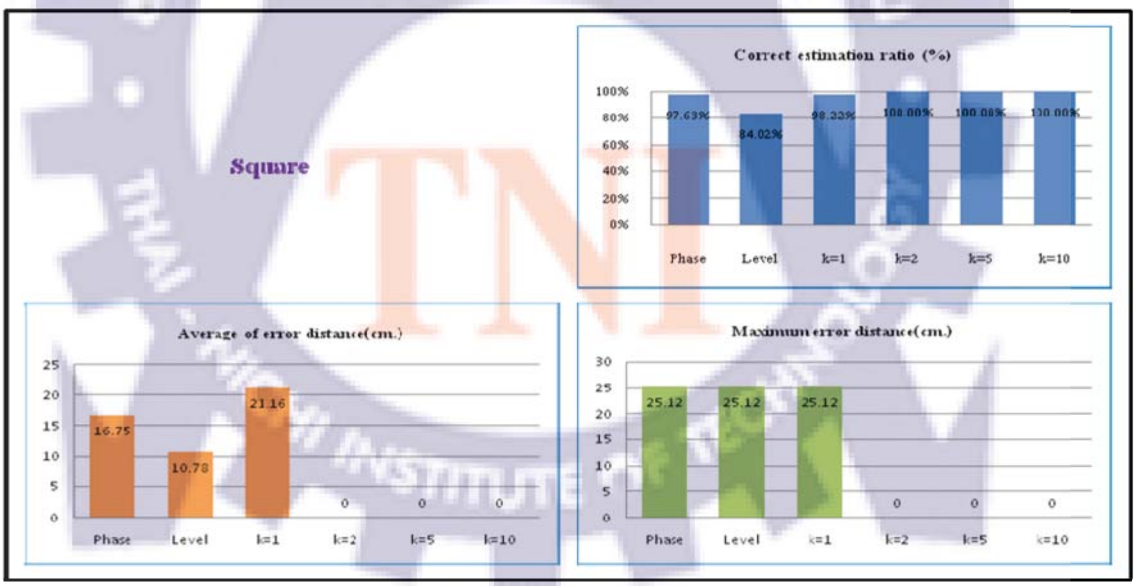

Figure a-20 The correct estimation ratio, average of error distance and maximum error distance of square equation by using the information of phase, power level and four weight of power level which k=1, k=2, k=5 and k=10

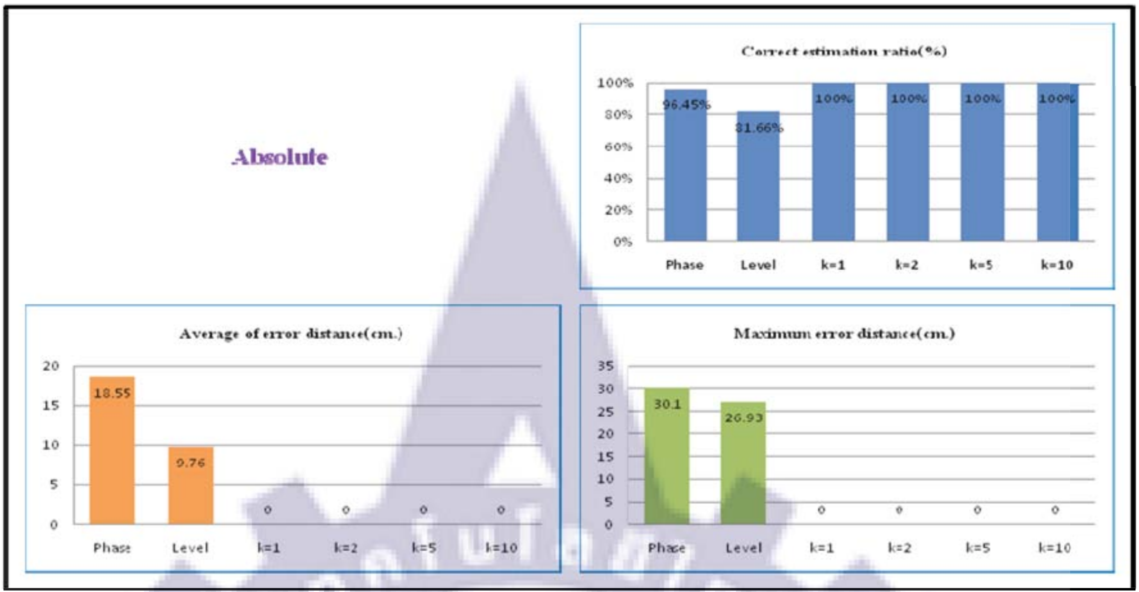

Figure a-21 The correct estimation ratio, average of error distance and maximum error distance of absolute equation by using the information of phase, power level and four weight of power level which k=1, k=2, k=5 and k=10

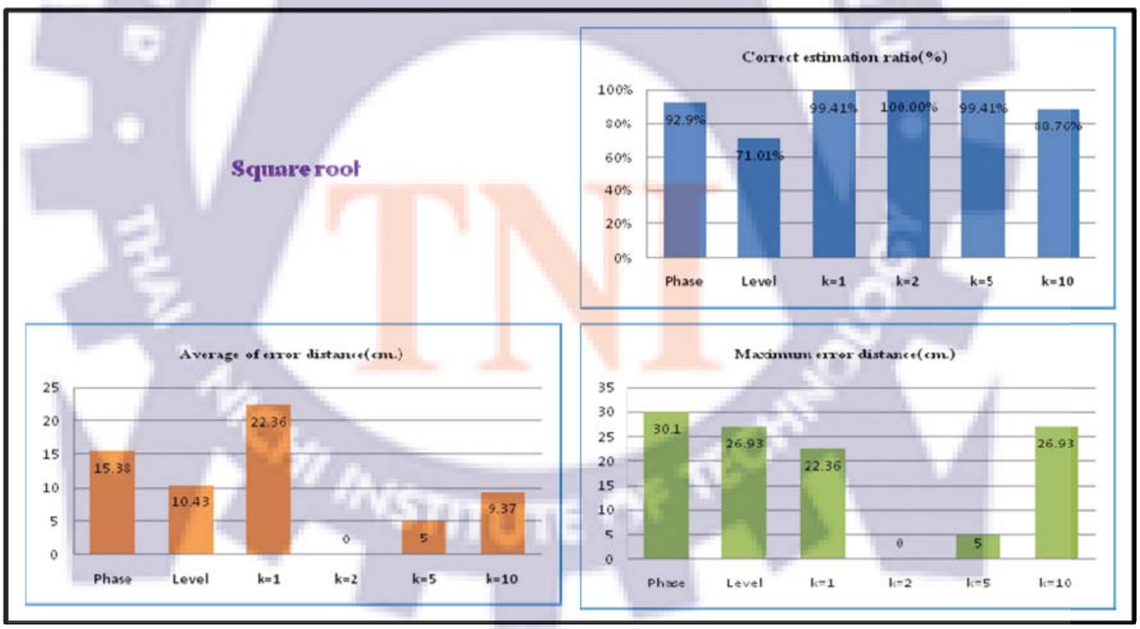

Figure a-22 The correct estimation ratio, average of error distance and maximum error distance of square root equation by using the information of phase, power level and four weight of power level which k=1, k=2, k=5 and k=10

Next, the experimental result of 5cm interval is shown.

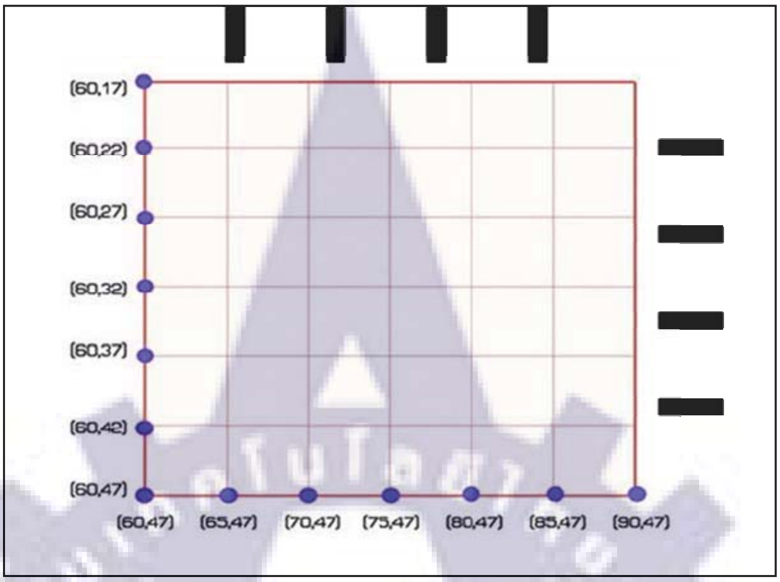

Figure a-23 The measurement condition and measurement step is 5 cm interval

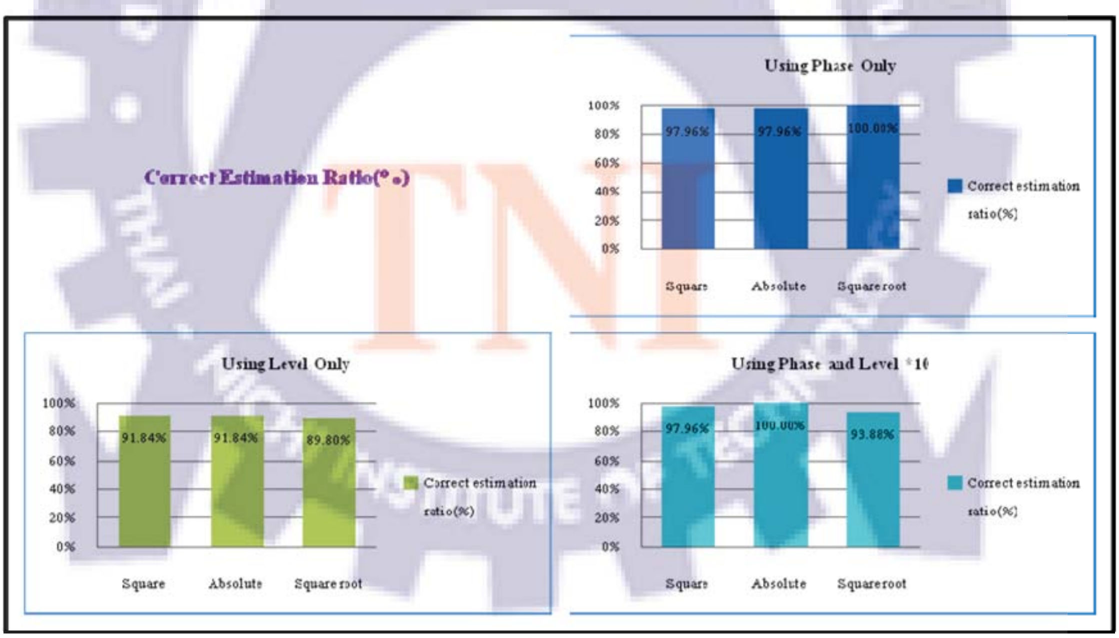

Figure a-24 The correction estimation ratio of phase, power level and summation of phase and power level(x10) information with equations 3.1, 3.2 and 3.3

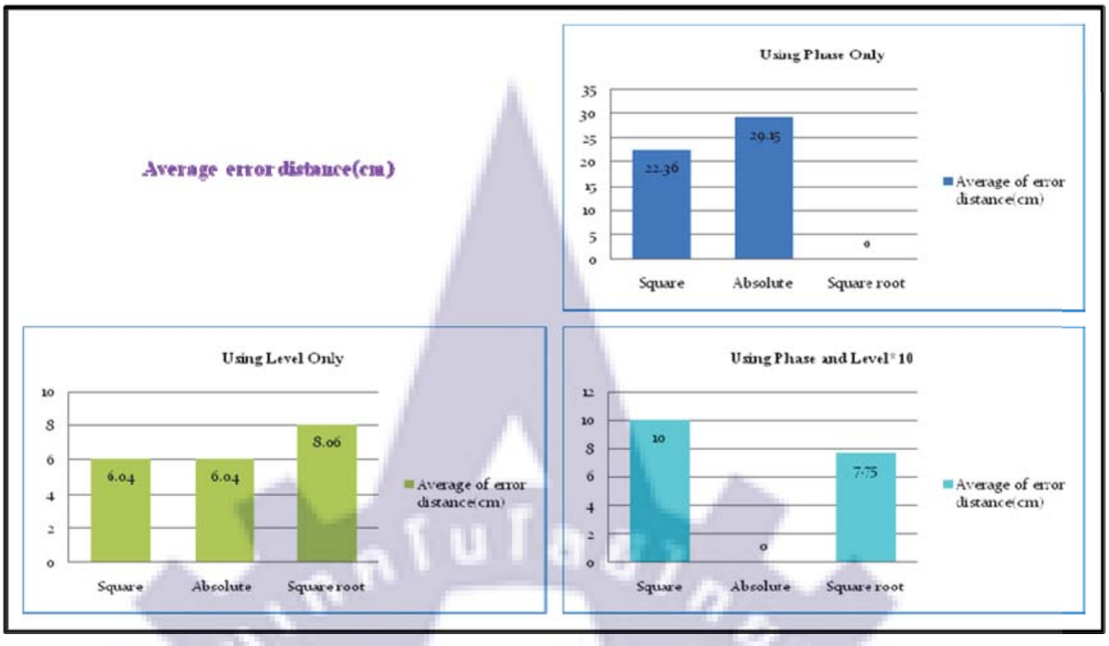

Figure a-25 The average error distance of phase, power level and summation of phase and power level(x10) information with equations 3.1, 3.2 and 3.3

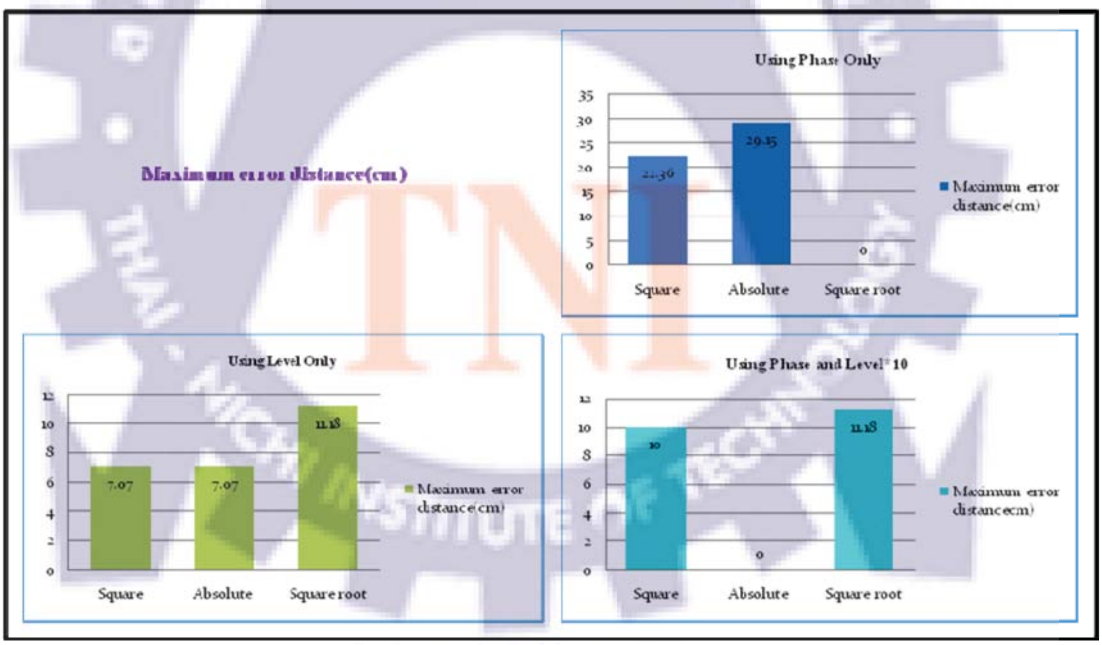

Figure a-26 The maximum error distance of phase, power level and summation of phase and power level(x10) information with equations 3.1, 3.2 and3.3

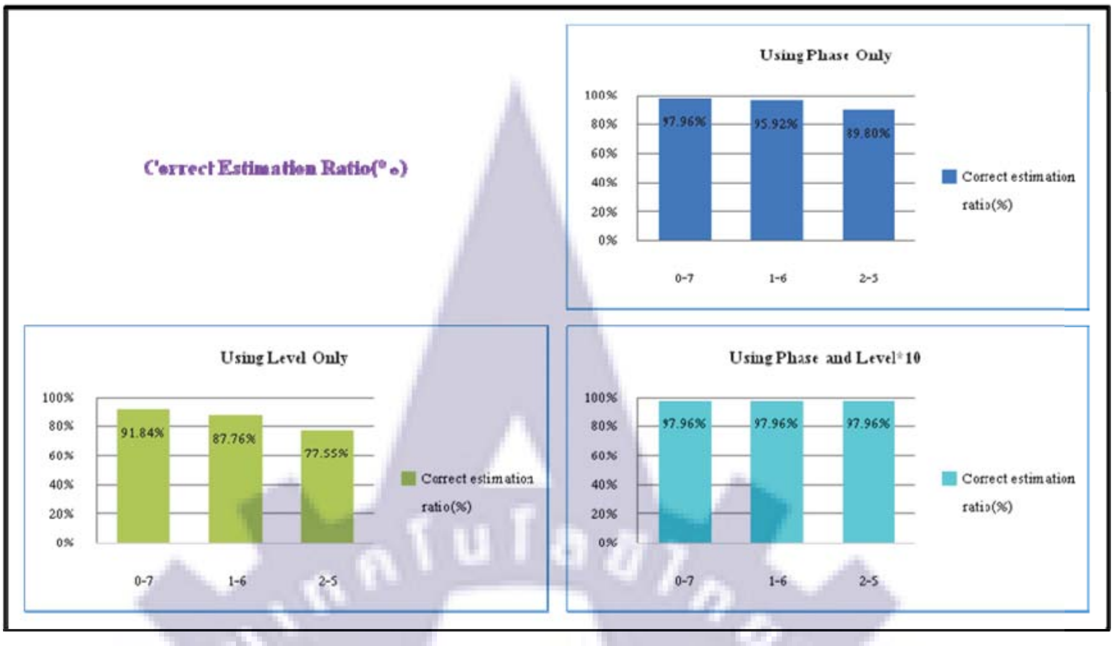

Figure a-27 The correct estimation of phase, power level and summation of phase and power level(x10) information in the three ranges of the input electrode

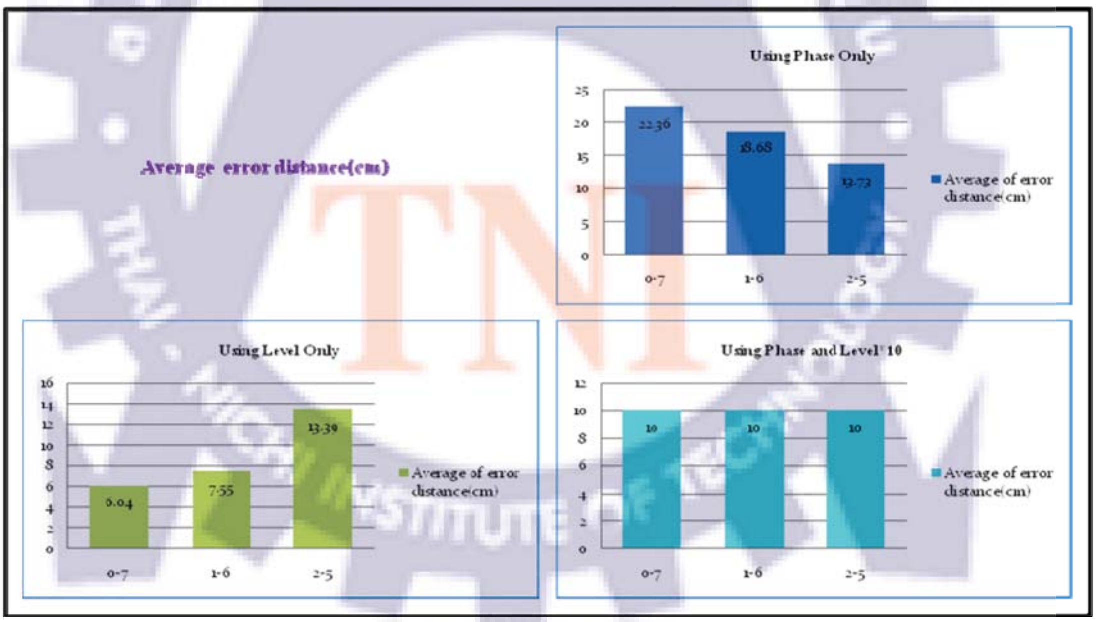

Figure a-28 The average error distance of phase, power level and summation of phase and power level(x10) information in the three ranges of the input electrode

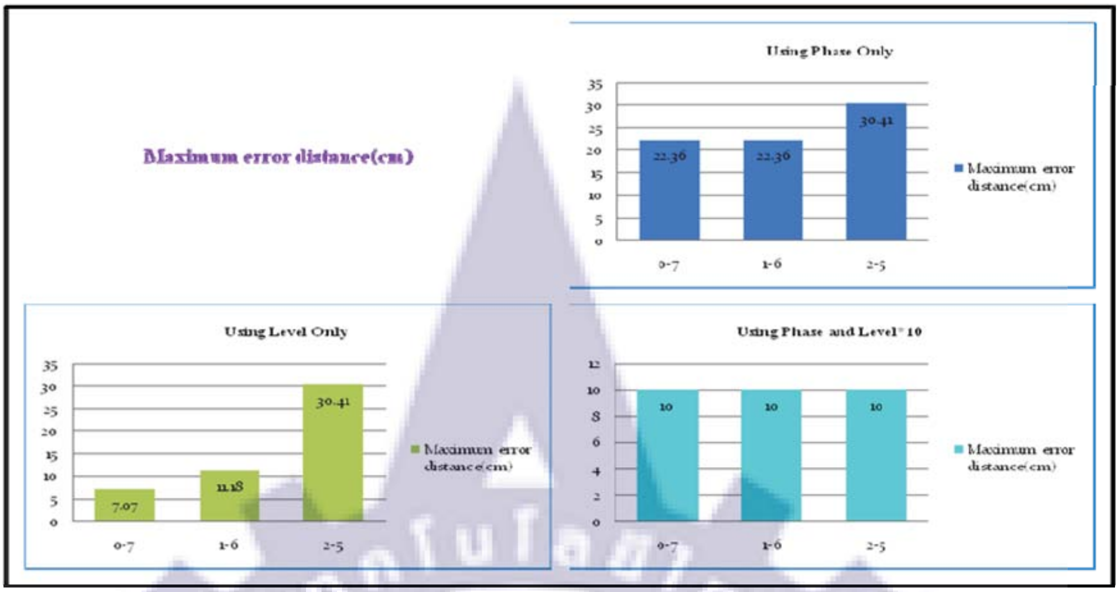

Figure a-29 The maximum error distance of phase, power level and summation of phase and power level(x10) information in the three ranges of the input electrode

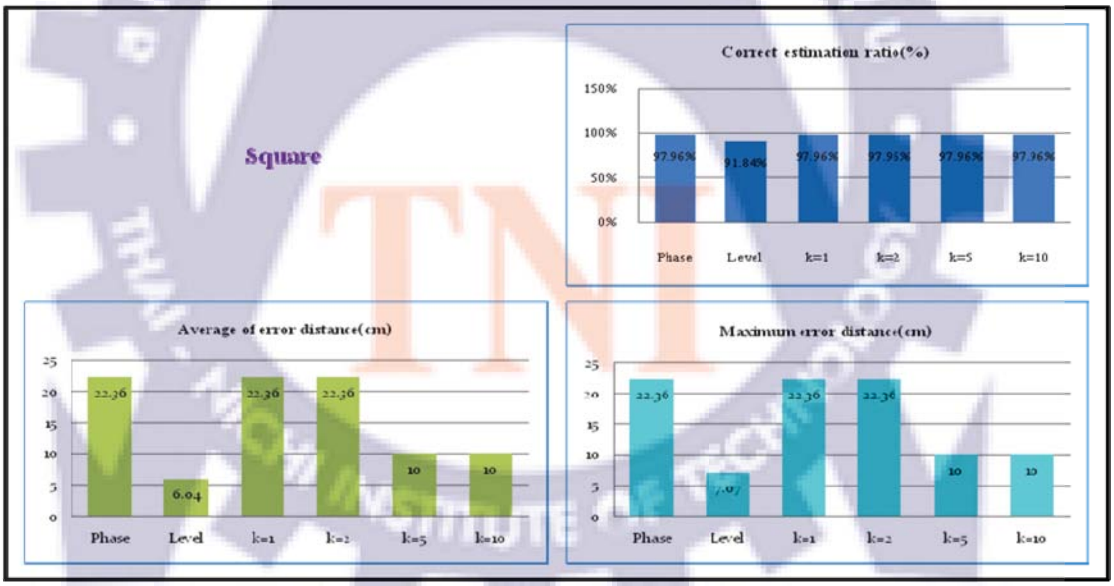

Figure a-30 The correct estimation ratio, average of error distance and maximum error distance of square equation by using the information of phase, power level and four weight of power level which k=1, k=2, k=5 and k=10

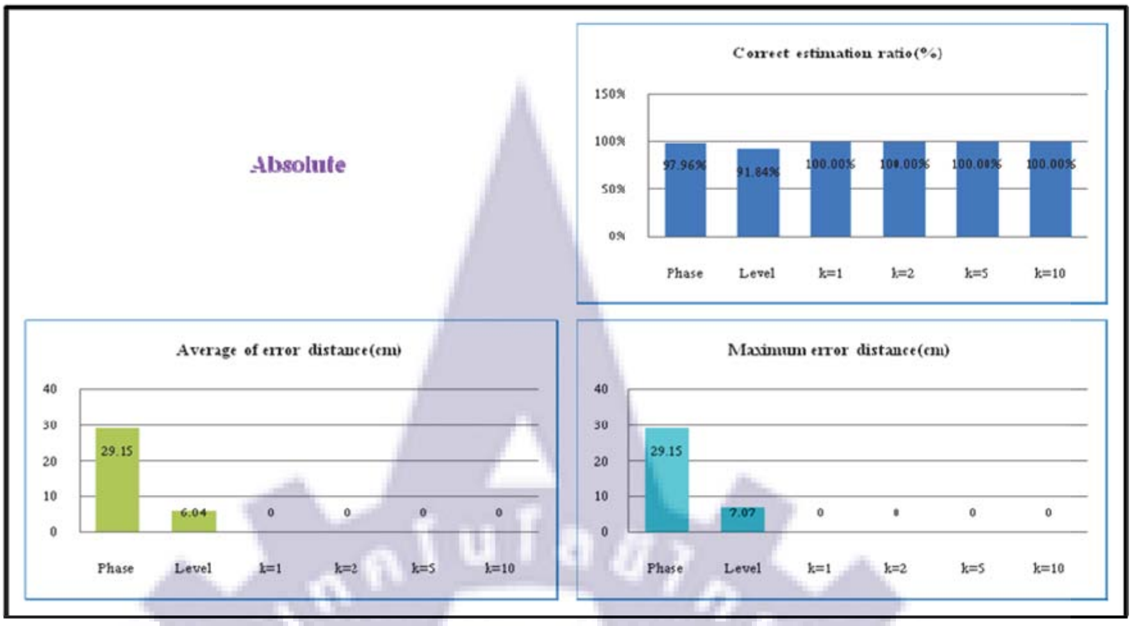

Figure a-31 The correct estimation ratio, average of error distance and maximum error distance of absolute equation by using the information of phase, power level and four weight of power level which k=1, k=2, k=5, k=10

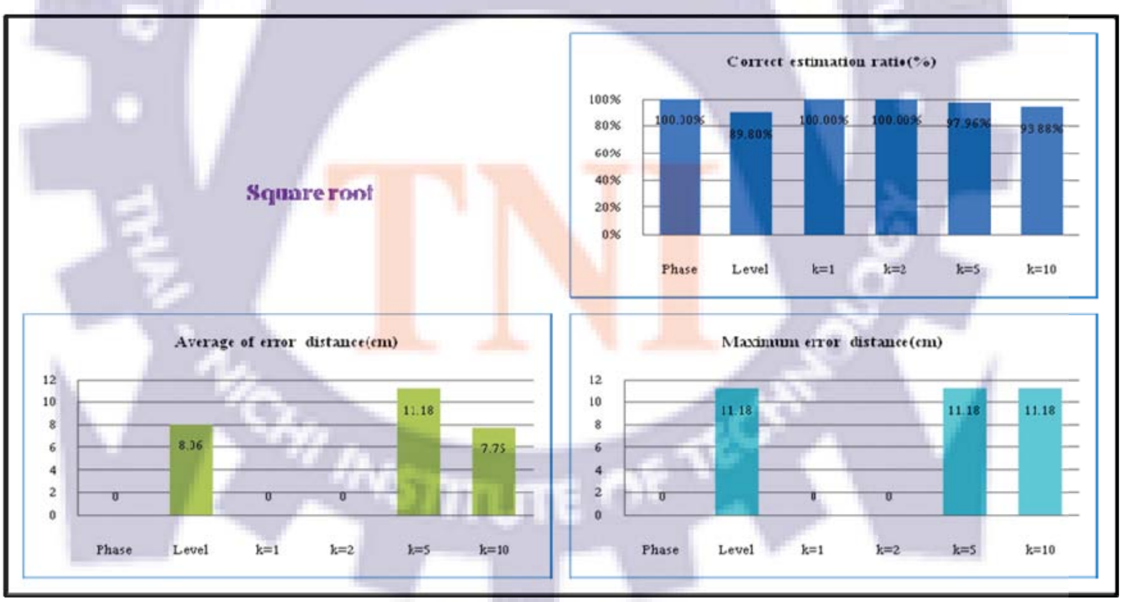

Figure a-32 The correct estimation ratio, average of error distance and maximum error distance of square root equation by using the information of phase, power level and four weight of power level which k=1, k=2, k=5 and k=10

Next the experimental result that input electrodes are clipped on the top and bottom of 2DC sheet and the measurement steps of 2.5cm and 5cm respectively are shown. It is starting with experimental result of 2.5cm interval.

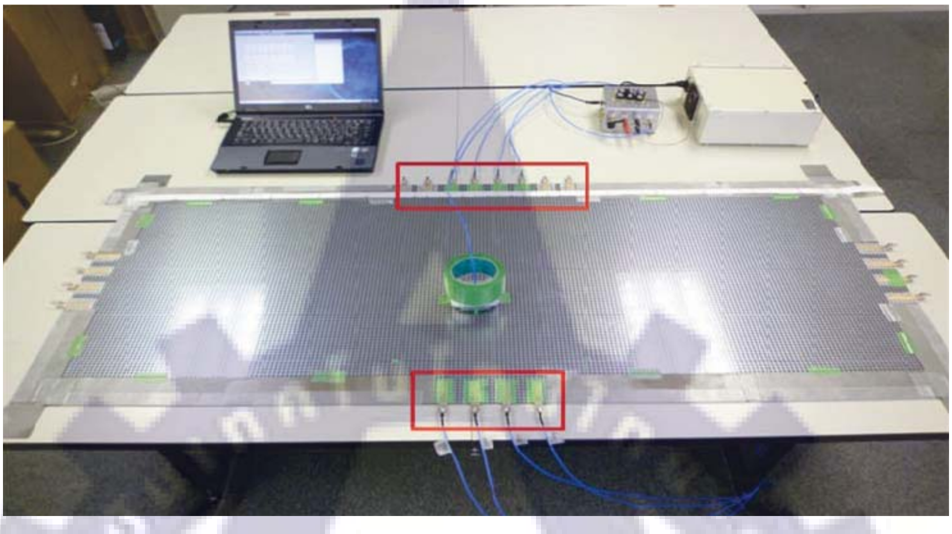

Figure a-33 The experiment set up

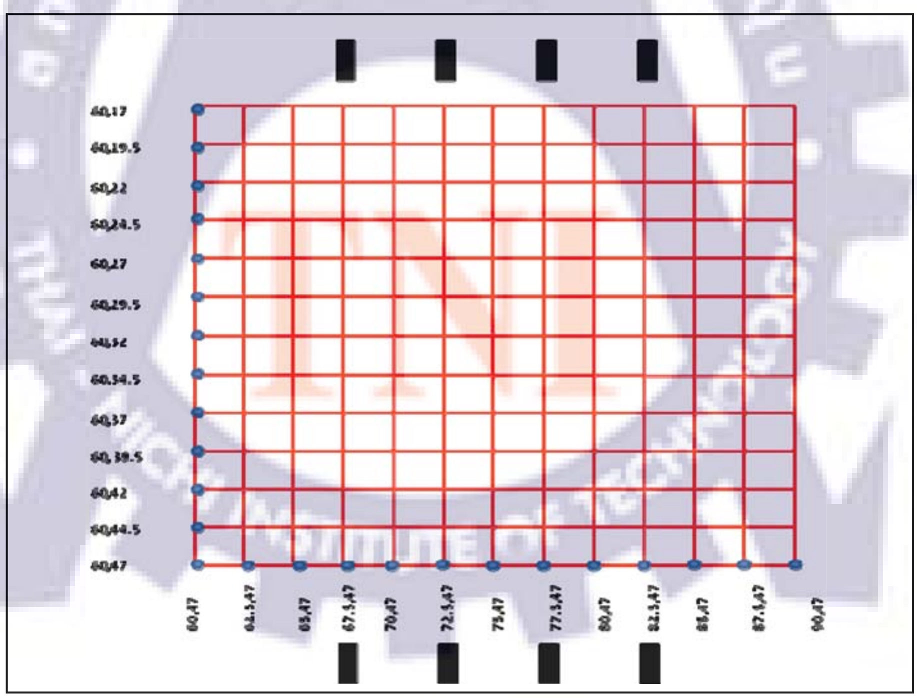

Figure a-34 The measurement condition and measurement step is 2.5 cm interval

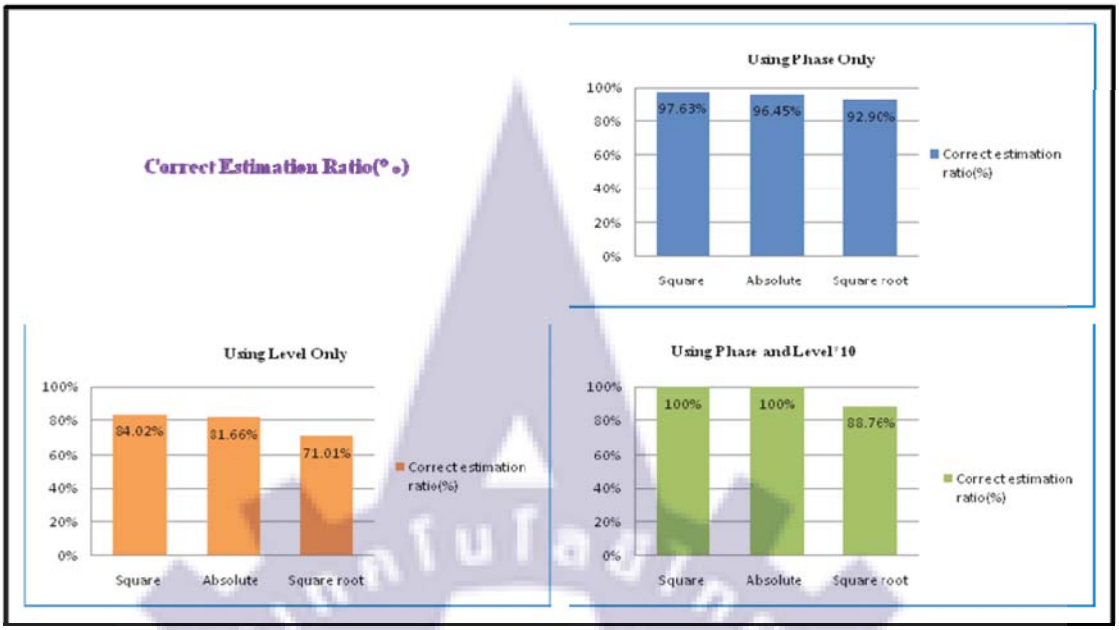

Figure a-35 The correction estimation ratio of phase, power level and summation of phase and power level(x10) information with equations 3.1, 3.2 and 3.3

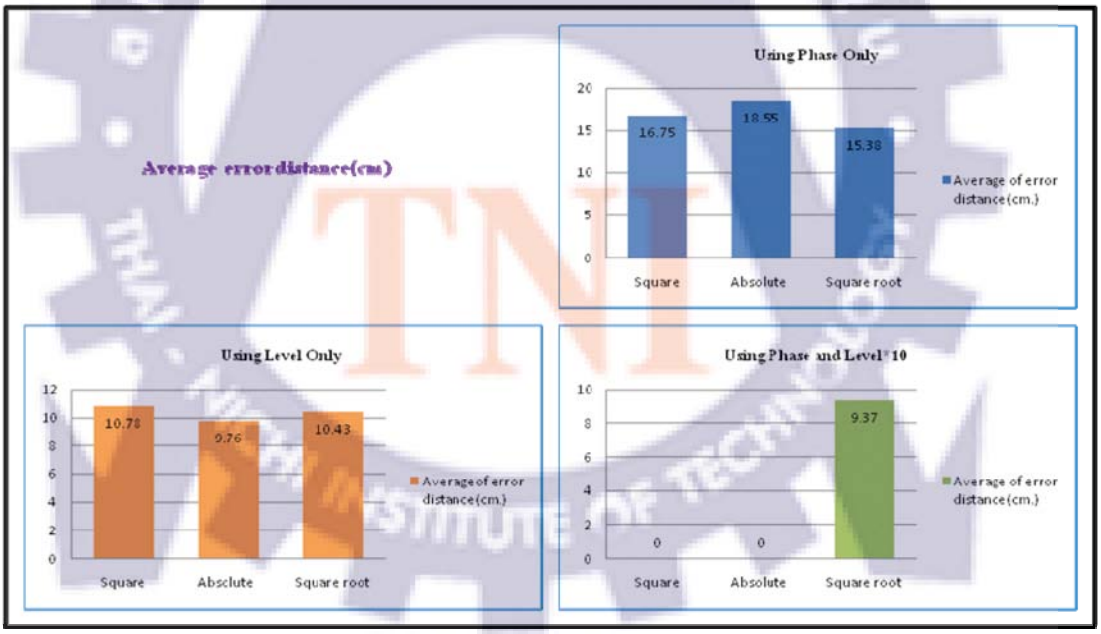

Figure a-36 The average error distance of phase, power level and summation of phase and power level(x10) information with equations 3.1, 3.2 and 3.3

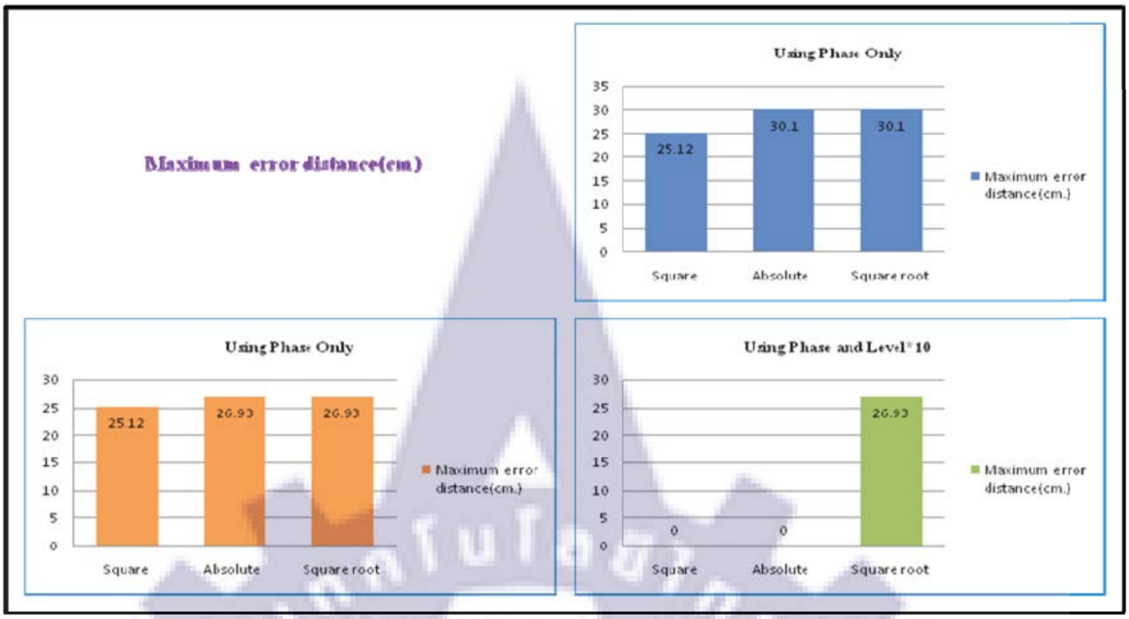

Figure a-37 The maximum error distance of phase, power level and summation of phase and power level(x10) information with equations 3.1, 3.2 and 3.3

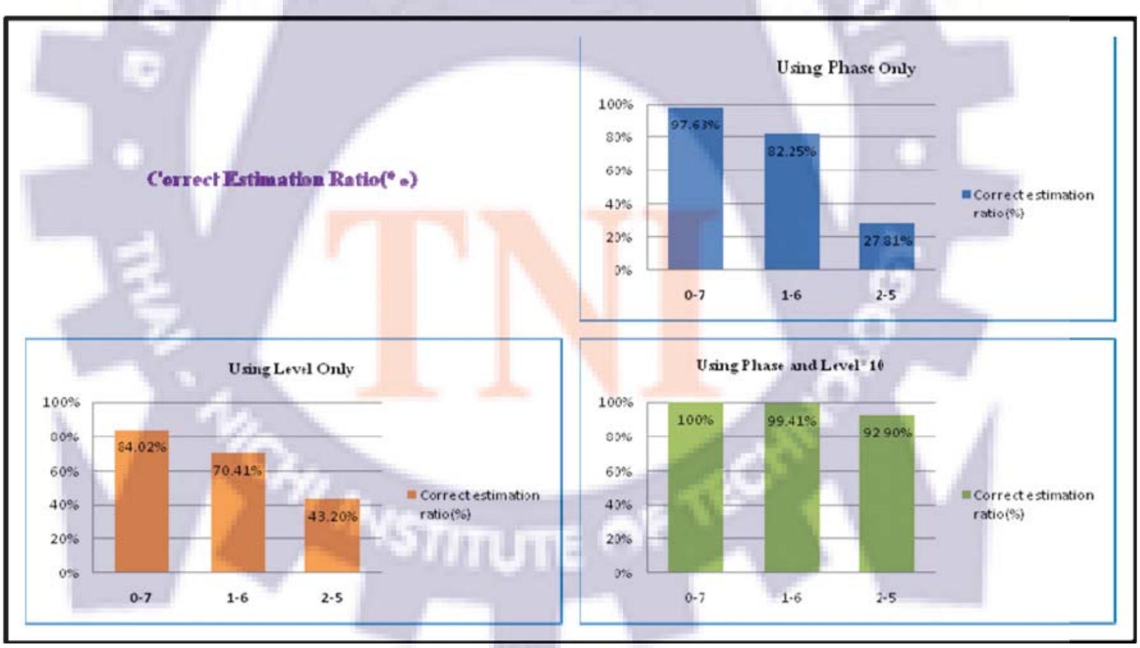

Figure a-38 The correct estimation of phase, power level and summation of phase and power level(x10) information in the three ranges of the input electrode

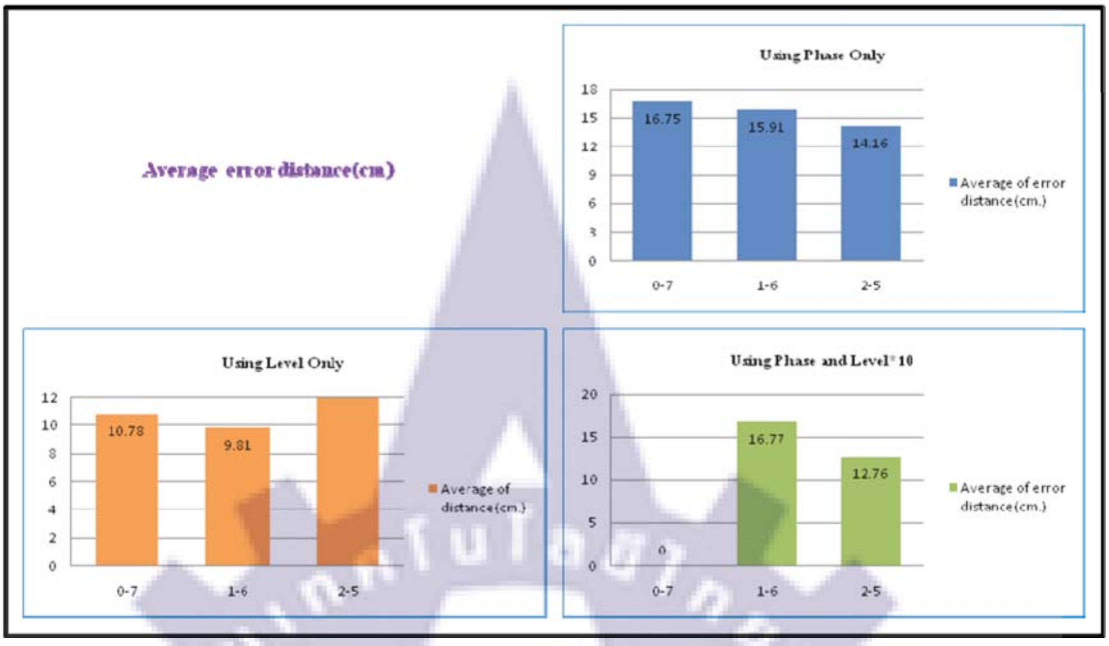

Figure a-39 The average error distance of phase, power level and summation of phase and power level(x10) information in the three ranges of the input electrode

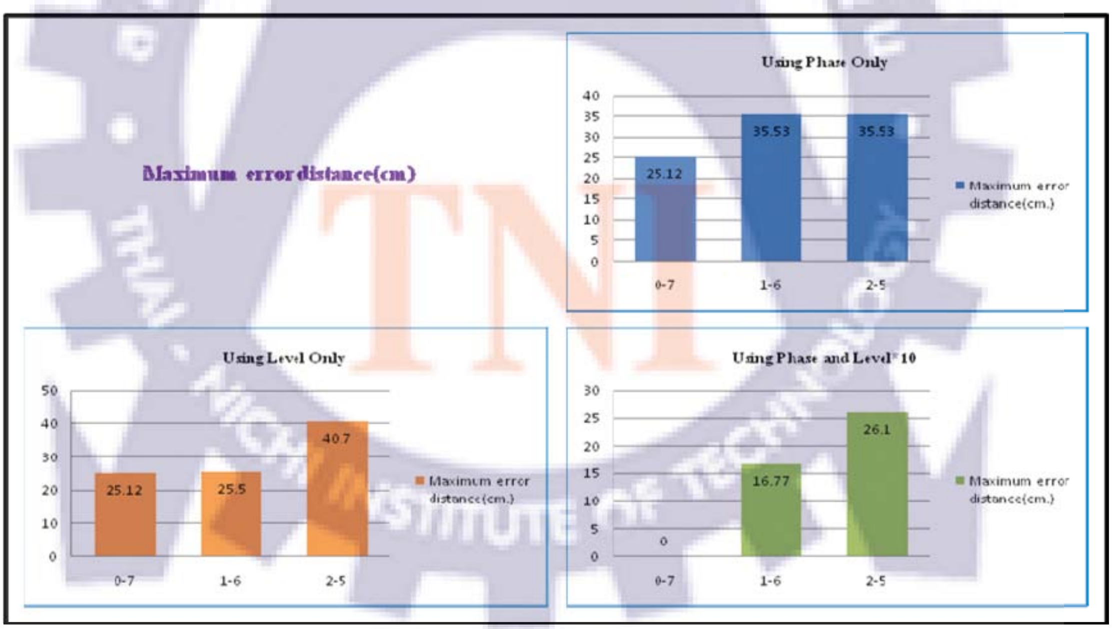

Figure a-40 The maximum error distance of phase, power level and summation of phase and power level(x10) information in the three ranges of the input electrode

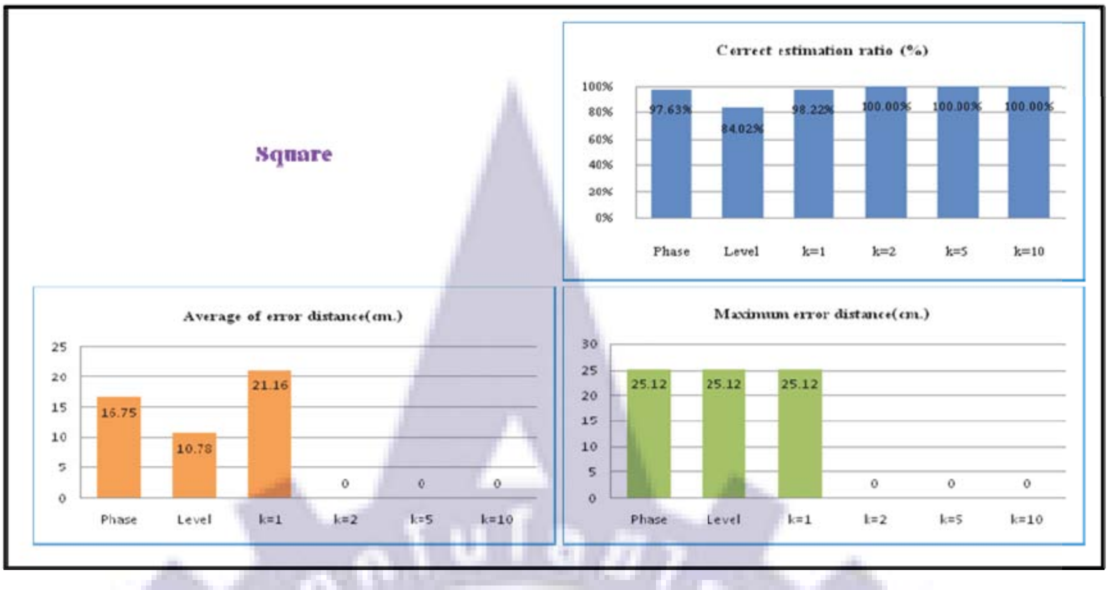

Figure a-41 The correct estimation ratio, average of error distance and maximum error distance of square equation by using the information of phase, power level and four weight of power level which k=1, k=2, k=5 and k=10

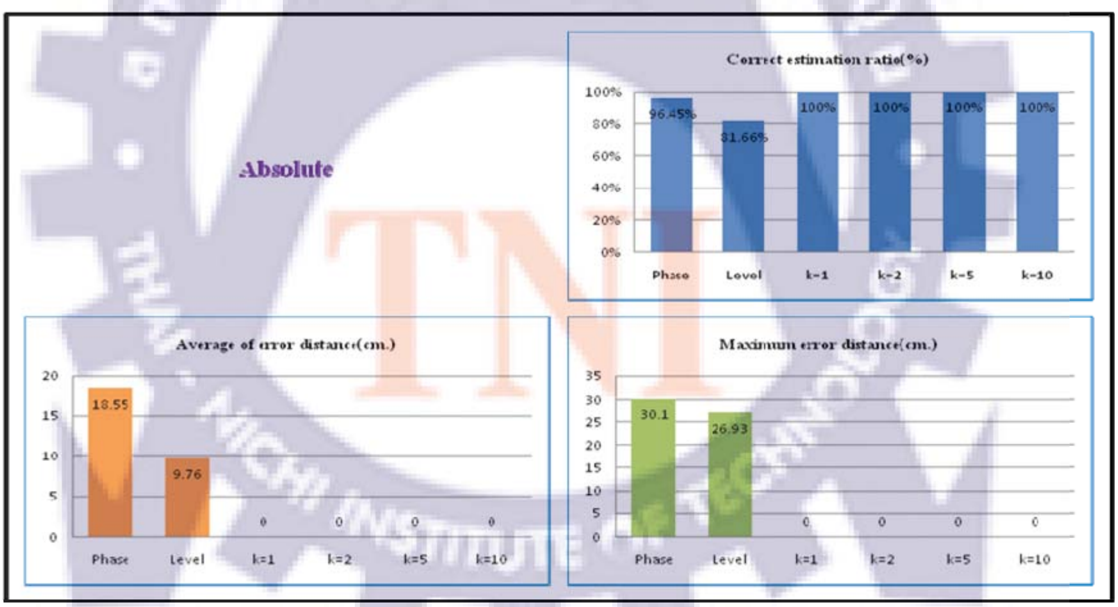

Figure a-42 The correct estimation ratio, average of error distance and maximum error distance of absolute equation by using the information of phase, power level and four weight of power level which k=1, k=2, k=5 and k=10

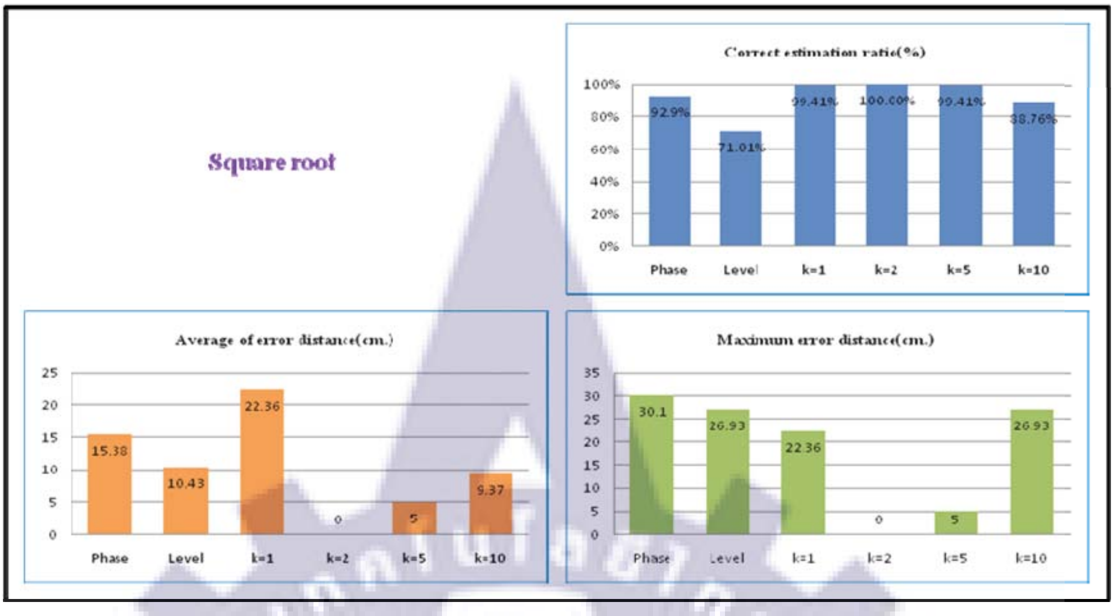

Figure a-43 The correct estimation ratio, average of error distance and maximum error distance of square root equation by using the information of phase, power level and four weight of power level which k=1, k=2, k=5, k=10

Next the experimental result of 5cm interval is shown.

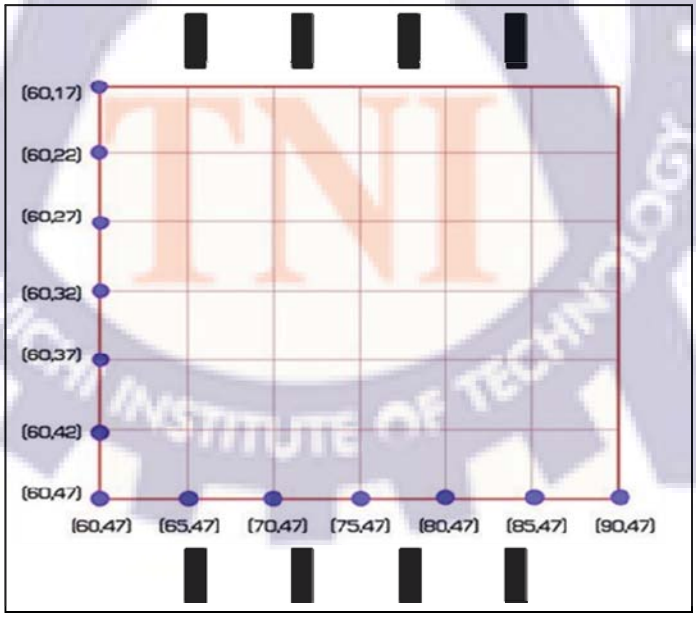

Figure a-44 The measurement condition and measurement step is 5 cm interval

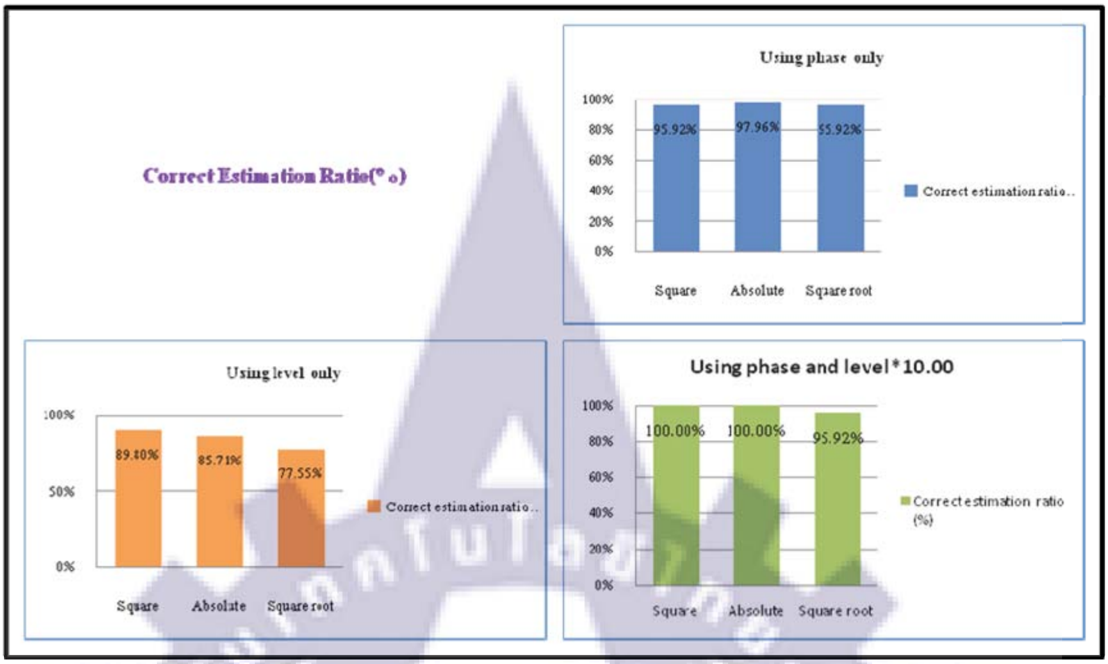

Figure a-45 The correction estimation ratio of phase, power level and summation of phase and power level(x10) information with equations 3.1, 3.2 and 3.3

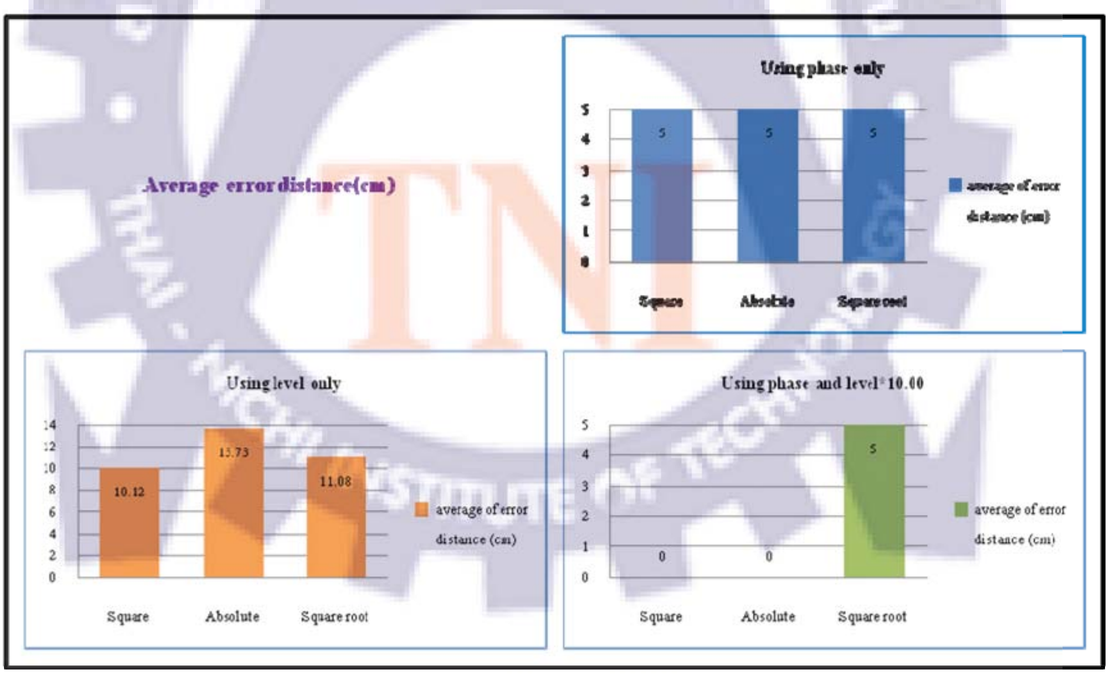

Figure a-46 The average error distance of phase, power level and summation of phase and power level(x10) information with equations 3.1, 3.2 and 3.3

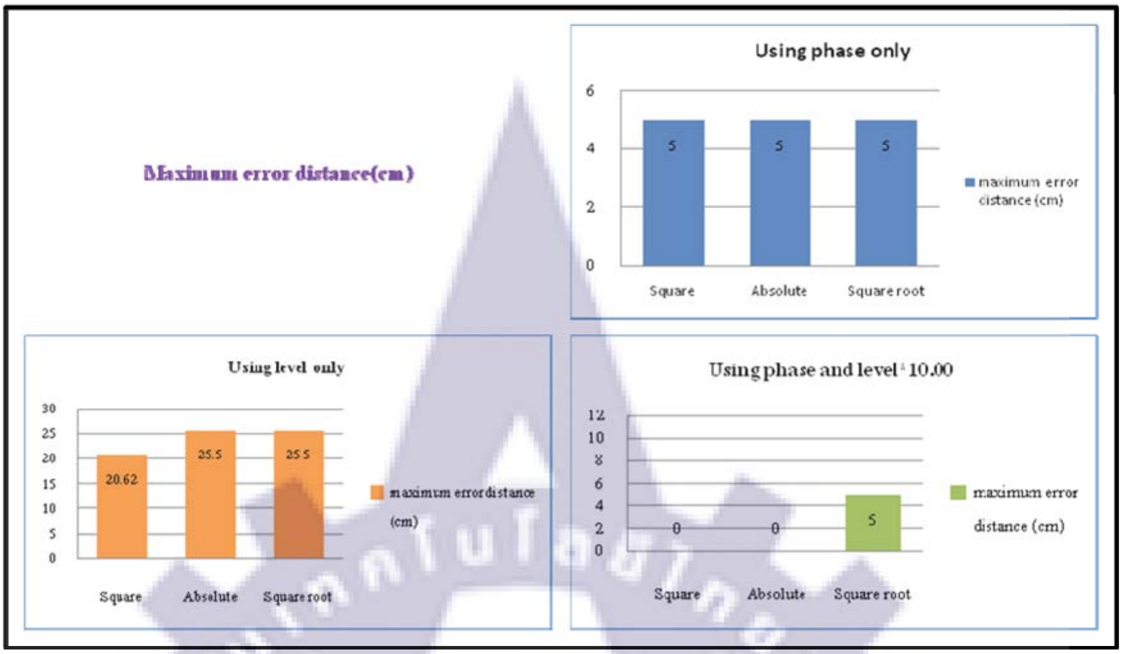

Figure a-47 The maximum error distance of phase, power level and summation of phase and power level(x10) information with equations 3.1, 3.2 and 3.3

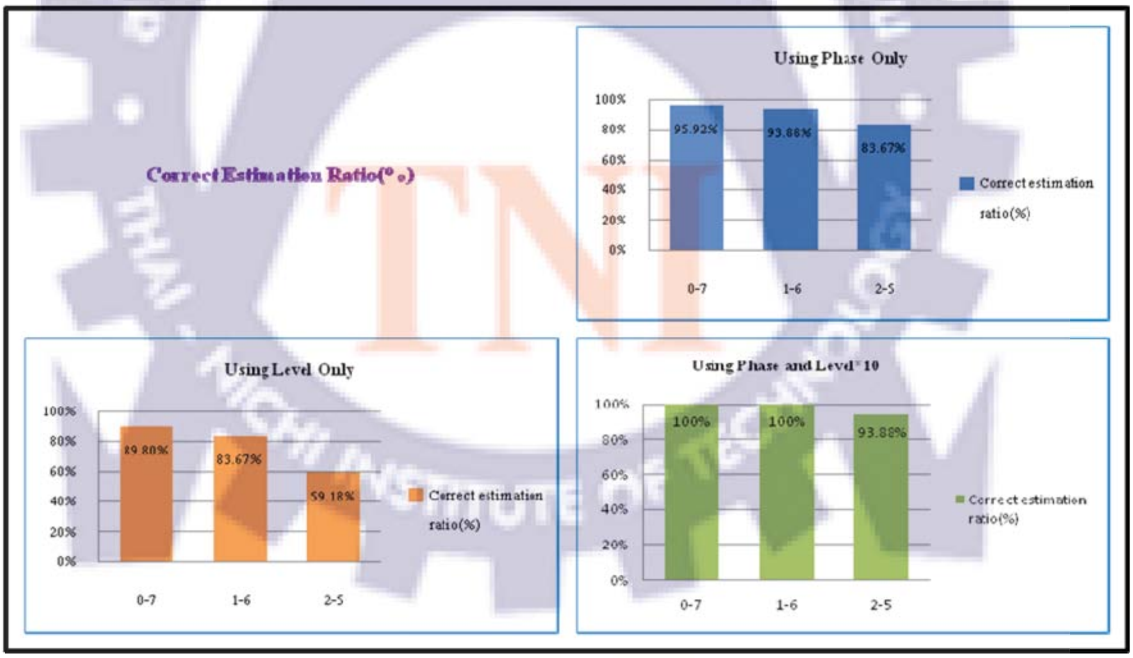

Figure a-48 The correct estimation of phase, power level and summation of phase and power level(x10) information in the three ranges of the input electrode

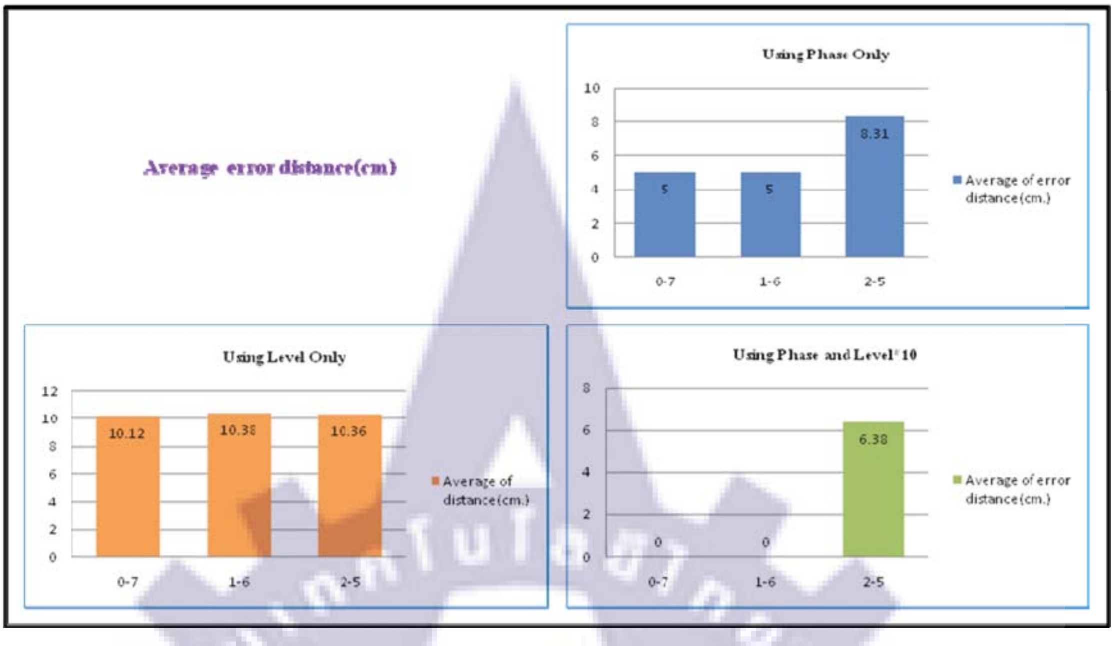

Figure a-49 The average error distance of phase, power level and summation of phase and power level(x10) information in the three ranges of the input electrode

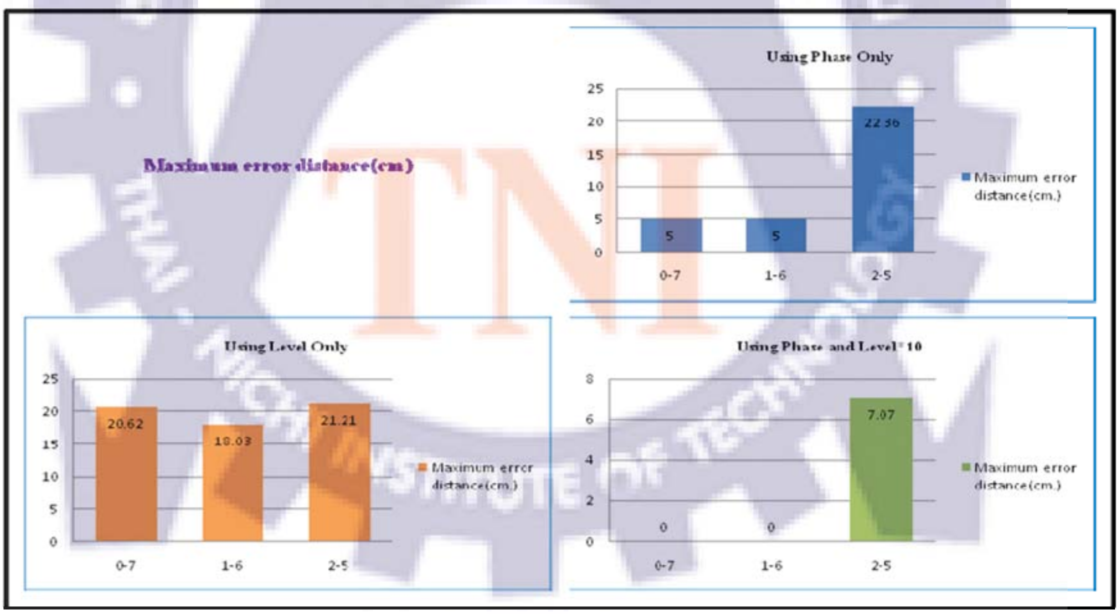

Figure a-50 The maximum error distance of phase, power level and summation of phase and power level(x10) information in the three ranges of the input electrode

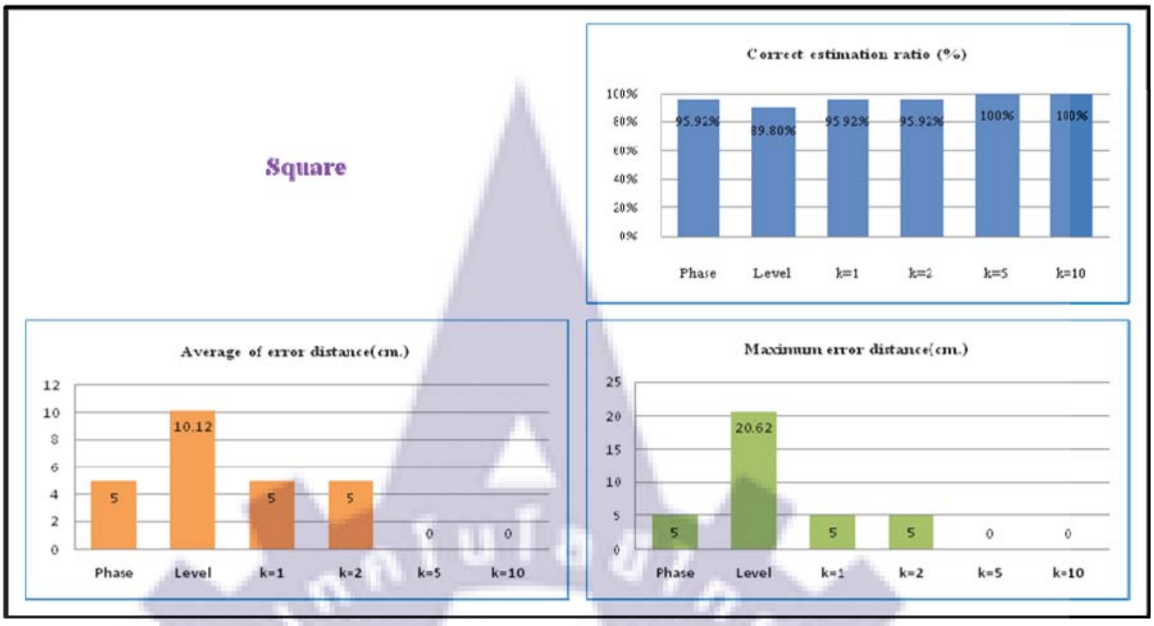

Figure a-51 The correct estimation ratio, average of error distance and maximum error distance of square equation by using the information of phase, power level and four weight of power level which k=1, k=2, k=5, k=10

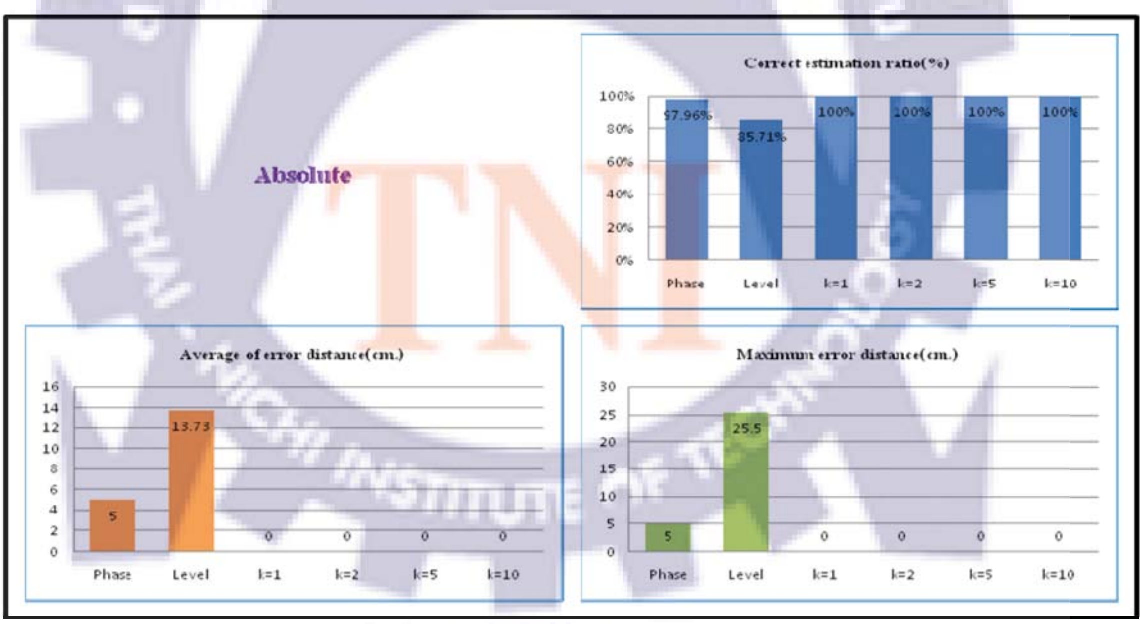

Figure a-52 The correct estimation ratio, average of error distance and maximum error distance of absolute equation by using the information of phase, power level and four weight of power level which k=1, k=2, k=5, k=10

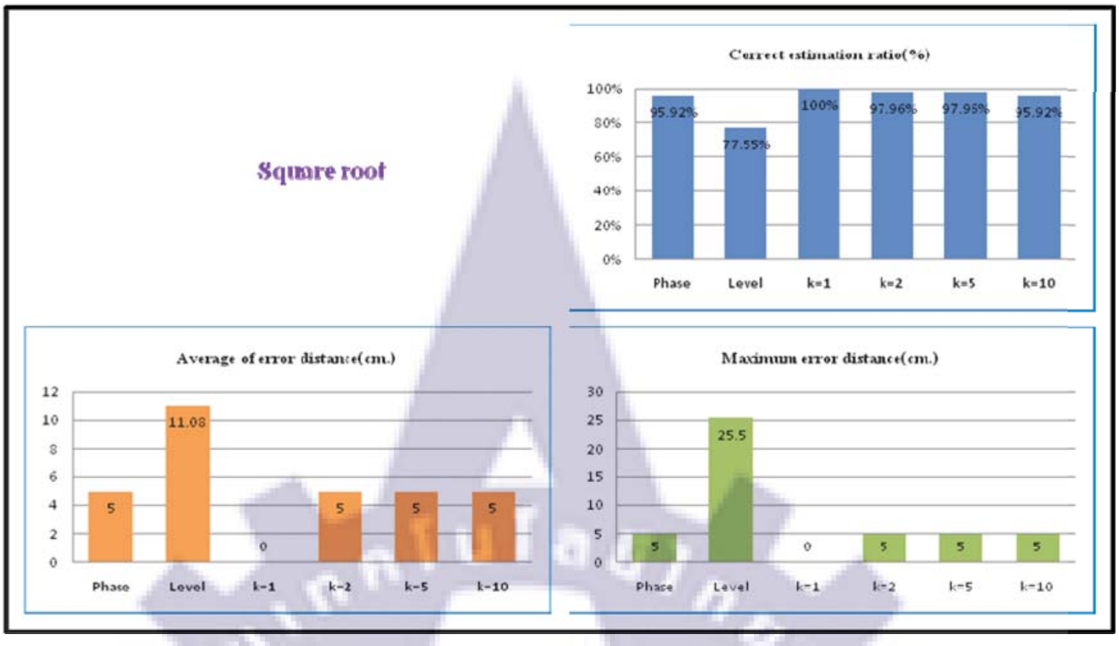

Figure a-53 The correct estimation ratio, average of error distance and maximum error distance of square root equation by using the information of phase, power level and four weight of power level which k=1, k=2, k=5, k=10

Next the experimental result that input electrodes are clipped at the 4 sides of 2DC sheet and the measurement steps of 2.5cm and 5cm respectively are shown. It is starting with experimental result of 2.5cm interval.

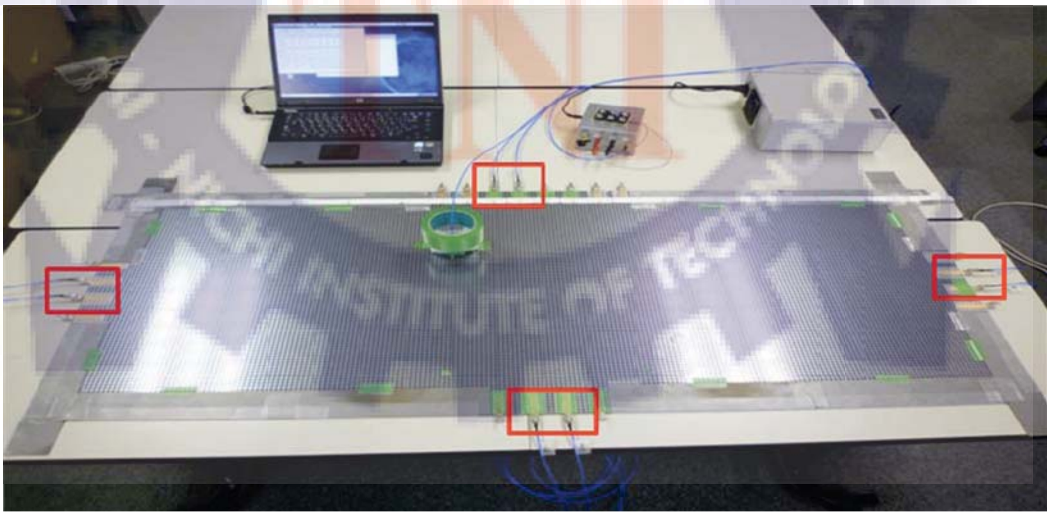

Figure a-54 The experiment set up

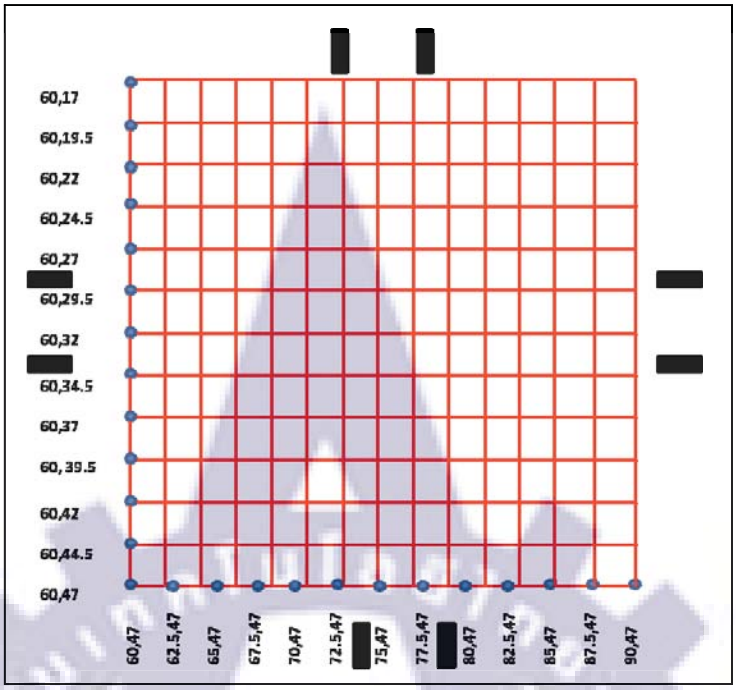

Figure a-55 The measurement condition and measurement step is 2.5 cm interval

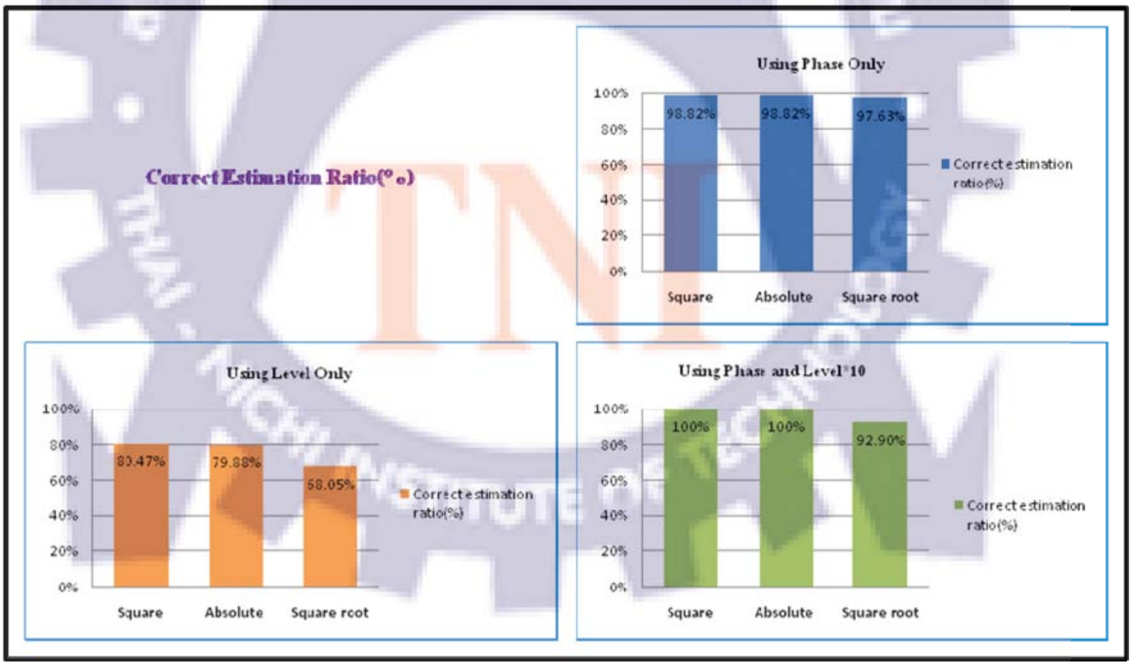

Figure a-56 The correction estimation ratio of phase, power level and summation of phase and power level(x10) information with equations 3.1, 3.2 and 3.3

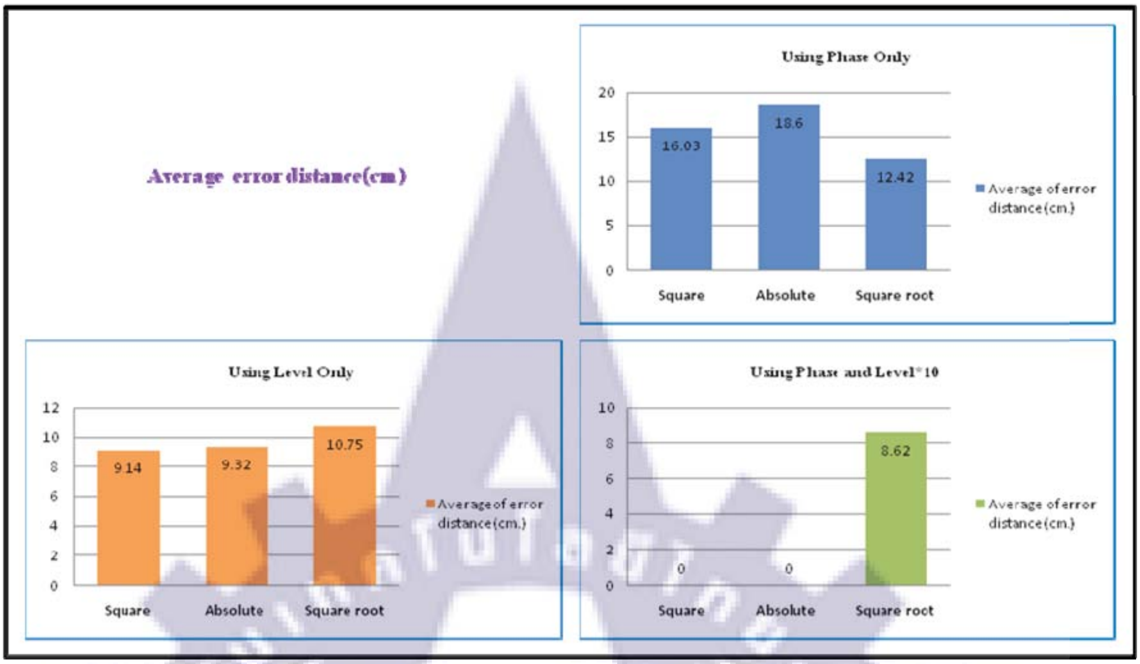

Figure a-57 The average error distance of phase, power level and summation of phase and power level(x10) information with equations 3.1, 3.2 and 3.3

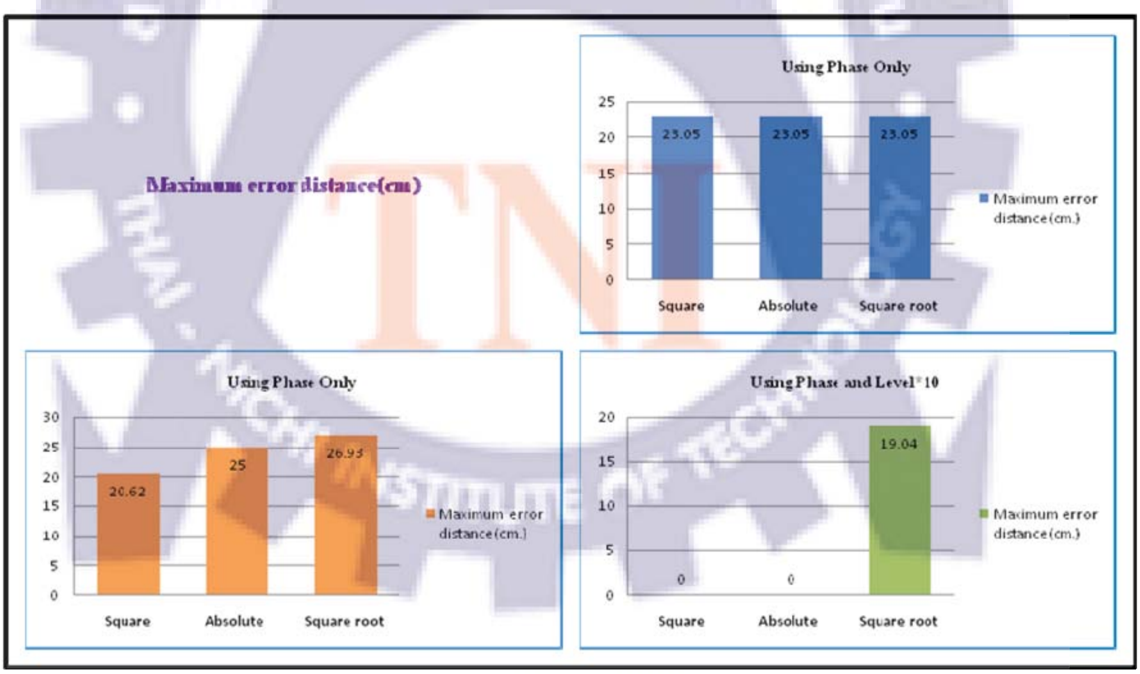

Figure a-58 The maximum error distance of phase, power level and summation of phase and power level(x10) information with equations 3.1, 3.2 and 3.3

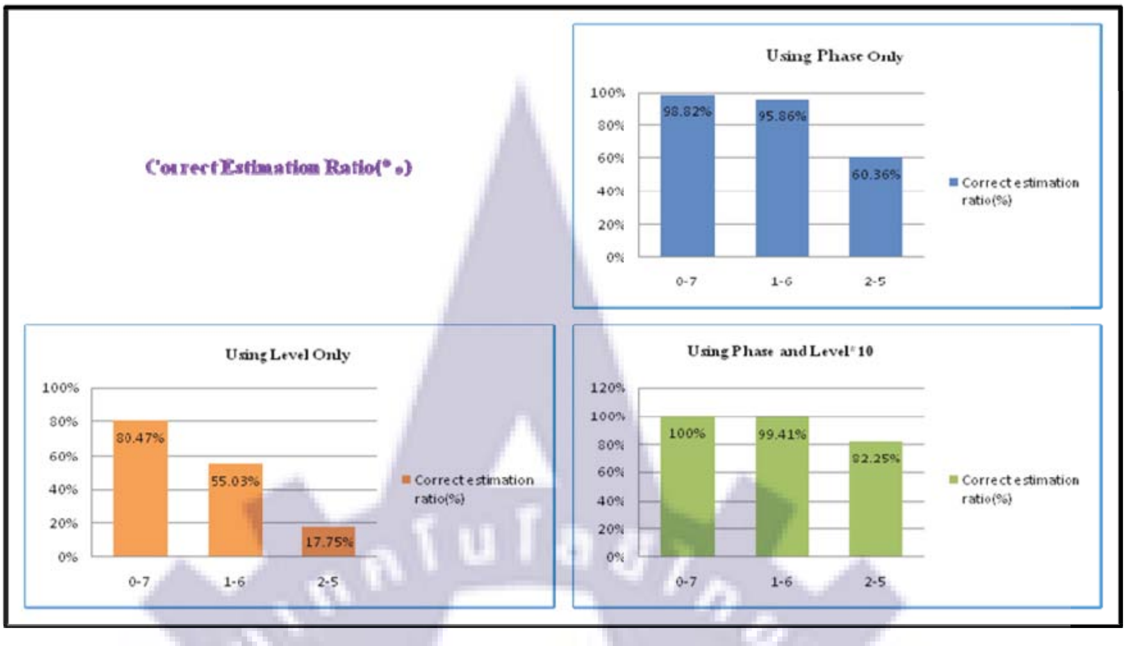

Figure a-59 The correct estimation of phase, power level and summation of phase and power level(x10) information in the three ranges of the input electrode

Figure a-60 The average error distance of phase, power level and summation of phase and power level(x10) information in the three ranges of the input electrode

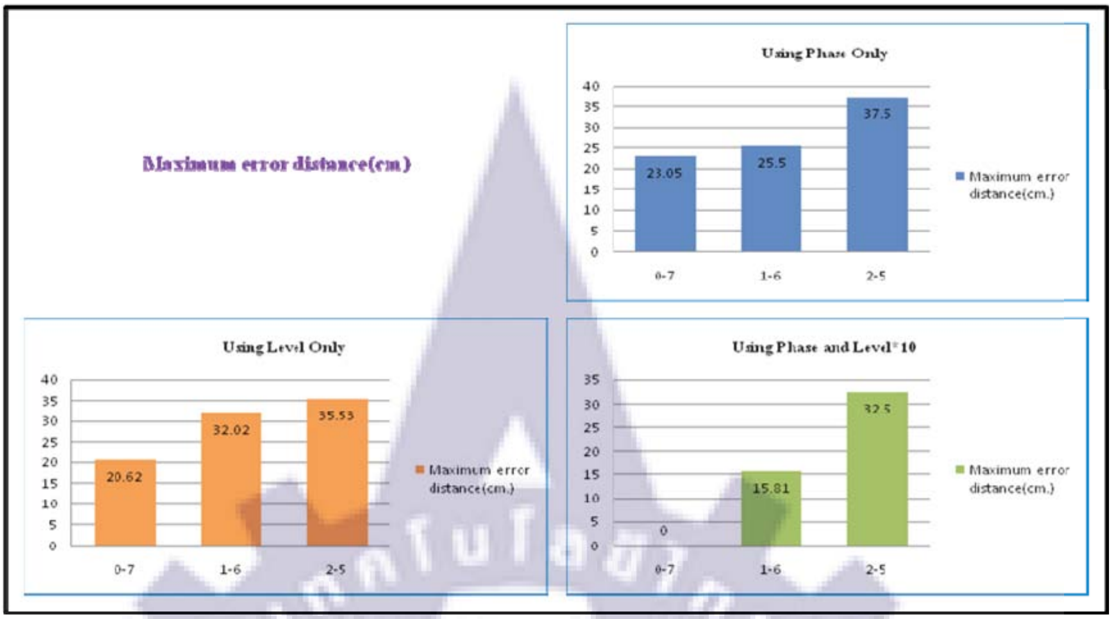

Figure a-61 The maximum error distance of phase, power level and summation of phase and power level(x10) information in the three ranges of the input electrode

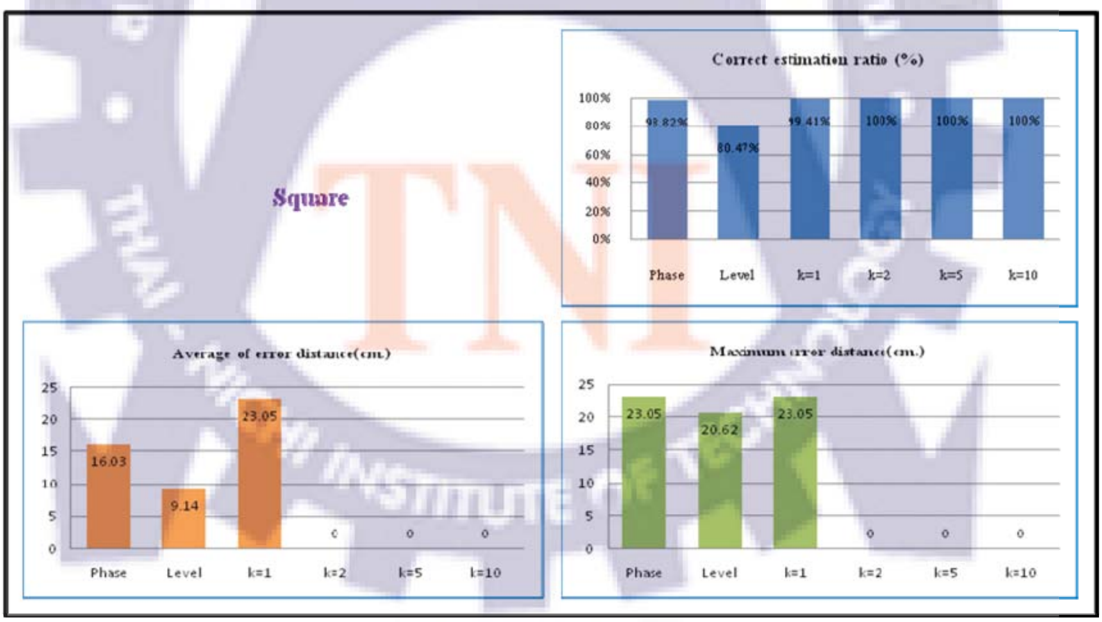

Figure a-62 The correct estimation ratio, average of error distance and maximum error distance of square equation by using the information of phase, power level and four weight of power level which k=1, k=2, k=5, k=10

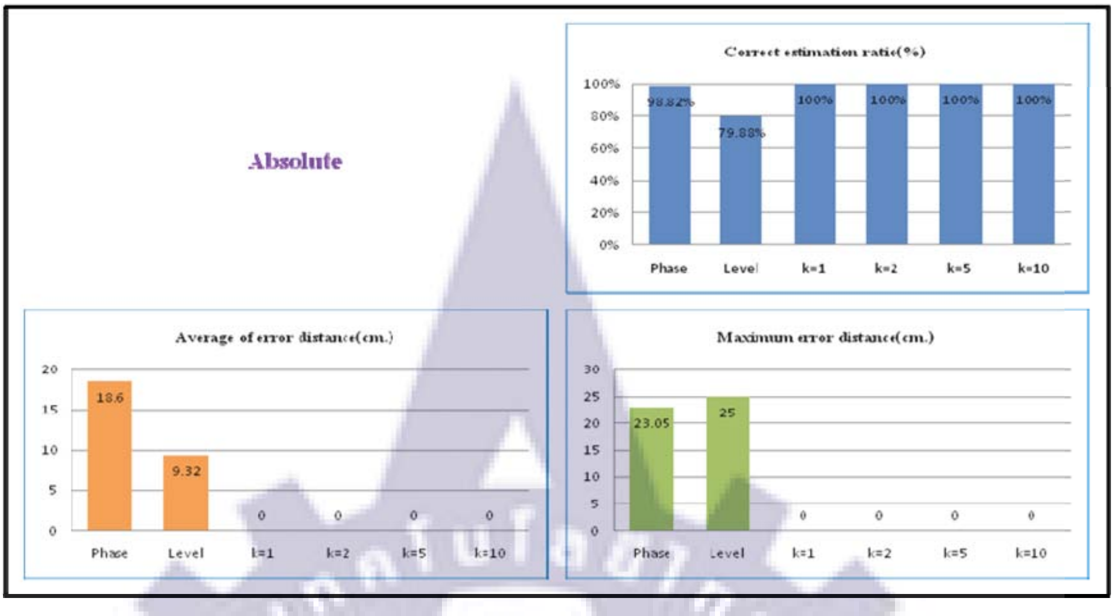

Figure a-63 The correct estimation ratio, average of error distance and maximum error distance of absolute equation by using the information of phase, power level and four weight of power level which k=1, k=2, k=5, k=10

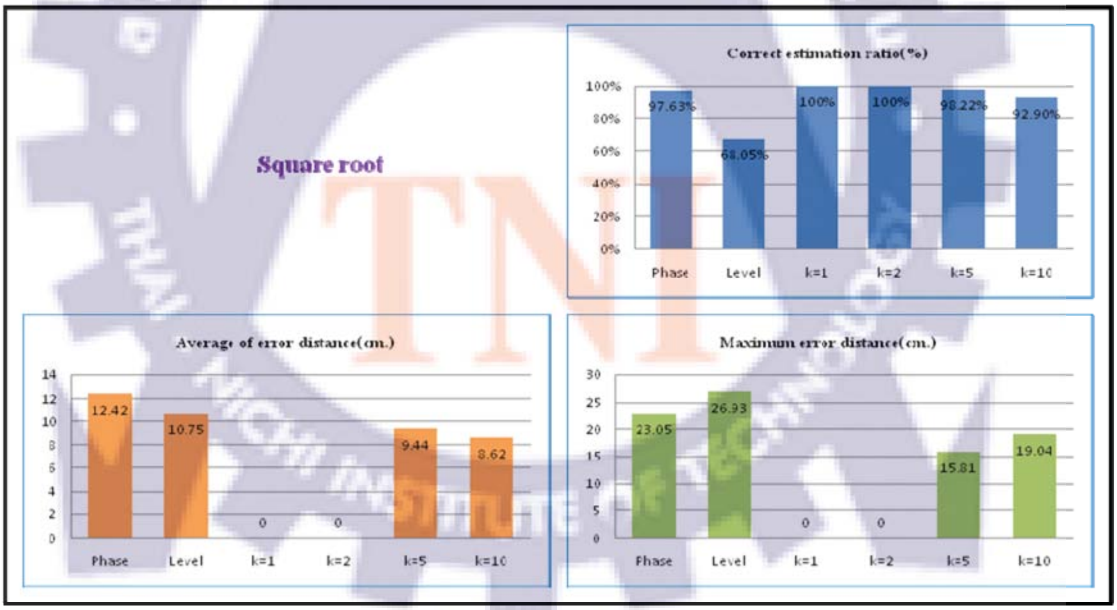

Figure a-64 The correct estimation ratio, average of error distance and maximum error distance of square root equation by using the information of phase, power level and four weight of power level which k=1, k=2, k=5, k=10

At last, the experimental result of 5cm interval is shown.

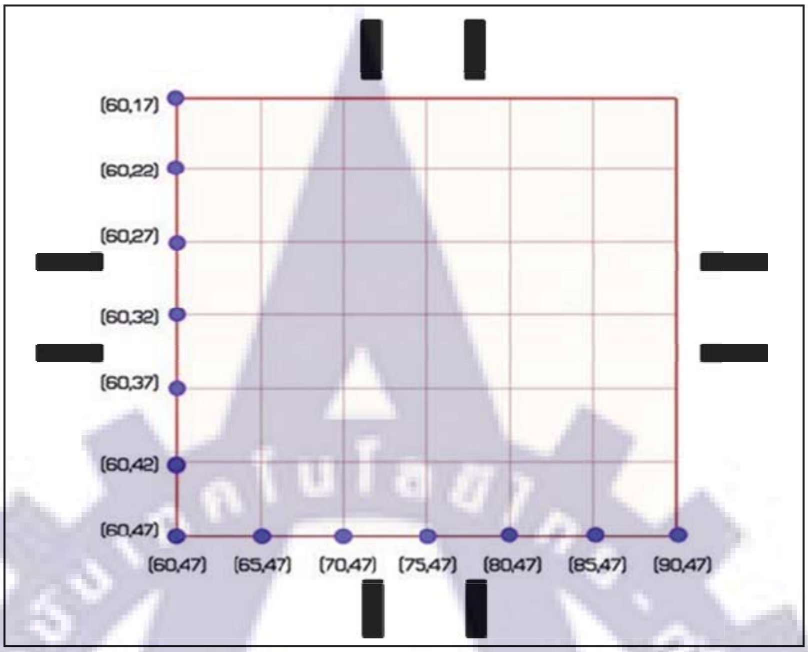

Figure a-65 The measurement condition and measurement step is 5 cm interval

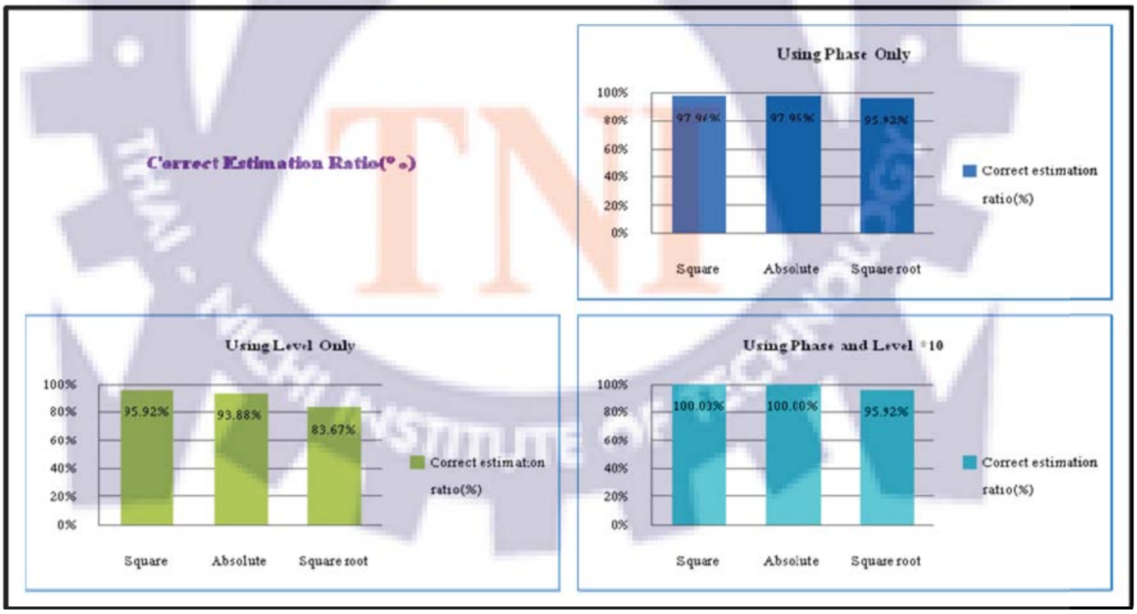

Figure a-66 The correction estimation ratio of phase, power level and summation of phase and power level(x10) information with equations 3.1, 3.2 and 3.3

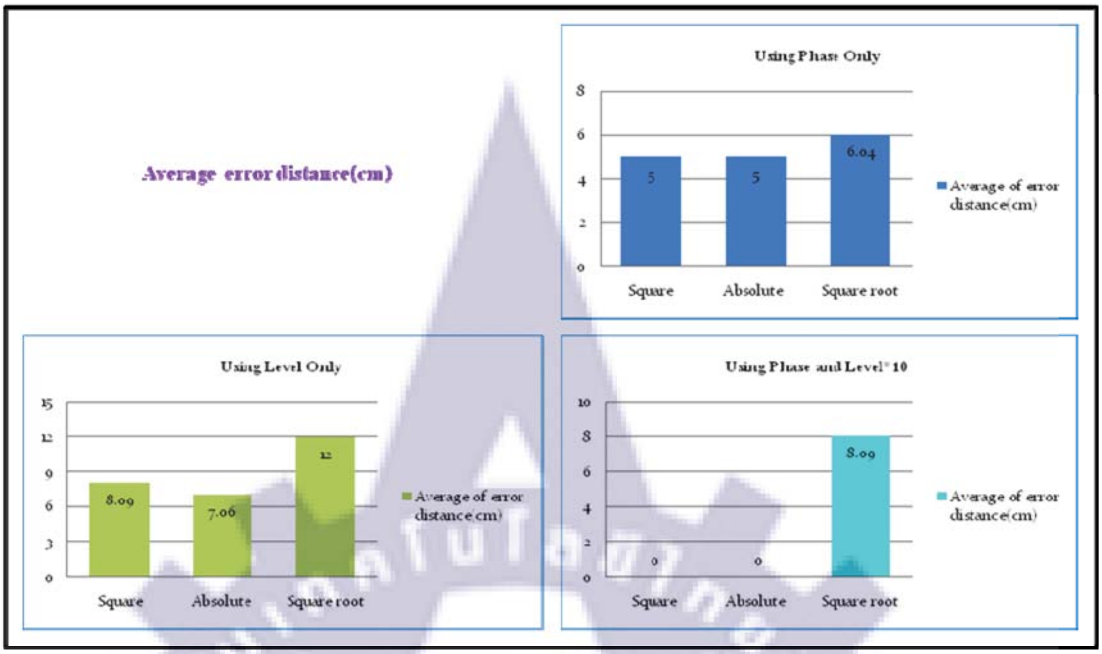

Figure a-67 The average error distance of phase, power level and summation of phase and power level(x10) information with equations 3.1, 3.2 and 3.3

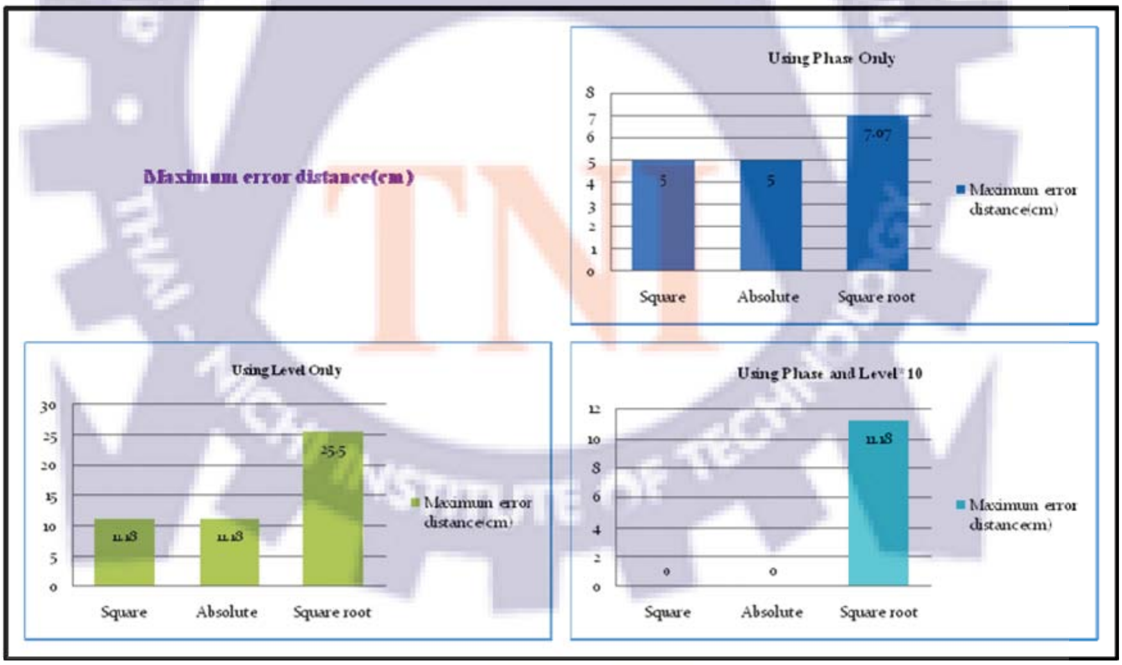

Figure a-68 The maximum error distance of phase, power level and summation of phase and power level(x10) information with equations 3.1, 3.2 and 3.3

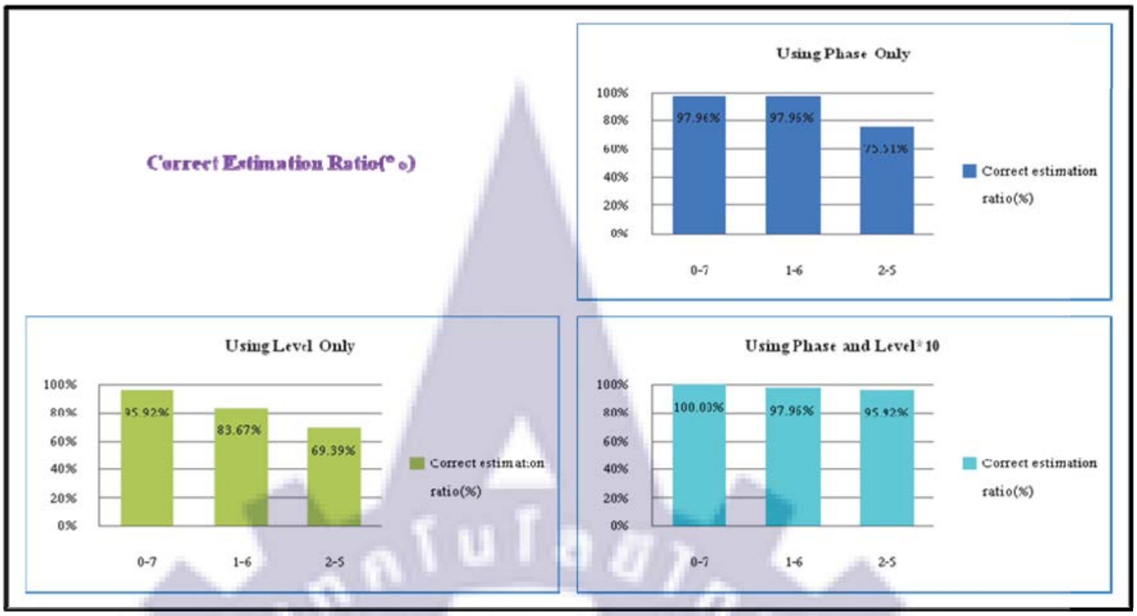

Figure a-69 The correct estimation of phase, power level and summation of phase and power level(x10) information in the three ranges of the input electrode

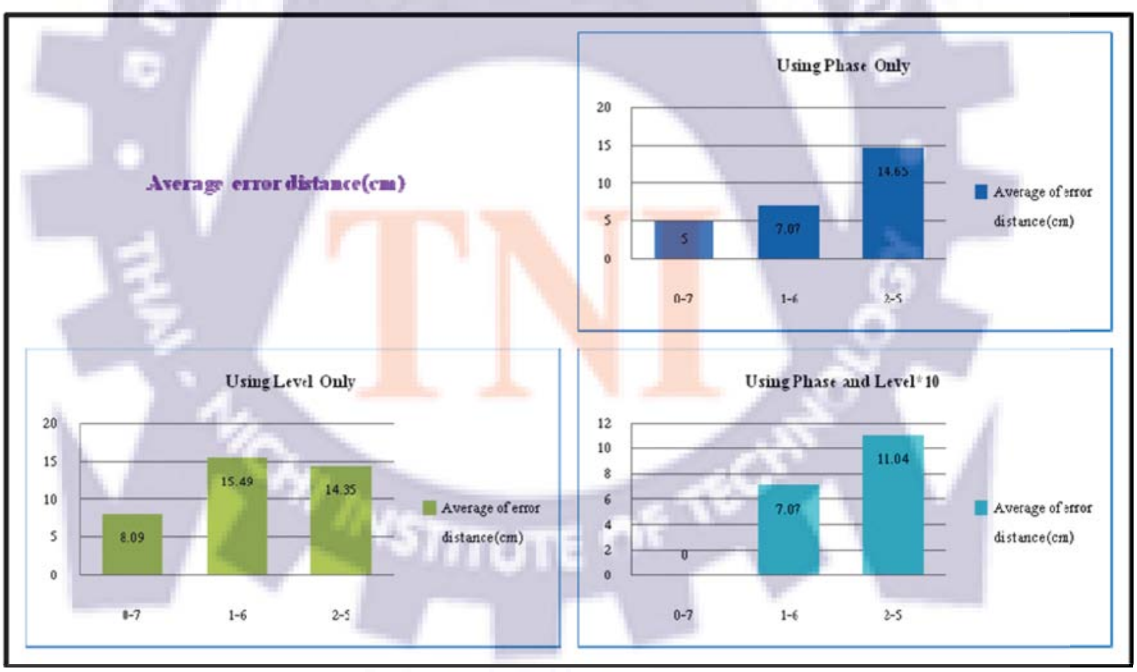

Figure a-70 The average error distance of phase, power level and summation of phase and power level(x10) information in the three ranges of the input electrode

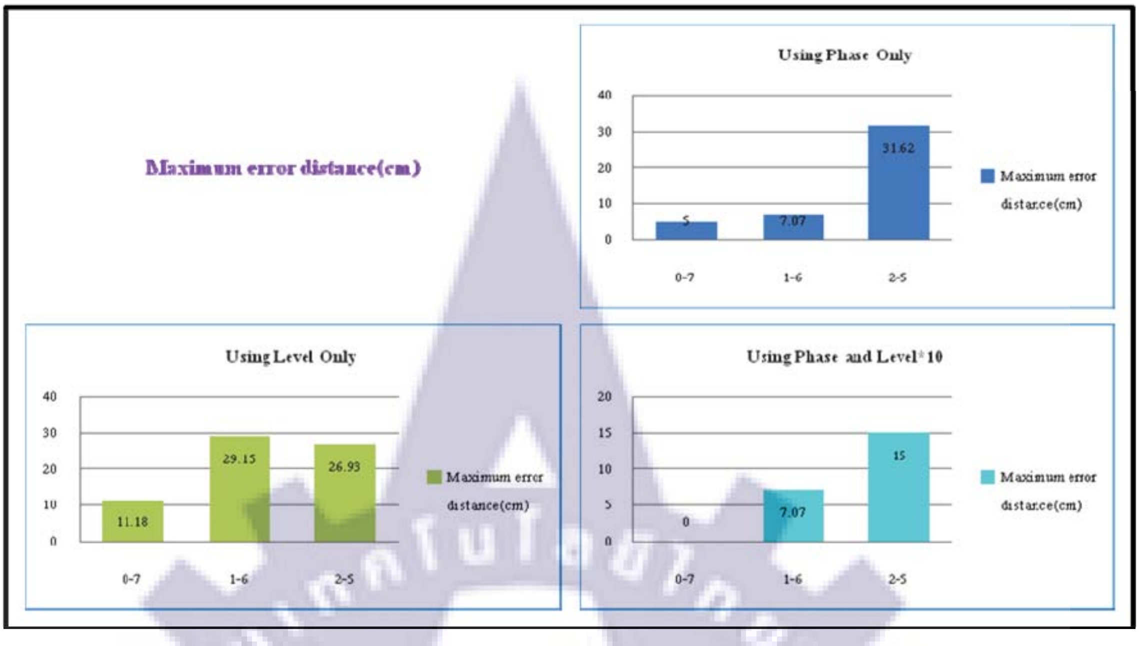

Figure a-71 The maximum error distance of phase, power level and summation of phase and power level(x10) information in the three ranges of the input electrode

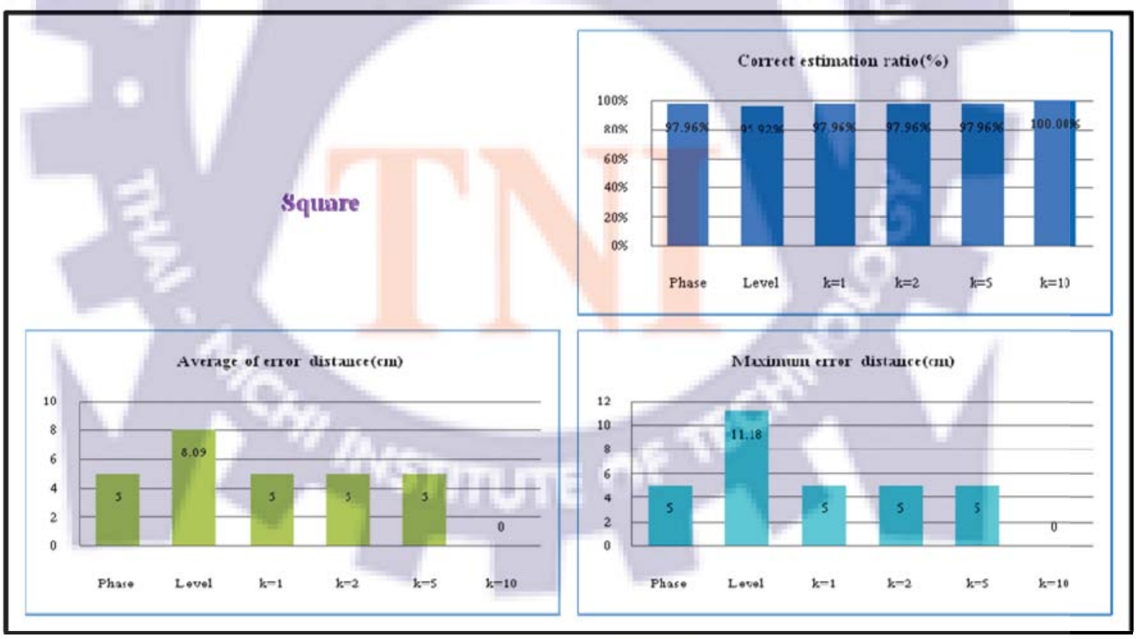

Figure a-72 The correct estimation ratio, average of error distance and maximum error distance of square equation by using the information of phase, power-level and four weight of power level which k=1, k=2, k=5, k=10

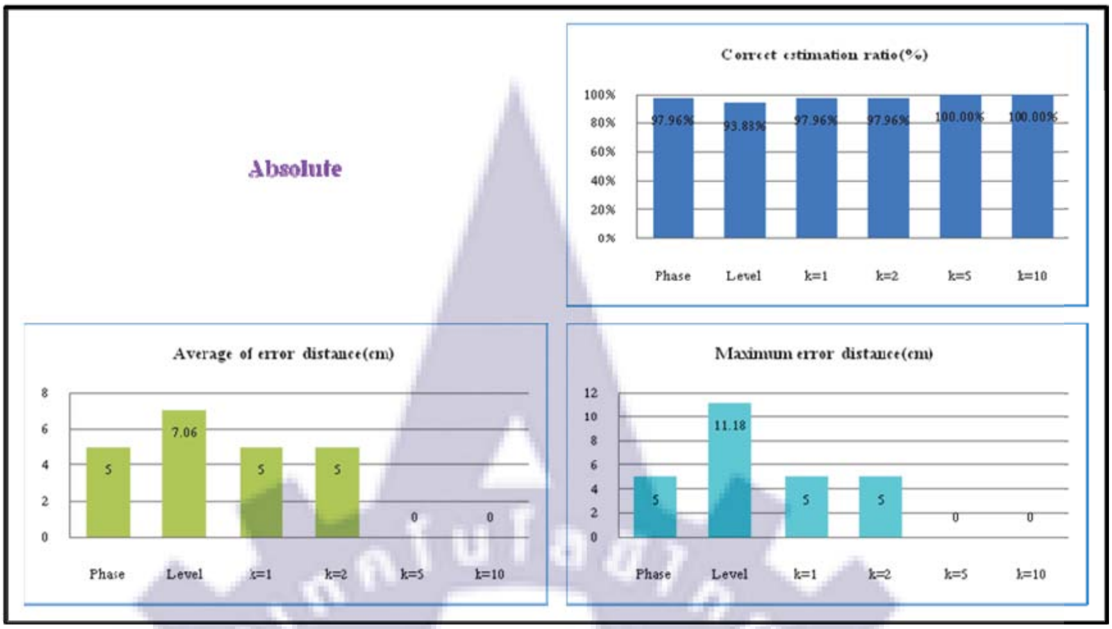

Figure a-73 The correct estimation ratio, average of error distance and maximum error distance of absolute equation by using the information of phase, power level and four weight of power level which k=1, k=2, k=5, k=10

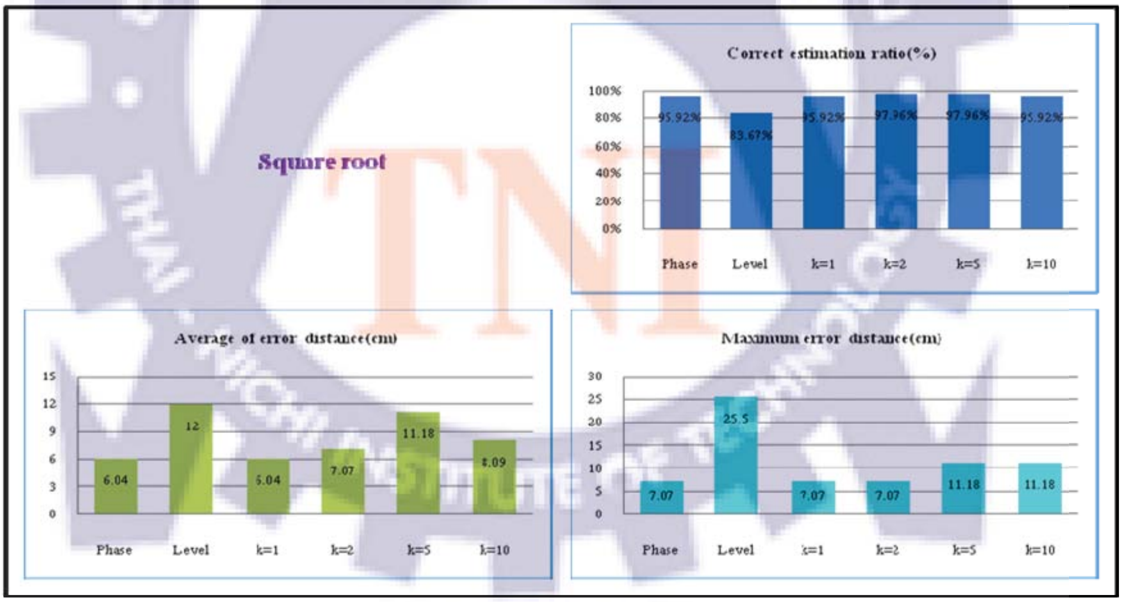

Figure a-74 The correct estimation ratio, average of error distance and maximum error distance of square root equation by using the information of phase, power level and four weight of power level which k=1, k=2, k=5, k=10

Next is the compare table of total result in the experimental that 8 electrodes are clipped at the top, top-right, top-bottom and 4 sides of the edge of 2DC sheet witch measurement step are 5cm and 2.5 cm respectively. Table a-1 show the correct estimation ratio using the information of phase, power level and the summation information of phase and power level(x10) with three equation that are square (3.1), absolute (3.2) and square root (3.3) which measurement step is 5 cm.

Table a-1 The correct estimation using phase, power level and phase+(power level(x10))

Position of electrode array	Correct estimation ratio(%)								
	Phase			Power level			Phase+(Levelx10)		
	Square	Absolute	Square root	Square	Absolute	Square root	Square	Absolute	Square root
Top	69.39	77.55	79.59	75.51	77.55	83.67	81.63	89.8	87.76
Top – Right	97.96	97.96	100	91.84	91.84	89.8	97.96	100	93.88
Top – Bottom	95.92	97.96	95.92	89.8	85.71	77.55	100	100	95.92
4 Sides	97.96	97.96	95.92	95.92	93.88	83.67	100	100	95.92

Table a-2 show the average error distance using the information of phase, power level and the summation information of phase and power level(x10) in three equation that are square (3.1), absolute (3.2) and square root (3.3) which measurement step is 5 cm.

Table a-2 The average of error distance using phase, power level and phase+(power level(x10))

Position of electrode array	Average of error distance(cm)								
	Phase			Power level			Phase+(Levelx10)		
	Square	Absolute	Square root	Square	Absolute	Square root	Square	Absolute	Square root
Top	5.67	5.45	5.5	8.6	8.48	8.27	6.67	7	6.67
Top – Right	22.36	29.15	0	6.04	6.04	8.06	10	0	7.75
Top – Bottom	5	5	5	10.12	13.73	11.08	0	0	5
4 Sides	5	5	6.04	8.09	7.06	12	0	0	8.09

Table a-3 show the maximum error distance using the information of phase, power level and the summation information of phase and power level(x10) in three in three equation that are square (3.1), absolute (3.2) and square root (3.3) which measurement step is 5 cm.

Table a-3 The maximum error distance using phase, power level and phase+(power level(x10))

Position of electrode array	Maximum error distance(cm)								
	Phase			Power level			Phase+(Levelx10)		
	Square	Absolute	Square root	Square	Absolute	Square root	Square	Absolute	Square root
Top	10	10	10	11.18	11.18	11.18	10	10	10
Top – Right	22.36	29.15	0	7.07	7.07	11.18	10	0	11.18
Top – Bottom	5	5	5	20.62	25.5	25.5	0	0	5
4 Sides	5	5	7.07	11.18	11.18	25.5	0	0	11.18

Table a-4 show the correct estimation ratio using the information of phase, power level and the summation information of phase and power level(x10) in three ranges of input electrode which array 0-7, array 1-6 and array 2-5. The measurement step is 5 cm.

Table a-4 The correct estimation with number of input electrode

Position of electrode array	Correct estimation ratio(%)								
	Phase			Power level			Phase+(Levelx10)		
	0-7	1-6	2-5	0-7	1-6	2-5	0-7	1-6	2-5
Top	69.39	63.27	44.9	75.51	65.31	53.06	81.63	79.59	65.31
Top – Right	97.96	95.92	89.8	91.84	87.76	77.55	97.96	97.96	97.96
Top – Bottom	95.92	93.88	83.67	89.8	83.67	59.18	100	100	100
4 Sides	97.96	97.96	75.51	95.92	83.67	69.39	100	97.96	95.92

Table a-5 shows the average of position error using the information of phase, power level and the summation information of phase and power level(x10) in three ranges of input electrode which array 0-7, array 1-6 and array 2-5. The measurement step is 5 cm.

Table a-5 The average of position error with number of input electrode

Position of electrode array	Average of error distance(cm)								
	Phase			Power level			Phase+(Levelx10)		
	0-7	1-6	2-5	0-7	1-6	2-5	0-7	1-6	2-5
Top	5.67	5.83	10.33	8.6	8.94	9.87	6.67	7	7.59
Top – Right	22.36	18.68	13.73	6.04	7.5	13.39	10	10	10
Top – Bottom	5	5	8.31	10.12	10.38	10.36	0	0	6.38
4 Sides	5	7.07	14.65	8.09	15.49	14.35	0	7.07	11.04

Table a-6 shows the maximum error distance using the information of phase, power level and the summation information of phase and power level x 10 in three ranges of input electrode which array 0-7, array 1-6 and array 2-5. The measurement step is 5 cm.

Table a-6 The maximum error distance with number of input electrode

Position of electrode array	Maximum error distance(cm)								
	Phase			Power level			Phase+(Levelx10)		
	0-7	1-6	2-5	0-7	1-6	2-5	0-7	1-6	2-5
Top	10	10	25.5	11.18	20	35.36	10	10	15.81
Top – Right	22.36	22.36	30.41	7.07	11.18	30.41	10	10	10
Top – Bottom	5	5	22.36	20.62	18.03	21.21	0	0	7.07
4 Sides	5	7.07	31.62	11.18	29.15	26.93	0	7.07	15

Table a-7 shows the result of the correct estimation ratio, average of position error and maximum error distance using six information separately that are phase, level, four weights of level that are k=1, k=2, k=5 and k=10 with square equation. The measurement step is 5 cm.

Table a-7 The correct estimation ratio, average of position error and maximum error distance of square equation

Position of electrode array	Square																	
	Correct estimation ratio(%)						Average of error distance(cm)						Maximum error distance(cm)					
	Phase	Level	K=1	K=2	K=5	K=10	Phase	Level	K=1	K=2	K=5	K=10	Phase	Level	K=1	K=2	K=5	K=10
Top	69.39	75.51	67.35	71.43	75.51	81.63	5.67	8.6	5.63	5.71	5.83	6.67	10	11.18	10	10	10	10
Top - Right	97.96	91.84	97.96	97.96	97.96	97.96	22.36	6.04	22.36	22.36	10	10	22.36	7.07	22.36	22.36	10	10
Top - Bottom	95.92	89.8	95.92	95.92	100	100	5	10.12	5	5	0	0	5	20.62	5	5	0	0
4 Sides	97.96	95.92	97.96	97.96	97.96	100	5	8.09	5	5	5	0	5	11.18	5	5	5	0

Table a-8 shows the result of the correct estimation ratio, average position error and maximum error distance using the six information separately that are phase, level, four weights of level that are k=1, k=2, k=5 and k=10 with absolute equation. The measurement step is 5 cm.

Table a-8 The correct estimation ratio, average error distance and maximum error distance of absolute equation

Position of electrode array	Absolute																	
	Correct estimation ratio(%)						Average of error distance(cm)						Maximum error distance(cm)					
	Phase	Level	K=1	K=2	K=5	K=10	Phase	Level	K=1	K=2	K=5	K=10	Phase	Level	K=1	K=2	K=5	K=10
Top	77.55	77.55	77.55	79.59	87.76	89.8	5.45	8.48	5.45	5.5	7.5	7	10	11.18	10	10	10	10
Top - Right	97.96	91.84	100	100	100	100	29.15	6.04	0	0	0	0	29.15	7.07	0	0	0	0
Top - Bottom	97.96	85.71	100	100	100	100	5	13.73	0	0	0	0	5	25.5	0	0	0	0
4 Sides	97.96	93.88	97.96	97.96	100	100	5	7.06	5	5	0	0	5	11.18	5	5	0	0

Table a-9 shows the result of the correct estimation ratio, average of position error and maximum error distance using the six information separately that are phase, level, four weights of level that are k=1, k=2, k=5 and k=10 with square root equation. The measurement step is 5 cm.

Table a-9 The correct estimation ratio, average of position error and maximum error distance of phase, level, weight of level by using square root equation

Position of electrode array	Square Root																	
	Correct estimation ratio(%)						Average of error distance(cm)						Maximum error distance(cm)					
	Phase	Level	K=1	K=2	K=5	K=10	Phase	Level	K=1	K=2	K=5	K=10	Phase	Level	K=1	K=2	K=5	K=10
Top	79.59	83.67	87.76	87.76	87.76	87.76	5.5	8.27	6.67	7.5	6.67	6.67	10	11.18	10	10	10	10
Top - Right	100	89.8	100	100	97.96	93.88	0	8.06	0	0	11.18	7.75	0	11.18	0	0	11.18	11.18
Top - Bottom	95.92	77.55	100	97.96	97.96	95.92	5	11.08	0	5	5	5	5	25.5	0	5	5	5
4 Sides	95.92	83.67	95.92	97.96	97.96	95.92	6.04	12	6.04	7.07	11.18	8.09	7.07	25.5	7.07	7.07	11.18	11.18

Table a-10 show the correct estimation ratio using the information of phase, power level and the summation information of phase and power level (x10) in three equation that are square (3.1), absolute (3.2) and square root (3.3) which measurement step is 2.5 cm.

Table a-10 The correct estimation using phase, power level and phase+(power level(x10))

Position of electrode array	Correct estimation ratio(%)								
	Phase			Power level			Phase+(Levelx10)		
	Square	Absolute	Square root	Square	Absolute	Square root	Square	Absolute	Square root
Top	76.33	79.88	14.79	77.51	76.33	14.79	91.12	93.49	14.79
Top - Right	97.63	96.45	92.9	84.02	81.66	71.01	100	100	88.76
Top - Bottom	96.45	95.86	95.27	85.8	82.84	79.88	98.22	98.82	89.94
4 Sides	98.82	98.82	97.63	80.47	79.88	68.05	100	100	92.9

Table a-11 show the average error distance using the information of phase, power level and the summation information of phase and power level(x10) in three equation that are square (3.1), absolute (3.2) and square root (3.3) which measurement step is 2.5 cm.

Table a-11 The average of error distance using phase, power level and phase+(power level(x10))

Position of electrode array	Average of error distance(cm)								
	Phase			Power level			Phase+(Levelx10)		
	Square	Absolute	Square root	Square	Absolute	Square root	Square	Absolute	Square root
Top	6.22	5.73	11.8	9.23	9.65	11.91	6.7	6.85	11.26
Top - Right	16.75	18.55	15.38	10.78	9.76	10.43	0	0	9.37
Top - Bottom	8.84	7.7	7.39	9.78	8.97	10.29	19.24	23.71	8.35
4 Sides	16.03	18.6	12.42	9.14	9.32	10.75	0	0	8.62

Table a-12 show the maximum error distance using the information of phase, power level and the summation information of phase and power level(x10) in three in three equation that are square (3.1), absolute (3.2) and square root (3.3) which measurement step is 2.5 cm.

Table a-12 The maximum error distance using phase, power level and phase+(power level(x10))

Position of electrode array	Maximum error distance(cm)								
	Phase			Power level			Phase+(Levelx10)		
	Square	Absolute	Square root	Square	Absolute	Square root	Square	Absolute	Square root
Top	27.61	27.61	27.59	28.5	28.5	28.5	28.5	28.46	26.93
Top - Right	25.12	30.1	30.1	25.12	26.93	26.93	0	0	26.93
Top - Bottom	21.21	21.21	13.46	42.43	42.43	42.43	42.43	42.43	42.43
4 Sides	23.05	23.05	23.05	20.62	25	26.93	0	0	19.04

Table a-13 show the correct estimation ratio using the information of phase, power level and the summation information of phase and power level(x10) in three ranges of input electrode which array 0-7, array 1-6 and array 2-5. The measurement step is 2.5 cm.

Table a-13 The correct estimation with number of input electrode

Position of electrode array	Correct estimation ratio(%)								
	Phase			Power level			Phase+(Levelx10)		
	0-7	1-6	2-5	0-7	1-6	2-5	0-7	1-6	2-5
Top	76.33	64.5	37.28	77.51	66.27	42.01	91.12	85.8	75.74
Top - Right	97.63	82.25	27.81	84.02	70.41	43.2	100	99041	92.9
Top - Bottom	96.45	93.49	71.01	85.8	77.51	62.72	98.22	98.22	97.63
4 Sides	98.82	95.86	60.36	80.47	55.03	17.75	100	99.41	82.25

Table a-14 shows the average of position error using the information of phase, power level and the summation information of phase and power level(x10) in three ranges of input electrode which array 0-7, array 1-6 and array 2-5. The measurement step is 2.5 cm.

Table a-14 The average of position error with number of input electrode

Position of electrode array	Average of error distance(cm)								
	Phase			Power level			Phase+(Levelx10)		
	0-7	1-6	2-5	0-7	1-6	2-5	0-7	1-6	2-5
Top	6.22	6.76	9.51	9.23	9.34	9.57	6.7	7.05	7.12
Top – Right	16.75	15.91	14.16	10.78	9.81	12.36	0	16.77	12.76
Top – Bottom	8.84	8.62	9.05	9.78	10.44	12.46	19.24	17.48	14.03
4 Sides	16.03	15.51	13.81	9.14	13.16	13.21	0	15.81	12.86

Table a-15 shows the maximum error distance using the information of phase, power level and the summation information of phase and power level x 10 in three ranges of input electrode which array 0-7, array 1-6 and array 2-5. The measurement step is 2.5 cm.

Table a-15 The maximum error distance with number of input electrode

Position of electrode array	Maximum error distance(cm)								
	Phase			Power level			Phase+(Levelx10)		
	0-7	1-6	2-5	0-7	1-6	2-5	0-7	1-6	2-5
Top	27.61	27.95	28	28.5	29.15	29.15	28.5	28.5	28.5
Top - Right	25.12	35.53	35.53	25.12	25.5	40.7	0	16.77	26.1
Top - Bottom	21.21	21.21	23.72	42.43	42.43	42.43	42.43	42.43	42.43
4 Sides	23.05	25.5	37.5	20.62	32.02	35.53	0	15.81	32.5

Table a-16 shows the result of the correct estimation ratio, average of position error and maximum error distance using six information separately that are phase, level, four weights of level that are k=1, k=2, k=5 and k=10 with square equation. The measurement step is 2.5 cm.

Table a-16 The correct estimation ratio, average of position error and maximum error distance of square equation

Position of electrode array	Square																	
	Correct estimation ratio(%)						Average of error distance(cm)						Maximum error distance(cm)					
	Phase	Level	K=1	K=2	K=5	K=10	Phase	Level	K=1	K=2	K=5	K=10	Phase	Level	K=1	K=2	K=5	K=10
Top	76.33	77.51	77.51	79.88	85.8	91.12	6.22	9.23	5.91	5.89	5.91	6.7	27.61	28.5	27.61	27.61	27.61	28.5
Top - Right	97.63	84.02	98.22	100	100	100	16.75	10.78	21.16	0	0	0	25.12	25.12	25.12	0	0	0
Top – Bottom	96.45	85.8	97.63	98.22	98.22	98.22	8.84	9.78	15.68	19.24	19.24	19.24	21.21	42.43	42.43	42.43	42.43	42.43
4 Sides	98.82	80.47	99.41	100	100	100	16.03	9.14	23.05	0	0	0	23.05	20.62	23.05	0	0	0

Table a-17 shows the result of the correct estimation ratio, average position error and maximum error distance using the six information separately that are phase, level, four weights of level that are k=1, k=2, k=5 and k=10 with absolute equation. The measurement step is 2.5 cm.

Table a-17 The correct estimation ratio, average error distance and maximum error distance of absolute equation

Position of electrode array	Absolute																	
	Correct estimation ratio(%)						Average of error distance(cm)						Maximum error distance(cm)					
	Phase	Level	K=1	K=2	K=5	K=10	Phase	Level	K=1	K=2	K=5	K=10	Phase	Level	K=1	K=2	K=5	K=10
Top	79.88	76.33	85.21	87.57	93.49	93.49	5.73	9.65	5.79	6.26	8.09	6.85	27.61	28.5	30.1	30.1	30.1	28.5
Top - Right	96.45	81.66	100	100	100	100	18.55	9.76	0	0	0	0	30.1	26.93	0	0	0	0
Top - Bottom	95.86	82.84	97.63	98.22	98.82	98.82	7.7	8.97	14.65	17.67	23.71	23.71	21.21	42.43	42.43	42.43	42.43	42.43
4 Sides	98.82	79.88	100	100	100	100	18.6	9.32	0	0	0	0	23.05	25	0	0	0	0

Table a-18 shows the result of the correct estimation ratio, average of position error and maximum error distance using the six information separately that are phase, level, four weights of level that are k=1, k=2, k=5 and k=10 with square root equation. The measurement step is 2.5 cm.

Table a-18 The correct estimation ratio, average of position error and maximum error distance of phase, level, weight of level by using square root equation.

Position of electrode array	Square Root																	
	Correct estimation ratio(%)						Average of error distance(cm)						Maximum error distance(cm)					
	Phase	Level	K=1	K=2	K=5	K=10	Phase	Level	K=1	K=2	K=5	K=10	Phase	Level	K=1	K=2	K=5	K=10
Top	76.33	68.64	90.53	92.9	89.94	84.62	5.93	10.14	5.76	6.62	6.81	7.48	30.1	28.5	30.1	30.1	28.5	28.5
Top - Right	92.9	71.01	99.41	100	99.41	88.76	15.38	10.43	22.36	0	5	9.37	30.1	26.93	22.36	0	5	26.93
Top - Bottom	95.27	79.88	98.22	98.22	98.22	89.94	7.39	10.29	17.67	17.48	17.48	8.35	13.46	42.43	42.43	42.43	42.43	42.43
4 Sides	97.63	68.05	100	100	98.22	92.9	12.42	10.75	0	0	9.44	8.62	23.05	26.93	0	0	15.81	19.04

Figure a-75 Tapes that use to attach the input electrode on 2DC sheet

Figure a-76 The epilator that use in the experiment

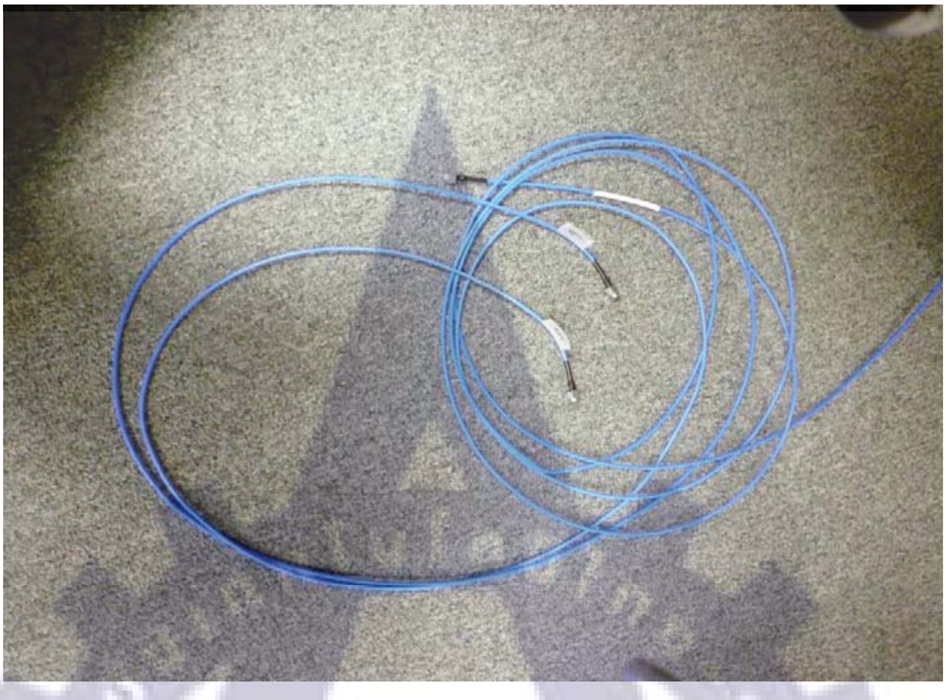

Figure a-77 The coaxial cable

Figure a-78 A ruler that use to measure the each point of experiment

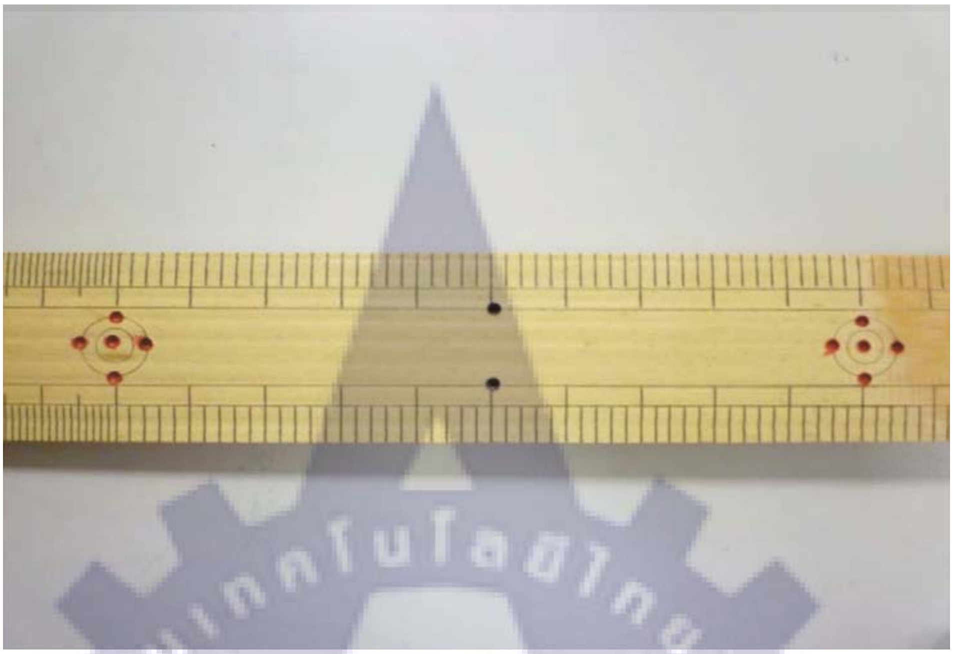

Figure a-79 A ruler that use to measure the each point of experiment

Appendix B

C Program.

```
#include <stdio.h>
#include <math.h>
#include <stdlib.h>
#include <string.h>
#define MAX_LEN 256
#define MAX_LINE 1000
int main(void)
{
FILE* fp1;
FILE* fp2;
char fname[80];
char *ch1;
char *ch2;
char buf1[MAX_LEN];
char buf2[MAX_LEN];
int num1 = 0;
int num2 = 0;
int i;
double data1[MAX_LINE][8];
double data2[MAX_LINE][8];
char* name1;
char* name2;
char* name1_list[MAX_LINE];
char* name2_list[MAX_LINE];
printf("Input phase file name 1:");
gets_s(fname);
fp1 = fopen(fname, "r");
if(fp1 == NULL){
printf("Can't open file\n");
exit(1);
}
int flag;
while(fgets(buf1, MAX_LEN-1, fp1) != NULL){
ch1 = strtok(buf1, " ");
i = 0;
flag = 0;
while(ch1 != NULL){
if(flag == 0){
```

```
name1_list[num1] = strdup(ch1);
flag = 1;
}else{
data1[num1][i] = atof(ch1);
i++;
}
ch1 = strtok(NULL, " ");
}
num1++;
}

fclose(fp1);
printf("Input phase file name 2:");
gets_s(fname);
fp2 = fopen(fname, "r");
if(fp2 == NULL){
printf("Can't open file\n");
exit(1);
}
while(fgets(buf2, MAX_LEN-1, fp2) != NULL){
flag = 0;
ch2 = strtok(buf2, " ");
i = 0;
while(ch2 != NULL){
if(flag == 0){
//name2 = ch2;
name2_list[num2] = strdup(ch2);
flag = 1;
}else{
data2[num2][i] = atof(ch2);
i++;
}
ch2 = strtok(NULL, " ");}
num2++;
}

fclose(fp2);
printf("Input level file name 1:");
gets_s(fname);
```

```
FILE* fp3;
fp3 = fopen(fname, "r");
if(fp3 == NULL){
printf("Can't open file\n");
exit(1);
}
char buf3[MAX_LEN];
char* ch3;
char* name3_list[MAX_LINE];
double data3[MAX_LINE][8];
int num3 = 0;
while(fgets(buf3, MAX_LEN-1, fp3) != NULL){
flag = 0;
ch3 = strtok(buf3, " ");
i = 0;
while(ch3 != NULL){
if(flag == 0){
//name2 = ch2;
name3_list[num3] = strdup(ch3);
flag = 1;
}else{
data3[num3][i] = atof(ch3);
i++;
}
ch3 = strtok(NULL, " ");}
num3++;
}
fclose(fp3);
printf("Input level file name 2:");
gets_s(fname);
FILE *fp4;
fp4 = fopen(fname, "r");
if(fp4 == NULL){
printf("Can't open file\n");
exit(1);
}
char buf4[MAX_LEN];
char* ch4;
char* name4_list[MAX_LINE];
```

```
double data4[MAX_LINE][8];
int num4 = 0;
while(fgets(buf4, MAX_LEN-1, fp4) != NULL){
flag = 0;
ch4 = strtok(buf4, " ");
i = 0;
while(ch4 != NULL){
if(flag == 0){
//name2 = ch2;
name4_list[num4] = strdup(ch4);
flag = 1;
}else{
data4[num4][i] = atof(ch4);
i++;
}
ch4 = strtok(NULL, " ");}
num4++;
}
fclose(fp4);
int j, k;
/*
for(k=0;k<num1;k++){
printf("%s: ", name1_list[k]);
for(j=0;j<8;j++){
printf("%f ", data2[k][j]);
}
printf("\n");
}
*/
double d1[MAX_LINE][7];
char si[3];
int start;
int end;
printf("Input start sink number(0 - 7) :");
gets_s(si);
start = atoi(si);
if(start < 0 || start >= 7){
printf("Input start sink number error. start sink num set to 0\n");
start = 0;
```

```
}
printf("Input end sink number(start+1 - 7):");
gets_s(si);
end = atoi(si);
if(end <= start || end > 7){
printf("Input end sink number error. end sink num set to 7\n");
end = 7;
}
for(k=0;k<num1;k++){
for(j=start;j<end;j++){
if(abs(data1[k][j] - data1[k][j+1])<180){
d1[k][j] = abs(data1[k][j] - data1[k][j+1]);
}else{
d1[k][j] = abs(abs(data1[k][j] - data1[k][j+1])-360);
}
}
}


double d2[MAX_LINE][7];
for(k=0;k<num2;k++){
for(j=start;j<end;j++){
if(abs(data2[k][j] - data2[k][j+1])<180){
d2[k][j] = abs(data2[k][j] - data2[k][j+1]);
}else{
d2[k][j] = abs(abs(data2[k][j] - data2[k][j+1])-360);
}
}
}
/*
for(k=0;k<num1;k++){
for(j=0;j<7;j++){
printf("%f ", d1[k][j]);
printf("%f ", d2[k][j]);
}
printf("\n");
}
*/
double min;
```

```
int min_num;
double buf_min;
int l;
double x_s;
double y_s;
double x_e;
double y_e;
char* a;
char* reg;
double td;
int td_num;
double e_max;
FILE* afp;
FILE* wfp;
FILE* xfp;
afp = fopen("result.txt", "w");
wfp = fopen("result_phase.plt", "w");
xfp = fopen("phase.dat", "w");
fprintf(wfp, "reset\n");
fprintf(wfp, "set term post eps color \"Arial\"\n");
fprintf(wfp, "set output \"phase_arrow.eps\"\n");
fprintf(wfp, "set xrange[60:90]\n");
fprintf(wfp, "set yrange[17:47]\n");
fprintf(wfp, "set xtics 5\n");
fprintf(wfp, "set ytics 17, 5\n");
fprintf(wfp, "set mxtics 4\n");
fprintf(wfp, "set mytics 4\n");
fprintf(wfp, "set nokey\n");
fprintf(wfp, "set size square\n");
fprintf(wfp, "set grid xtics ytics mxtics mytics\n");
printf("Input number(1:Power, 2:Abs, 3:Sqrt) : ");
gets_s(fname);
int form;
form = atoi(fname);
if(form != 1 && form != 2 && form !=3){
printf("wrong input number!\n");
exit(0);
}
td = 0.0;
```

```
td_num = 0;
e_max = 0;
int m;
for(k=0;k<num2;k++){
min = 10000000;
min_num = 0;
for(j=0;j<num1;j++){
buf_min = 0;
for(l=start;l<end;l++){
if(form == 1){
buf_min += pow((d1[j][l] - d2[k][l]), 2);
}else if(form == 2){
buf_min += abs(d1[j][l] - d2[k][l]);
}else if(form == 3){
buf_min += sqrt(abs(d1[j][l] - d2[k][l]));
}
//printf("%d %d %d %f \n", k, j, l, buf_min);
}
if(min > buf_min){
min = buf_min;
min_num = j;
}
}
//printf("%s -> %s\n", name1_list[k], name1_list[min_num]);
reg = strdup(name2_list[k]);
a = strtok(reg, ",");
if(a != NULL){
x_s = atof(a);
}else{
printf("input file error 1 %s!\n", name2_list[k]);
}
a = strtok(NULL, ",");
if(a != NULL){
y_s = atof(a);
}else{
printf("input file error 2 %s!\n", name2_list[k]);
}
reg = strdup(name1_list[min_num]);
a = strtok(reg, ",");
```

```
if(a != NULL){
x_e = atof(a);
}else{
printf("input file error 3! %s\n", name1_list[min_num]);
}
a = strtok(NULL, ",");
if(a != NULL){
y_e = atof(a);
}else{
printf("input file error 4! %s\n", name1_list[min_num]);
}
if(x_s == x_e && y_s == y_e){
fprintf(xfp, "%f  %f\n",x_s, y_s);
}else{
fprintf(wfp, "set arrow from %f,%f to %f,%f lw 4 lc %d\n", x_s, y_s, x_e, y_e, k+1);
td += sqrt(pow((x_s-x_e), 2)+pow((y_s-y_e), 2));
if(sqrt(pow((x_s-x_e), 2)+pow((y_s-y_e), 2)) > e_max){
e_max = sqrt(pow((x_s-x_e), 2)+pow((y_s-y_e), 2));
}
td_num++;
}
}
fprintf(afp, "**** using phase only ****\n");
fprintf(afp, "correct estimation ratio = %.2f%% (%d/%d)\n", (double)(num2-
td_num)/num2*100, num2-td_num, num2);
fprintf(afp, "average of error distance = %.2fcm (%.2fcm)\n", (double)td/td_num,
(double)td/num2);
fprintf(afp, "maximum error distance = %.2fcm\n", e_max);
fprintf(wfp, "plot \"phase.dat\" w p ps 2 pt 6\n");
fprintf(wfp, "set output\n");
fclose(wfp);
fclose(xfp);
double min2;
int min_num2;
double buf_min2;
FILE* wfp2;
wfp2 = fopen("result_level.plt", "w");
FILE* xfp2;
xfp2 = fopen("level.dat", "w");
```

```
fprintf(wfp2, "reset\n");
fprintf(wfp2, "set term post eps color \"Arial\"\n");
fprintf(wfp2, "set output \"level_arrow.eps\"\n");
fprintf(wfp2, "set xrange[60:90]\n");
fprintf(wfp2, "set yrange[17:47]\n");
fprintf(wfp2, "set xtics 5\n");
fprintf(wfp2, "set ytics 17, 5\n");
fprintf(wfp2, "set mxtics 4\n");
fprintf(wfp2, "set mytics 4\n");
fprintf(wfp2, "set nokey\n");
fprintf(wfp2, "set size square\n");
fprintf(wfp2, "set grid xtics ytics mxtics mytics\n");


td = 0.0;
td_num = 0;
e_max = 0.0;
for(k=0;k<num4;k++){
min2 = 10000000;
min_num2 = 0;
for(j=0;j<num3;j++){
buf_min2 = 0;
for(l=start;l<end+1;l++){
if(form == 1){
buf_min2 += pow((data3[j][l] - data4[k][l]), 2);
}else if(form == 2){
buf_min2 += abs(data3[j][l] - data4[k][l]);
}else if(form == 3){
buf_min2 += sqrt(abs(data3[j][l] - data4[k][l]));
}
//
}
//printf("%d %d %d %f \n", k, j, l, buf_min2);
if(min2 > buf_min2){
min2 = buf_min2;
min_num2 = j;
}
}
//printf("%s\n",name1_list[k]);
```

```
reg = strdup(name2_list[k]);
a = strtok(reg, ",");
if(a != NULL){
x_s = atof(a);
}else{
printf("input file error 1 %s!\n", name2_list[k]);
}
a = strtok(NULL, ",");
if(a != NULL){
y_s = atof(a);
}else{
printf("input file error 2 %s!\n", name2_list[k]);
}
reg = strdup(name1_list[min_num2]);
a = strtok(reg, ",");
if(a != NULL){
x_e = atof(a);
}else{
printf("input file error 3! %s\n", name1_list[min_num2]);
}
a = strtok(NULL, ",");
if(a != NULL){
y_e = atof(a);
}else{
printf("input file error 4! %s\n", name1_list[min_num2]);
}
if(x_s == x_e && y_s == y_e){
fprintf(xfp2, "%f%f\n",x_s, y_s);
}else{
fprintf(wfp2, "set arrow from %f,%f to %f,%f lw 4 lc %d\n", x_s, y_s, x_e, y_e, k+1);
td += sqrt(pow((x_s-x_e), 2)+pow((y_s-y_e), 2));
if(sqrt(pow((x_s-x_e), 2)+pow((y_s-y_e), 2)) > e_max){
e_max = sqrt(pow((x_s-x_e), 2)+pow((y_s-y_e), 2));
}
td_num++;
}
}
fprintf(afp, "**** using level only ****\n");
```

```
fprintf(afp, "correct estimation ratio = %.2f%% (%d/%d)\n", (double)(num2-
td_num)/num2*100, num2-td_num, num2);
fprintf(afp, "average of error distance = %.2fcm (%.2fcm)\n", (double)td/td_num,
(double)td/num2);
fprintf(afp, "maximum error distance = %.2fcm\n", e_max);
fprintf(wfp2, "plot \"level.dat\" w p ps 2 pt 6\n");
fprintf(wfp2, "set output\n");
fclose(wfp2);
fclose(xfp2);
printf("Input weight for level:");
gets_s(fname);
double weight;
weight = atof(fname);
double min3;
int min_num3;
double buf_min3;
FILE* wfp3;
wfp3 = fopen("result_total.plt", "w");
FILE* xfp3;
xfp3 = fopen("total.dat", "w");
fprintf(wfp3, "reset\n");
fprintf(wfp3, "set term post eps color \"Arial\"\n");
fprintf(wfp3, "set output \"total_arrow.eps\"\n");
fprintf(wfp3, "set xrange[60:90]\n");
fprintf(wfp3, "set yrange[17:47]\n");
fprintf(wfp3, "set xtics 5\n");
fprintf(wfp3, "set ytics 17, 5\n");
fprintf(wfp3, "set mxtics 4\n");
fprintf(wfp3, "set mytics 4\n");
fprintf(wfp3, "set nokey\n");
fprintf(wfp3, "set size square\n");
fprintf(wfp3, "set grid xtics ytics mxtics mytics\n");
td = 0.0;
td_num = 0;
e_max = 0.0;
for(k=0;k<num2;k++){
min3 = 10000000;
min_num3 = 0;
for(j=0;j<num1;j++){
```

```
buf_min3 = 0;
for(l=start;l<end;l++){
if(form == 1){
buf_min3 += pow((d1[j][l] - d2[k][l]), 2) + pow((data3[j][l] - data4[k][l]) * weight, 2);
}else if(form == 2){
buf_min3 += abs(d1[j][l] - d2[k][l]) + abs(data3[j][l] - data4[k][l]) * weight;
}else if(form == 3){
buf_min3 += sqrt(abs(d1[j][l] - d2[k][l])) + sqrt(abs(data3[j][l] - data4[k][l])) * weight;
}
//
}
if(form == 1){
buf_min3 += pow((data3[j][l] - data4[k][l]) * weight, 2);
}else if(form == 2){
buf_min3 += abs(data3[j][l] - data4[k][l]) * weight;
}else if(form == 3){
buf_min3 += sqrt(abs(data3[j][l] - data4[k][l])) * weight;
}
//printf("%d %d %d %f \n", k, j, l, buf_min3);
if(min3 > buf_min3){
min3 = buf_min3;
min_num3 = j;
}
}
reg = strdup(name2_list[k]);
a = strtok(reg, ",");
if(a != NULL){
x_s = atof(a);
}else{
printf("input file error 1 %s!\n", name2_list[k]);
}
a = strtok(NULL, ",");
if(a != NULL){
y_s = atof(a);
}else{
printf("input file error 2 %s!\n", name2_list[k]);
}
reg = strdup(name1_list[min_num3]);
a = strtok(reg, ",");
```

```
if(a != NULL){
x_e = atof(a);
}else{
printf("input file error 3! %s\n", name1_list[min_num3]);
}
a = strtok(NULL, ",");
if(a != NULL){
y_e = atof(a);
}else{
printf("input file error 4! %s\n", name1_list[min_num3]);
}
if(x_s == x_e && y_s == y_e){
fprintf(xfp3, "%f%f\n",x_s, y_s);
}else{
fprintf(wfp3, "set arrow from %f,%f to %f,%f lw 4 lc %d\n", x_s, y_s, x_e, y_e, k+1);
td += sqrt(pow((x_s-x_e), 2)+pow((y_s-y_e), 2));
if(sqrt(pow((x_s-x_e), 2)+pow((y_s-y_e), 2)) > e_max){
e_max = sqrt(pow((x_s-x_e), 2)+pow((y_s-y_e), 2));
}
td_num++;
}
}
fprintf(afp, "**** using phase and level*%.2f ****\n", weight);
fprintf(afp, "correct estimation ratio = %.2f%% (%d/%d)\n", (double)(num2-
td_num)/num2*100, num2-td_num, num2);
fprintf(afp, "average of error distance = %.2fcm (%.2fcm)\n", (double)td/td_num,
(double)td/num2);
fprintf(afp, "maximum error distance = %.2fcm\n", e_max);
fprintf(wfp3, "plot \"total.dat\" w p ps 2 pt 6\n");
fprintf(wfp3, "set output\n");
fclose(afp);
fclose(wfp3);
fclose(xfp3);
}
```

Appendix C

Figure c-80 NICT building

Figure c-81 Name of researcher who come or not come

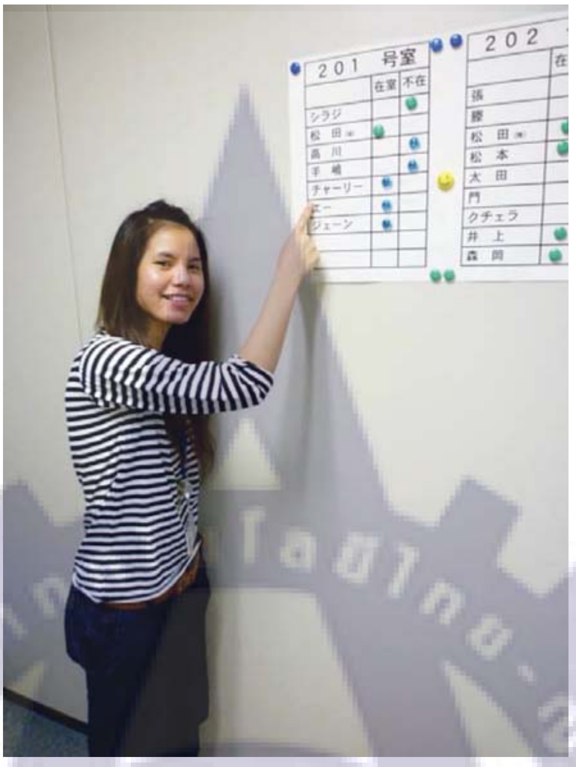

Figure c-82 My name that working today

Figure c-83 The part of my laboratory researcher team

Figure c-84 My NICT ID card

Figure c-85 The measuring method

Figure c-86 Presentation with my laboratory researcher team

Figure c-87 Presentation with my laboratory researcher team

Figure c-88 The international researchers supporter

Curriculum Vitae

Name – Surname		Supaporn Chantanakorn
Date of Birth		3rd December 1988

Educational

2007 – Present	:	Thai-Nichi Institute of Technology (TNI) Faculty of Information Technology (GPAX 3.84)
2000 – 2007	:	Wattanothaipayap School (GPAX 3.81)
1994 – 2000	:	Anubaan Chiangmai School (GPAX 3.85)

Scholarship

2007 – Present	:	TNI Fully financial support scholarship
2000 – 2007	:	Scholarship for outstanding students at Wattanothaipayap School

Activity and Training

May - Sep 2010	:	Internship at National Institute of Information and Communication Technology(NICT),Japan
Nov 2008 - Feb 2009	:	Teaching Assistant of C Language Lab
Jun - Aug 2008	:	Training in Marketing Department at Technology Promotion Association (Thailand- Japan); TPA
5-7 Oct 2007	:	Home stay with Japanese Family in Thailand
July 2007	:	Embedded System Seminar
2007 - 2008	:	Header of Academic section for IT's students

Award

Nov 2009	:	The Second Runner up of TNI's Japanese Speech Contest
Aug 2009	:	The Winner of the Best J-Activity Japan Festa in Bangkok 2009 by Mainichi
2008	:	TNI Oracle Certificate
2008	:	Level 4 for Japanese Language Proficiency Test