THE DEVELOPMENT OF TREE HEIGHT MEASUREMENT TOOL FOR FOREST RESOURCE INVENTORY

PRAWIT RAYA

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Thesis
Entitled

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…………………………………….
Mr. Prawit Raya
Candidate

…………………………………….
Asst.Prof. Gritsanaruck Theeraraj,
M.Sc. (Technology of Environmental Management)
Major-Advisor

…………………………………….
Assoc.Prof. Sura Pattanakiat**,**
Ph.D. (Forestry)
Co-Advisor

…………………………………….
Prof. Banchong Mahaisavariya,
M.D.
Faculty of Graduate Studies

…………………………………….
Assoc.Prof. Sayam Aroonsrimorakot,
Dean
M.Sc.(Technology of Environmental Management)
Acting Chair
Master of Science Program in Appropriate Technology for Resources and Environmental Development
Faculty of Environment and Resource Studies

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on
May 2, 2008

…………………………………….
Mrs. Prawit Raya
Candidate

…………………………………….
Dr. Chongrak Watcharinrat,
Ph.D. (Forestry)
Chair

…………………………………….
Asst.Prof. Gritsanaruck Theeraraj,
M.Sc. (Technology of Environmental Management)
Member

…………………………………….
Assoc.Prof. Sura Pattanakiat**,**
Ph.D. (Forestry)
Member

…………………………………….
Prof. Banchong Mahaisavariya,
M.D.
Dean
Faculty of Graduate Studies
Mahidol University

…………………………………….
Asst.Prof. Sittipong Dilokwanich,
Ph.D. (Human Geography)
Dean
Faculty of Environment and Resource Studies
Mahidol University

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Prawit Raya

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FOR FOREST RESOURCE INVENTORY

PRAWIT RAYA 4637153 ENAT/M

M.Sc. (APPROPRIATE TECHNOLOGY FOR RESOURCES
AND ENVIRONMENTAL DEVELOPMENT)

THESIS ADVISORS : GRITSANARUCK THEERARAJ, M.Sc. , SURA PATTANAKIAT, Ph.D.

ABSTRACT

The objectives of this study were to design a tree height measurement tool for use in forest surveys that is competitive in price and quality with tools which are currently imported into Thailand.

This study employed trigonometric principles and theory for the tool construction and development process. The three main elements of this process were : 1) an observed distance from the object which is constructed by using a 50 meter tape measure ; 2) an angle measurement using a laser instrument ; 3) a height calculation from the distance and angle value constructed by using a microcontroller instrument. The accuracy of the new tool was tested by using it at known heights from 2 to 20 meters with various distances from the object of 2 to 15 meters. The error was estimated using percentage and polynomial trend line analysis. It was found that average error of the new tool was 1.698 %. The distance for acceptably accurate measurement was 11 meters for objects of more than 14 meters height. A comparison of the new tool with a commercial instrument, Disto Classic Laser, was done by measuring 28 trees in the natural situation. There was no significant difference between the measurements of the two instruments ($p=0.05$).

In conclusion, the new tool could be used for tree measurement because its accuracy is not significantly different from high priced commercial instruments. However, this tool still needs to be developed for easy handling in various topographic situations.

KEY WORDS : TREE HEIGHT / MEASUREMENT TOOL/FOREST INVENTORY

75 P.

การพัฒนาเครื่องมือวัดความสูงต้นไม้เพื่อการสำรวจทรัพยากรป่าไม้
(THE DEVELOPMENT OF TREE HEIGHT MEASUREMENT TOOL FOR FOREST RESOURCE INVENTORY)

ประวิทย์ รายา 4637153 ENAT/M
วท.ม.(เทคโนโลยีที่เหมาะสมเพื่อการพัฒนาทรัพยากรและสิ่งแวดล้อม)
คณะกรรมการควบคุมวิทยานิพนธ์ : กฤษณรักษ์ ธีรรัฐ, M.Sc., สุระ พัฒนเกียรติ, Ph.D.

บทคัดย่อ

การศึกษาครั้งนี้มีวัตถุประสงค์เพื่อออกแบบและจัดสร้างเครื่องมือวัดความสูงต้นไม้ เพื่อใช้ในการสำรวจทรัพยากรป่าไม้ และประเมินประสิทธิภาพของเครื่องมือที่สร้างขึ้นโดยเปรียบเทียบกับเครื่องมือที่ใช้กันอยู่ในปัจจุบัน ซึ่งส่วนใหญ่เป็นเครื่องมือที่มีการนำเข้าจากต่างประเทศ

ในการดำเนินการวิจัย อาศัยหลักการและทฤษฎีทางตรีโกณมิติ โดยจัดสร้างเครื่องมือที่มีองค์ประกอบสำคัญ 3 ส่วน คือ ส่วนแรกเป็นการวัดระยะทางจากจุดสังเกตไปยังวัตถุ โดยส่วนนี้เป็นการติดตั้งเทปวัดระยะที่มีความยาว 50 เมตร ส่วนที่สองเป็นการหาตำแหน่งอ้างอิงในการวัดค่ามุม โดยติดตั้งอุปกรณ์เลเซอร์เป็นตัวควบคุมและส่วนที่สามเป็นการคำนวณผลซึ่งเป็นการใช้อุปกรณ์ไมโครคอนโทรลเลอร์ในการคำนวณความสูงวัตถุจากค่าระยะทางและมุมที่วัดได้ นำเครื่องมือที่สร้างขึ้นไปทดสอบวัดความสูงที่ระดับ 2 – 20 เมตร ตามความแปรผันของระยะห่างจากวัตถุ(2 - 15 เมตร) ประเมินค่าความคลาดเคลื่อนด้วยวิธีร้อยละ และหาความสัมพันธ์ของระยะทางที่เหมาะสมด้วยวิธี polynomial trend line พบว่าเครื่องมือมีค่าความคลาดเคลื่อนเฉลี่ยร้อยละ 1.698 และระยะห่างที่เหมาะสมคือ 11 เมตร สำหรับวัตถุที่มีความสูงตั้งแต่ 14 เมตรขึ้นไป เมื่อนำเครื่องมือที่สร้างขึ้นไปทดสอบวัดความสูงต้นไม้เปรียบเทียบกับเครื่องมือ Disto Classic Laser ที่ใช้ในการสำรวจป่าไม้ในปัจจุบันจำนวน 28 ต้น พบว่าไม่มีความแตกต่างกันอย่างมีนัยสำคัญทางสถิติที่ระดับความเชื่อมั่น 0.05

ดังนั้น เครื่องมือที่สร้างขึ้นสามารถนำมาประยุกต์ใช้ในการวัดความสูงของต้นไม้ได้ โดยมีความถูกต้องใกล้เคียงกับเครื่องมือจากต่างประเทศ และมีราคาถูกกว่ามาก แต่อย่างไรก็ตามยังจำเป็นต้องปรับปรุงเครื่องมือให้มีความสะดวกในการพกพา และสามารถทำการวัดได้ในทุกสภาพภูมิประเทศ

75 หน้า

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CHAPTER I
INTRODUCTION

1.1 Background and justifications

Forest is a vital natural resource which is an important part of the cycle of environment. Environment consists of water, Oxygen, Carbon dioxide and Nitrogen and others. The forest is also help to maintain equipoise of ecology system whether minerals, substance and others help to preserve soil and water. The forest helps to absorb rain and also to reduce erosion to the soil. Forest is the source of raw material such as wood from forest is used for construction, fuel. We get food from forest and herbs. Forest is the inhabitancy for all wild lives. The forest helps to reduce air pollution, attract Carbon Dioxide to use in the synthetic process, Carbon Dioxide is controlled its quantity which effects to the earth temperature. Current the forestry areas are reduced as shown in Table 1-1.

Deforestation or deteriorated forestry areas are from the following main causes:

Deforestation or deteriorated forestry areas are from human action such as increasing the number of population with need more agricultural areas, need of agricultural expansion, wooding, construction on dams, water reservoirs, transportation, dam to block river and mine etc.

From such causes to lose in forestry resources in large amount, the planning has been managed on forestry resources in order to solve such problem efficiently. The management planning needs to collect information and data on forest such as kind of forests, forestry land usage, component of wood, density, size of growth, quantity of secondary wood, quantity of reproduction, wood volume as well as data on landscape especially height of slope to be basic information to plan for making wood, to make road or forestry-road and to plan for forestry management of such areas.

Table 1-1 Forest Areas from Remote Sensing Images 1985- 2004

B.C.	**Forest Areas (Square kilometer)**
1985	150,866
1988	143,803
1989	143,417
1991	136,698
1993	133,554
1995	131,485
1998	129,722
2000	170,110.78
2004	167,590.98

Remark: Forestry areas excluded rubber trees and fruits gardens

Source: Royal Forest Department. Ministry of Agriculture and Cooperatives (http://www.forest.go.th/stat41/tab1.htm)

Survey on forestry resources to obtain complete, correct, sufficient information for management planning, it take a long time since there are a few personnel who are in charge of surveying when comparing to forestry areas of Thailand. In addition, the tools used for survey are currently spend long time to survey such Haga which is kind of tool used for tree height measurement which is necessary to measure the distance between the observation point to the tree as the tools set (at 15,20,25 and 30 meter) before pointing, observing in order to measure the tree height causing time consuming for measurement. The distance set by the tool may be difficult to survey the actual forest conditions since the real forest condition shall be disadvantage for surveying such as high slope etc and also long distance is difficult to observe the tree peak with eyesight is difficult to do, resulting to height value is high error etc. The tools used for height measurement consuming less time with high accuracy such as height measurement used the principle of laser with high price (more than 100,000 baht). Therefore, dispersion of tools to authority with duty of forestry survey is not thoroughly and the tools are needed to be imported from oversea resulting problem of repairing as well.

As a result, the solution to such problem is to invent the tools for forestry resources survey to use within our country with the efficiency to measure equally to the tools from oversea. This study has been done on researching of tool production for forestry resources survey; that is tool used for tree-height measurement using principle of laser. Since tree-height values is a variation to calculate for volume of wood with high accuracy tool and take less time to survey as well.

Information of forestry resources which are correct and sufficient shall be used to decide for management planning suitably further as well as in order to reduce cost of technology, design from oversea.

1.2 Objectives

1.2.1 To design and to develop tree-height measurement tool for forest resource survey.

1.2.2 To identify the efficiency of developed tool by compairing with existing commercial tool.

1.3 Limitation of studying

1.3.1 Equipment used in the research shall be domestic material only.

1.3.2 Tree-height measuring tool for accuracy shall be tested by material and tree with certain height.

1.4 Conceptual framework

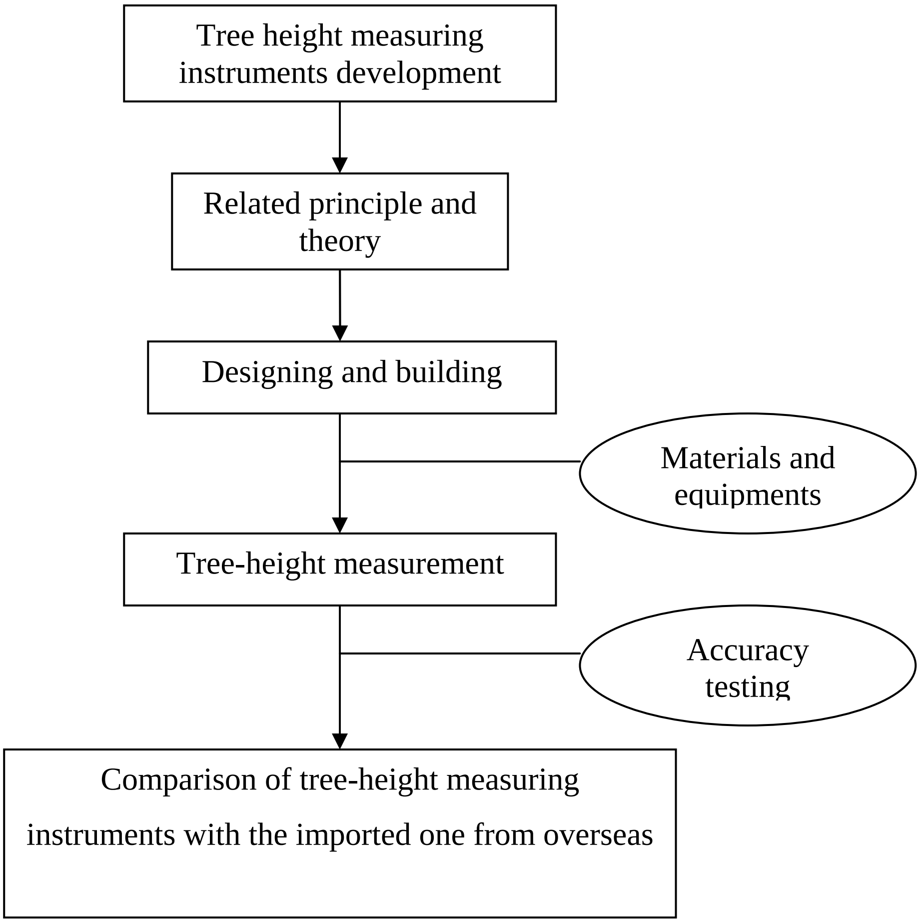


Figure 1-1 Conceptual framework

1.5 Expected result

The efficient tree height measuring instrument functions as well as the laser principle instrument imported from oversea.

CHAPTER II
LITERATURE REVIEW

2.1 Forestry resources surveying

Forestry resources survey is a collective data of both biological and physical conditions of existing forestry resources such as forest type, forest area, the use of land forest, tree' s component, tree's growth rate, secondary wood and plants, as well as other information. The geographical information includes height, slope, soil type, and rock type. These data will be used for making wood, reforestation, road construction and forest management planning in the future. (Satit, 1982)

The aims and objectives of forest resources survey

- To survey the land usage in order to use as basic information for agricultural, forest t and water source development;
- To obtain the other ecosystem data of forest, such as secondary wood condition, cover crop, feeding crop, beautiful plants, type of forest and the beautiful landscape for recreation;
- To gain the geographical information, including land height and land slope;
- To get the proportion of forest structure, type of trees, forest volume, the spreading of trees, size of trees in the forest for fundamental information in planning for timber exporting (Satit, 1982)

From the above information, basic information of forest is highly important for forestry resource management. Tree volume (v) is one of important pivot. It can be calculated by the following. (Michel S.Philip, 1994)

$$v = ghf\ (m^3)$$

When v = tree volume (cubic meter)

h = height of tree (meter)

g = cross-section of tree stem (square meter)

f = a coefficient employed to reduce the volume of a cylinder ($v=gh$) that of the tree or log

From the tree volume calculation, it is necessary to know cross-section of tree stem and height of a tree which derived from the survey.

2.2 Calculation of cross-section of tree stems

In order to calculate cross-section of tree stem, it is important to know the factor used in the calculation. In another words, Diameter at breast height of trees or perimeter is needed to calculate the cross-section of tree stems. Diameter at breast height can be obtained at 1.30 meter height from base of a tree. There is variety of measuring instruments used for measuring the diameter or perimeter of trees, such as simple and complicated function system, but also used by the trigonometry concept such as Caliper, Pentaprism, Spigel and Relascope etc.

2.3 Tree-height measurement

The height of trees is essential for calculating tree volume. Moreover, height of the tree at any specific year will be used to estimate the productive capacity of that growing area. (Kanitinan, 2005). Therefore, the accuracy of tree height is very important.

Tree-height measurement is popular to measure at 2 levels; those are,

1) Total height, it is the height of the tree from the ground to the top of the tree.
2) Merchantable height, it is the height from ground to useable stem.

Merchantable height can be divided into 2 types.

1) Fixed top limit is the merchantable height from ground to the stem point of specific diameter or specific perimeter. For example, the height of a pine tree from ground to the stem point which diameter is 10 cm. The fixed top limit is appropriate for the tree of which the stem and tip are symmetry, bush, and similarity.

2) Utilization Point is the merchantable height, which considers the utilization point of tree. Normally in Thailand, tree height measurement will start from the ground to a first fresh branch. Because, it is assumed that above this point, the tree may be defective and useless. (Vipak and his team, 2002).

Forestry industry organization has redefined the meaning of tree height by considering tree utilization, or the tree height that can be made use of in many aspects and the consideration of tree utilization pattern for the most benefit such as pole, window frame, door frame, furniture which have different height.

Tree- height measurement methods: tree-height measurement can be done by 2 methods as follows.

2.3.1 Direct method, this method can be performed into 2 ways which are measuring from the tree tip and measuring from the ground by measuring pole. This method is suitable for the young tree and not too high. However, this method is rarely used (Kittinan, 2005)

2.3.2 Indirect method, the mathematics and scientific concept have been used to measure the tree height. Indirect method has been divided into two sub-methods.

(2.1) Trigonometric Method

1) Tree-height measurement by using the trigonometric can be divided into 3 principles as follows:

- Tree-height measurement by using trigonometric principle, in case the level of observer is at the distance of the stem.

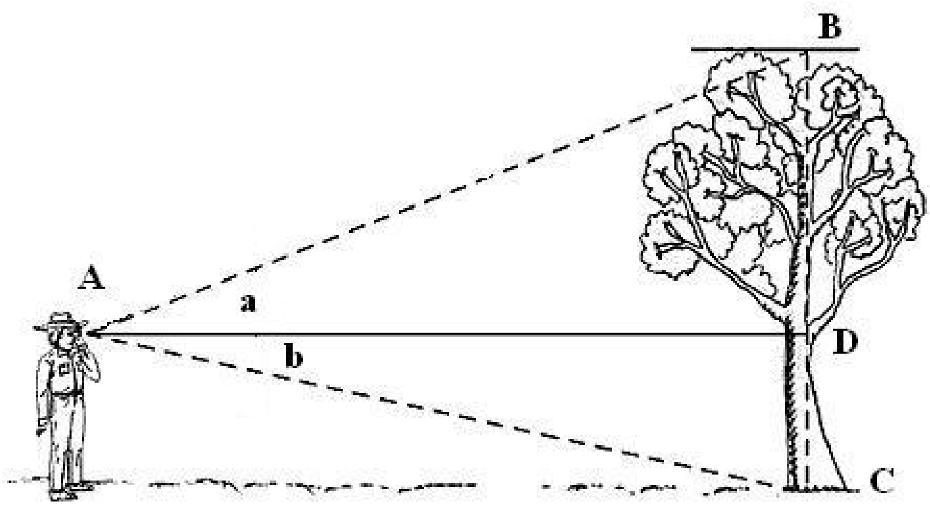


Figure 2-1 Tree-height measurements by using trigonometric principle, in case the observer is at the distance of the stem.

Here, the tree-height = BC

= BD + DC

= AD tan a + AD tan b

= AD (tan a + tan b)

Since AD = AC cos b

It is obtained, tree-height measurement = AC cos b (tan a + tan b)

If AC and AD overlaps each other, the formula shall be;

Tree-height = AC tan a

- Tree-height measurement by using trigonometric principle, in case the observer is in the higher position than the tree top.

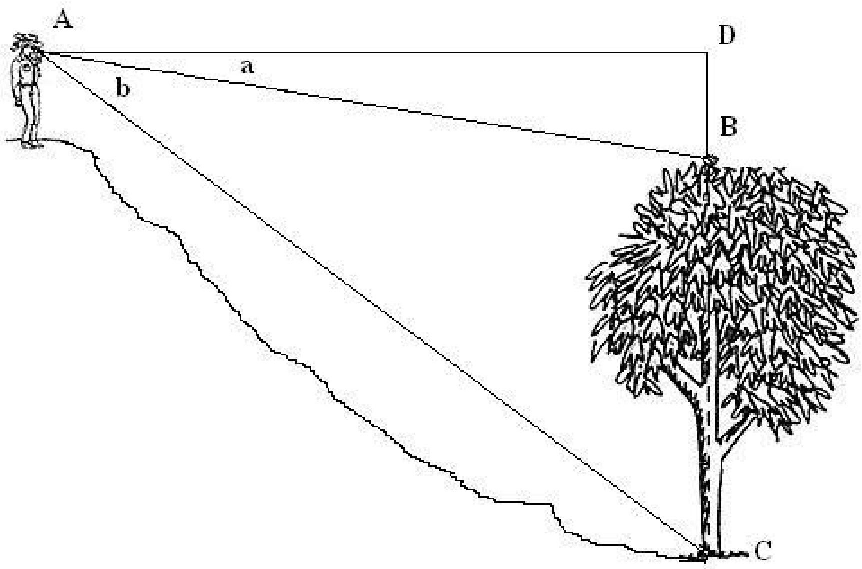


Figure 2-2 Tree-height measurements by using trigonometric principle, in case the observer is in the higher position that the tree top.

From above figure, tree-height shall be = CD - BD

= AD tan b AD tan a

= AD (tan b - tan a)

- Tree-height measurement by using trigonometric principle, in case the observer is lower than the tree stub.

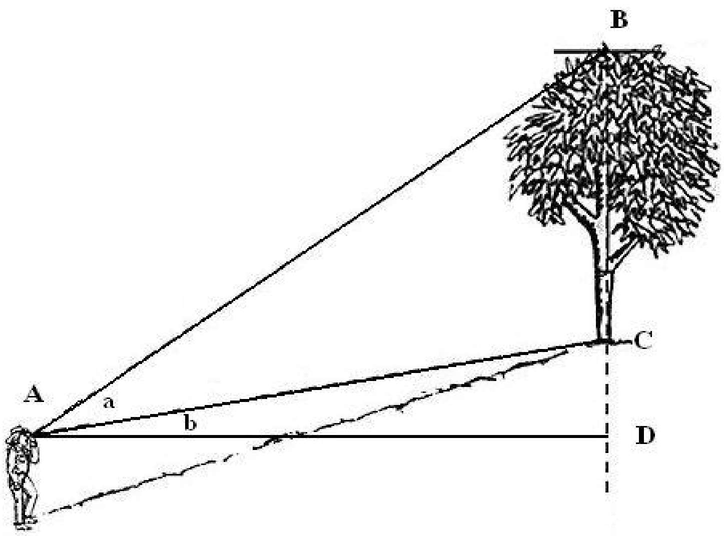


Figure 2-3 Tree-height measurements by using trigonometric principle, in case the observer is in the lower position than the foot of the tree.

From above figure, tree-height shall be = BC

= BD - CD

= AD tan a - AD tan b

= AD (tan a - tan b)

Samples of height measuring tools using trigonometric principle.

- Abney Level, is a kind of height and slope measurement, cheap price, medium size and medium weight. Abney Level is strong, but the measuring tube is easily broken.

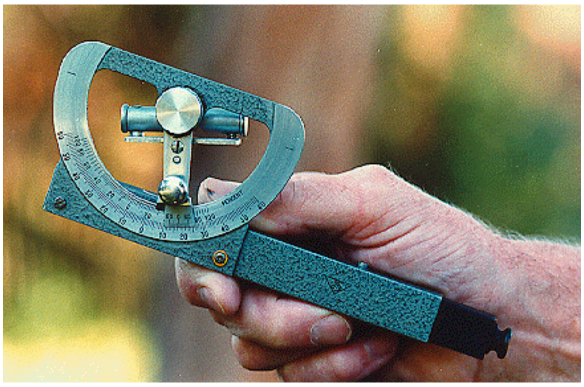


Figure 2-4 Abney Level

- Blume Leiss , is a kind of height measuring tool with medium size and weight, strong, and cheap. Height measurement can be read directly if the measurer standing at the distance of 15, 20, 30 and 40 meter from the tree.

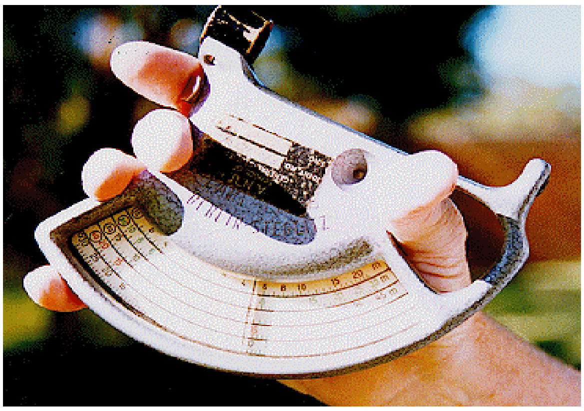


Figure 2-5 Blume Leiss

- Haga, is a kind of height measuring tool with medium size and weight, strong and cheap. Height measurement can be read directly if the measurer standing at the distance of 15, 20, 25 and 30 meter from the tree. Choosing scale by turning the scale bar.

Figure 2-6 Haga

The use of the height measuring tools using these principles such as Abney Level, Haga, Suunto and Relaskop, are required the distance between a tree and a surveyor. In addition, a table is required when Abney Level is used for measuring. This method is the time consuming method and it is difficult when measuring leaning tree. Errors can happen from difference ways, such as wrong the horizontal distance and, tree marking, and leaning tree that is hard to measure. The relation between viewing angle of a surveyor and the tree height can also give an error. The smaller the viewing angle is, more accuracy of the tree height is. To make the viewing angle small, the surveyor has to stand far away from the tree. As a result, it causes difficulty in marking the tree top and the bole of a tree. Thus these difficulties cause an error of measuring (Kittinan, 2005)

2.3 2.2 Geometric Method

There are 2 geometric theories related to the tree height measurement.

1) Isosceles Triangle Principle

Measuring principle shall use Isosceles Triangle Principle. The instrument to measure the tree-height, this principle can be divided into 3 cases as follows:

- Height measuring by using Isosceles Triangle principle, in this case the observer is at the distant the tree stem.

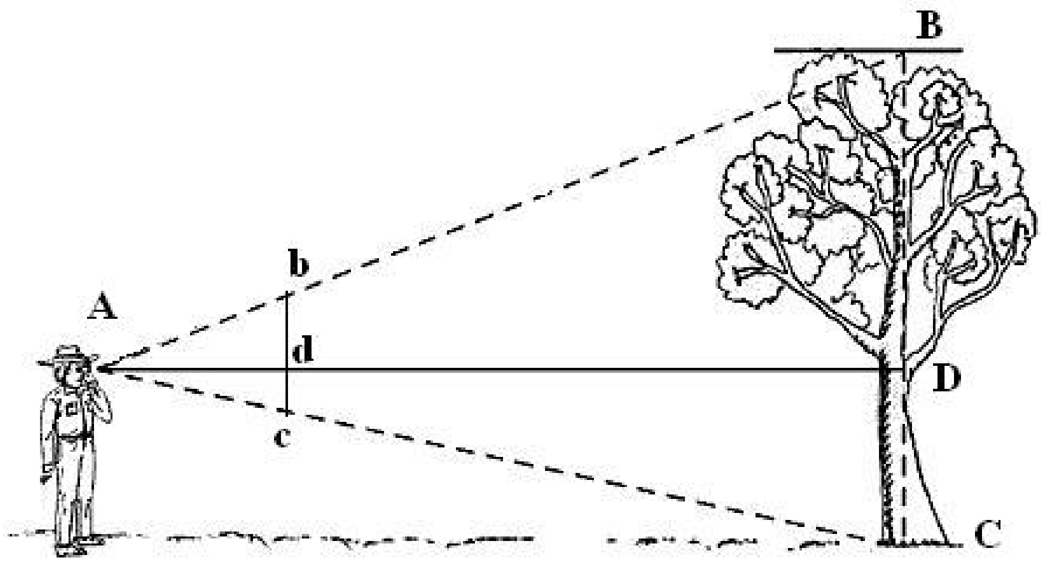


Figure 2-7 Height measuring using Isosceles Triangle Principle, in case the observer is at the distant the trees stem.

$$BD : bd = AD : Ad$$

$$BD = \frac{bd \times AD}{Ad}$$

$$DC : dc = AD : Ad$$

$$DC = \frac{dc \times AD}{Ad}$$

Therefore, the height of tree $= BC = BD + DC$

$$= \frac{bd \times AD}{Ad} + \frac{dc \times AD}{Ad}$$

- Height measuring using Isosceles Triangle Principle, in case the observer is in the lower position than the tree stub.

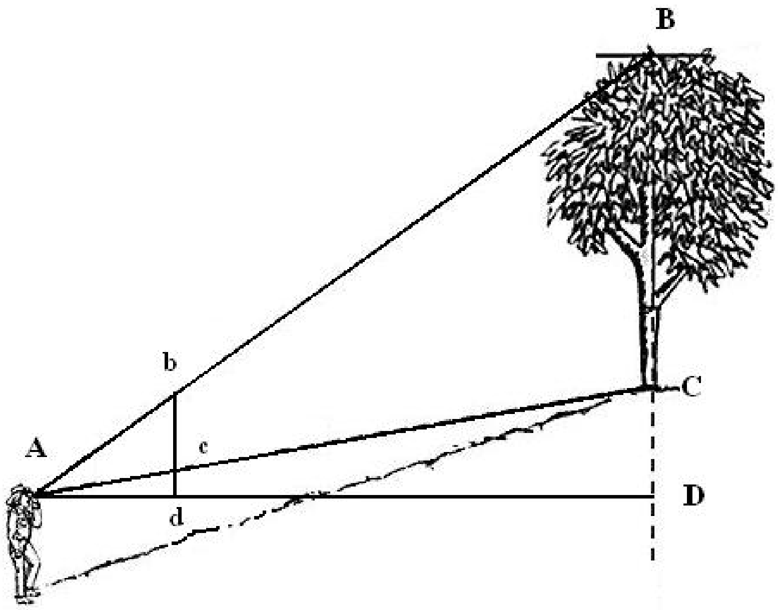


Figure 2-8 Height measuring using Isosceles Triangle Principle, in case the observer is in the lower position than the tree stub.

Here; the tree-height $= BD - DC$

$$= \frac{AD\ (bd - dc)}{Ad}$$

$$= \frac{AD \times bc}{Ad}$$

- Height measuring using Isosceles Triangle Principle, in case the observer is in the higher position than the tree peak.

Here, the tree –height $= CD - BC$

$$= \frac{AD\ (cd - bd)}{Ad}$$

$$= \frac{AD \times bc}{Ad}$$

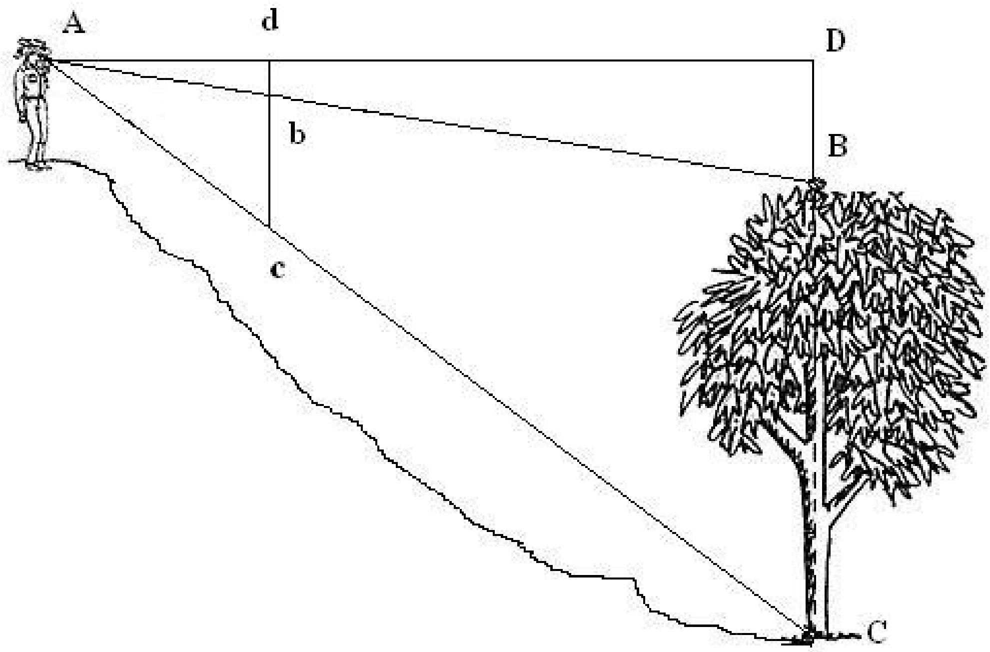


Figure 2-9 Height measuring using Isosceles Triangle Principle, in this case the observer is in the higher position than the tree peak.

The instrument working by this principle is the stick 1/10. But by using this method, the height result is highly incorrect. The mistake comes from estimation of distance, namely hand shaking when measuring and incorrect setting of the stick. Moreover if measuring the tree that higher than 100 feet (about 27 meters), error in reading the result comes from the tightness of scale as a result, the inaccurate result slightly high and this instrument has limitation when measuring leaning trees.

(2.2.2) Pythagorus principle

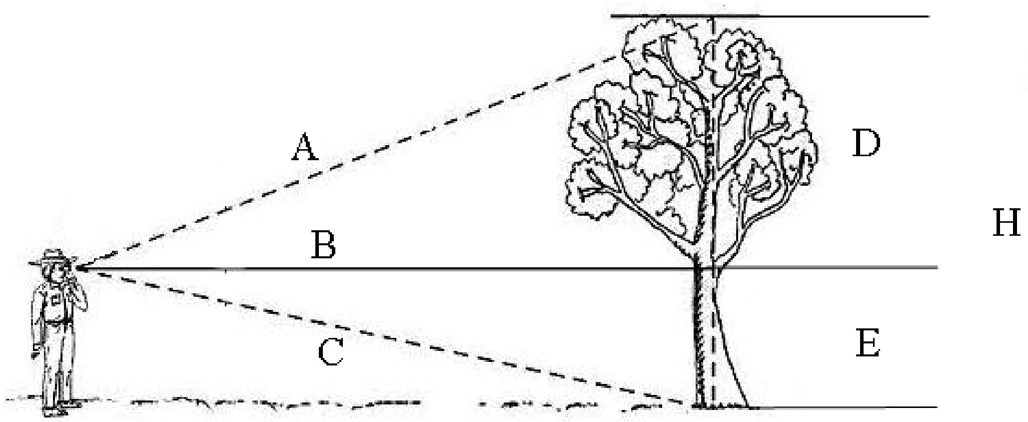


Figure 2-10 heights measuring using Pythagorus principle.

From the figure $D^2 = A^2 - B^2$

$E^2 = C^2 - B^2$

Here; the tree-height (H) = D + E

$$= \sqrt{A^2 - B^2} + \sqrt{C^2 - B^2}$$

The measuring instrument using in this principle are Criterion Laser Meter. Since Laser light source with dominant characteristic; that is light wave is in good order as beam, high density, fixed wavelength) J. Wilcon & J.F.B. Hawker, 2545) The measuring principle by using laser can be divided into 2 steps as follows:

1) Distance searching. Calculation, to calculate tree height by using Pythagorus principle, it is important to know 3 values which are distance from observing point to the tree stub, distance from observing point to the stem of the tree, and the distance from the observing point to the stem and to the observer. Searching distance by laser can be divided into 3 principles.

1.1) Measuring distance using Interferometry technique (Wilson, Haeker) can be used to measure distance with the principle of two waves interposition. The distance is measured by counting light fringe (happening while wave contains supportive phase) and dark fringe (happening while the wave contain deduction phase) occurred alternatively as fringe in order to use as parameter to calculate the distance. Measuring instrument using Interferometry technique is used for measuring thickness of work piece required high accuracy. In addition, this technique can be applied to industrial measurement as well. (Atchariya, 1993)

1.2) Measuring distance by counting time of light traveling to and reflect. The light shall be very short pulse with telescopic to collect light reflecting in return with photo detector to catch the light and timer. (J.Wilson & J.F.B. Hawker, 1987). The sample of measuring instrument is laser rangefinder, it measures since the light starts and exposes to the light which can be modulated to electric signal to light signal and emerging continuous wave or sending pulse. (Price and Uren, 1989)

1.3) Measuring distance using phase comparing technique between sending and receiving signals using diode laser as carrier to send required frequency signal with modulation of amplitude, the sending to the air to the material and reflect to the light receiver, then demodulation the signals in order to compare phase between sending and receiving signal. Phase differences of both signals took to calculate the distance. The height measuring instrument will rely on the comparing principles of phase since the distance value obtained from measuring shall be high accuracy and also capable of measuring distance in the wide range of (5 meter – 10 kilometer) (Korakot and Chana, 1997). Calculation for distance can be obtained from the multiply value of wave length with wave plus fraction of distance of wave length.

2) Steps of height calculation from the distance measured.

Calculation tree height will rely on Pythagorus principle; that is in form of triangle, square area on opposite of triangle plus square area on the both sides. Height measuring in case of 0 slope shall define the observing point to the tree peak as the opposite side of right angle (a) and the shortest distance from observing point of the tree as the opposite angle (b), it shall be:

$$\text{Tree-height} = \sqrt{a^2 - b^2} + \text{height from the ground to observing point}$$

The tree-height measuring instrument depending on laser principle will measure distance with technique of phase comparing. Since the value of distance obtained from measuring will be highly accurate with less error. (TruPulse™ 200 Rangefinder/Hypsometer , with error +/- 1foot) can be used in measuring distance in the wide range of (5 meter – 10 kilometer) and took less time for measurement since it is no need to know the distance between the tree and the measurer before measuring with capability to use with the incline tree. Because the instrument must be imported from oversea, it results to difficult with expensive maintenance.

From above advantages and disadvantages of the tree-height measuring instrument, it contributes to development of the efficient height instrument for domestic usage comparing to the height instruments imported from oversea. In this experiment, trigonometry principles have been used and use special characteristic of laser; that is parallel light with high density, certain direction in order to identify referred point in searching angle of tree height of such instrument instead of pointing with eyesight through the exiting instruments. Nevertheless, technology on material and equipment related to laser is not developed much in Thailand, as a result the laser equipment produced in the country doesn't have enough quality to further development in order to be the instrument for tree-height measurement.

2.4 Microcontroller

A microcontroller is a computer with most of the necessary support chips onboard. All computers have several things in common, namely:

- A central processing unit (CPU) that 'executes' programs
- Some random-access memory (RAM) where it can store data that is variable.
- Some read only memory (ROM) where programs to be executed can be stored.
- Input and output (I/O) devices that enable communication to be established with the outside world i.e connection to device such as keyboard, mouse, monitors and other peripherals.

A microcontroller may take an input from the device it is controlling and controls the device by sending signals to different components in the device. A microcontroller is often small and low cost. The components may be chosen to minimize size and to be as inexpensive as possible.

The actual processor used to implement a microcontroller can vary widely. In many products, such as microwave ovens, the demand on the CPU is fairly low and price is an important consideration. In these cases, manufacturers turn to dedicated microcontroller chips-devices that were originally designed to be low-cost, small, low-power, embedded CPUs. (David and his team, 2004).

First, microcontrollers were developed in the mid-1970s. These were basically calculator-based processors with small ROM program memories, very limited RAM data memories, and a handful of input/output ports.

The 8051 family was introduced in the early 1980s by Intel. Since its introduction, the 8051 has been one of the most popular microcontrollers and has been second-soured by many manufacturers. The 8051 currently has many different versions and some types include on-chip analogue-to-digital converters, a considerably large size of program and data memories, pulse-width modulation on outputs, and flash memories that can be erased and reprogrammed by electrical signals. (Dogan, 2002).

The 8051 is an 8-bit, low-power, high-performance microcontroller. There are a large number of devices in the 8051 family with similar architecture and each member of the family is downward compatible with each other. The basic 8051 microcontroller has the flowering features:

- 4 K bytes of program memory
- 256 x 8 RAM data memory
- 32 programmable I/O lines
- Two 16-bit timer/counters
- Six interrupt sources
- Programmable serial UART port
- External memory interface
- Standard 40-pin package

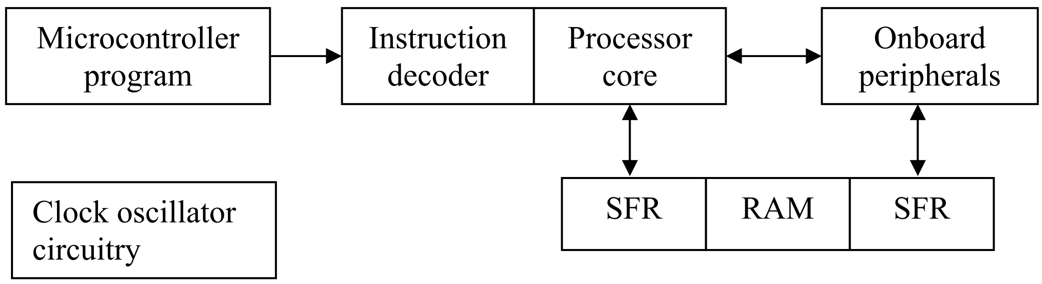


Figure 2-11 Block diagram of a microcontroller (David and his team, 2004).

A microcontrollers is a general-purpose device (Ayala, 2005)

- To read data
- Perform limited calculations on that data
- Control its environment based on those calculations
- Controls the operation of a machine

2.5 Related research

Santi (Santi,1995) has tried to build wood-height meter, using PVC blue pipe, with thickness 8.5 diameter with 3 size of those pipes; ½ ” , ¾” and 1” respectively to create wood-height meter of 7 meter height. The creation method is easy by using the principle of drawing-antenna, by giving the PVC tip with ½”, length 220 cm., the middle PVC with size of ¾”, length 160 cm. and the first pipe is PVC 1 inch size, 150 cm length to assembly as the wood-measuring meter with 500 cm height with ¾” PVC, 110 and 100 cm, for each length as accessory, all set can be measured the height of 700 cm.

CHAPTER III
RESEARCH METHODOLOGY

3.1 Equipment used in experiment

- Standard equipment used in this study is height measuring tool which is currently used. The brand of the height measuring tool is Disto Classic[3]. Here are the tool's details as follows; laser power 620-690 nm/0.95 mw, Class II with the principle of using phase comparison technique between sending and receiving signals. Then the distance values from calculation as height. The correct value of the tool used for distance measurements are between 0.2-100 meters, at +/-3 mm.
- Distance measuring tape
- Result recording tape
- Measuring Pole
- Plywood with 0.5 centimeters thick, 20x30 centimeter size
- Hinge
- Can's spray cover
- Laser diode 625 nm, 5 mw power
- Switch
- Battery 1.5 v. and Battery 9 v.
- glued tape
- Sticker paper
- Circuit panel
- Microcontroler ATMEGA8515L
- LCD Display

3.2 A guideline of research

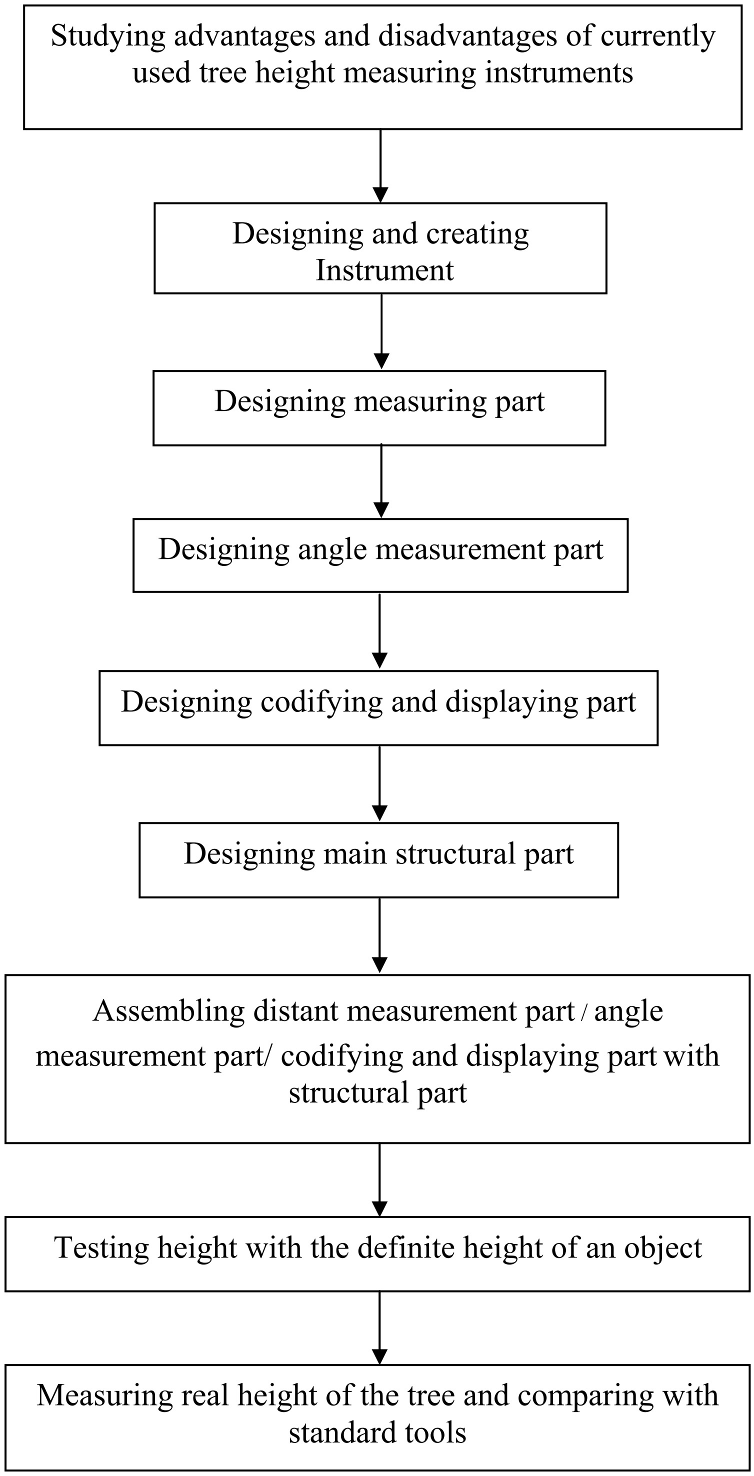


Figure 3-1 A guideline of research

3.2.1 Collection of primary data

Codifying data from document and related research to principle theory of tree height measuring in various types of Tree-height Measuring Tools as well as tree height equipment used the principle of laser which is a way to collect data in part of secondary data.

3.2.2 Design and making tools to measure the tree-height

In this research, trigonometry principle has been used to measure tree-height measurement by based on the laser principle. The laser used in this research is Diode laser. It is the equipment sending light as reference position in order to measure the up-risen angle to the tree peak and the angle of depression looking to the tree-stub in order to search angle value to calculate for the height further. While the distance from observation point of measuring to the tree shall be searched by using the measuring tape attached to the invented tools. Calculation for height value shall use microcontroller to calculate for height value by putting data of distance from observation point to the tree and the angle measured. Then the tools shall calculate height value by showing onto LCD display.

Process of making tool can be divided into parts as follows

3.2.2.1 Distant measuring part

3.2.2.2 Use 15 meters measuring tape as a distant measuring part

3.2.2.3 Angle measurement part

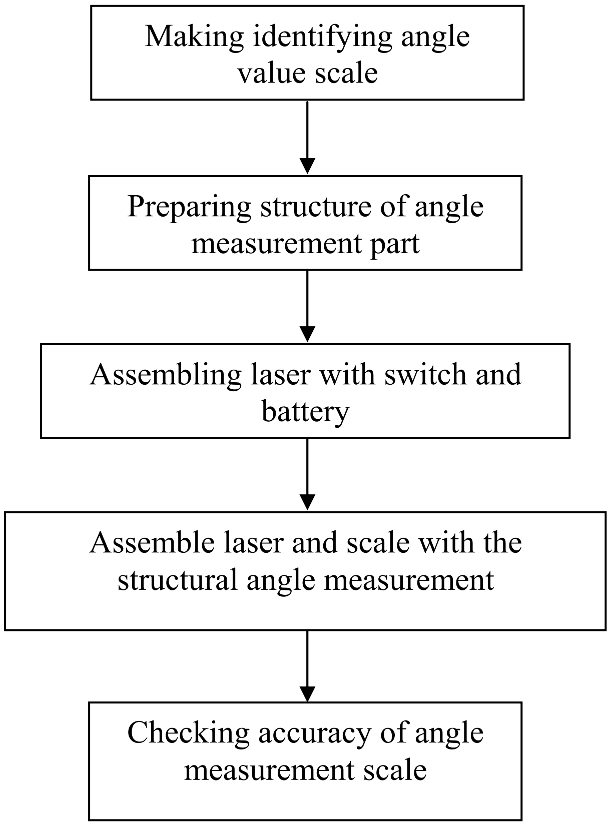


Figure 3-2 A guideline of design and making tools

3.2.2.4 Codifying and displaying part

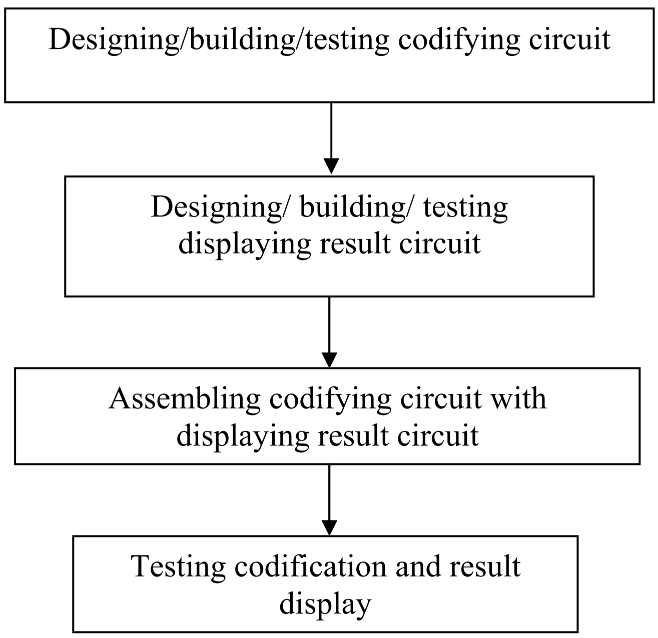


Figure 3-3 A guideline of codifying and displaying part

3.2.2.5 Main structural part

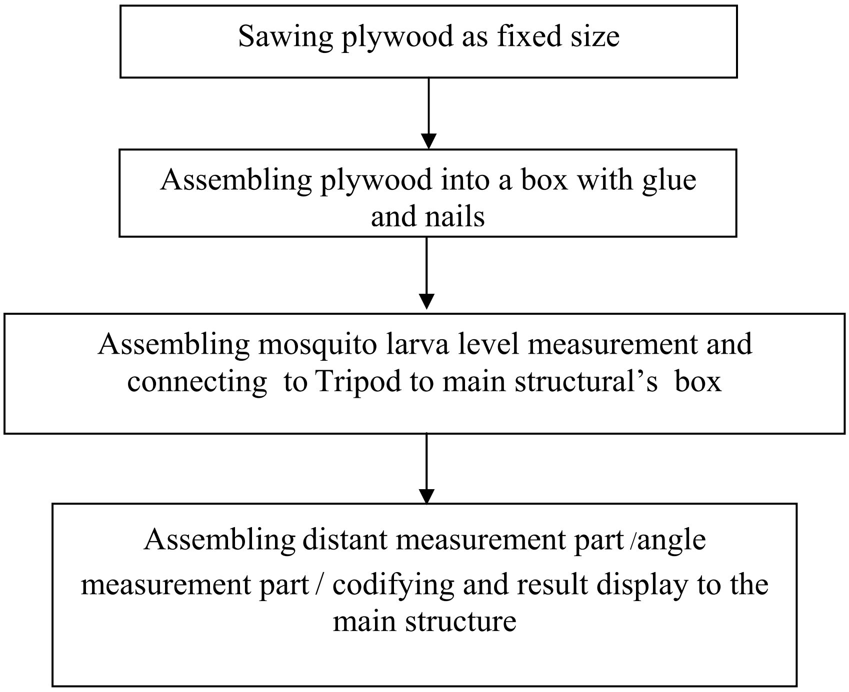


Figure 3-4 A guideline of main structural part

3.2.3 Tree-height measuring tools testing

3.2.3.1 Testing object with certain height

- The height of object Testing 2-20 meters shall be measured in the testing, by measuring at the distance for each position for meter, starting from the height from the ground 20 meters.
- Measuring height at any position shall be made at different distance by starting from the distance from material to observation point of 2 meter to the distance of object to observation point 15 meters; each position shall be far for 1 meter each.
- Measuring height for each position shall be repeated 3 times, then note the results.

3.2.3.2 Height value will be calculated in order to find the average height measured and calculate error percentage for each various height, the error percentage can be calculated by using the following formula; (Sirichai, 2006)

$$\text{Percentage error (\%)} = \frac{\text{Height Value Obtained - Actual Height Value x 100}}{\text{Actual Height Value}}$$

3.2.3.3 Then, find the relation between the real height with height value that measured at observation point 2 to 15 meters by find polynomial trendline and calculated R-squared value by using Microsoft Excel.

3.2.4 Comparison of height values obtained from the tree-height measuring invented tool and the Tree-height measuring tool Disto Classic[3] Laser

3.2.4.1 Testing actual tree-height measuring in Kasetsart University for 28 trees.

- The experiment shall measured tree-height with diameter more than 4.5 centimeter (DBH > 4.5 cm) with higher than 1.3 meter, for 28 trees.
- Tree measuring shall be measured as Merchantable Height by measuring Utilization Point. Height measurement shall consider on the actual Utilization Point in Thailand which is popular to measure three from the first fresh branch of the tree.
- Measuring each tree shall be 3 times repeated, the first time shall be measured with invented tools, and note the result, the second shall measure with standard tool at the same point, then note the result and the last is measured by Measuring Pole, then not the result.
- Measuring steps to tree-height by standard tool, the tool used has no function of height calculation, so in this experiment the Pythagorous's principle is used to calculate tree-height by taking distance measured for 3 values; those are distance from observation point to the tree peak (a), the shortest distance from observation point (b) and distance from observation point to tree stub (c) to calculate height by using the following formula;

$$\text{Tree-height} = \sqrt{a^2 - b^2} + \sqrt{c^2 - b^2}$$

- Take height value obtained form invented tool and standard tool to calculate error percentage by comparing to the actual height measure from Measuring Pole.

3.2.4.2 Take height value obtained from Article 3.2.3.1 to analyze efficient difference value of tree-height measurement obtained from invented and standard tools by using Independent-Samples T-Test.

3.3 Analysis of general information

The easy-complete sampling shall be used to with the trees for experiment and in analysis for accuracy of invented tool shall be calculated the value in form of error percentage and polynomial trendline in a chart by using Microsoft Excel. In the step of efficiency difference of tree-height measurement of height measuring tools with standard height measuring tool shall test difference value by using different testing of means between the 2 population groups (Independent-Samples T-test by using ready-program SPSS/PC (Statistic package for the Social Science/Personal Computer Plus.)

3.4 Analysis and summary on results

The conclusion of research results and suggestions from this research shall be made into reports further.

CHAPTER IV
RESULTS AND DISCUSSIONS

4.1 Tree-height measuring instrument

Details of instrument are as follows:

Built tree height measuring tools is indirect tree measurement used trigonometry principle to felicitate the calculation as follow (Santi, 2003))

From Figure 2-1 the tree-height = BC

= BD + DC

= AD tan a + AD tan b

= AD (tan a + tan b)

Built instrument has different parts as follows

4.1.1 Distance measurement

In order to build tools, 15-meters-long metal tape is a part to find the distant between the observers with object that needed to find height. The tape is attached to inner wall in the main structure.

4.1.2 Angle measurement part is comprised 3 sub- parts as follows

-Laser part using for identifying reference position and angle of depression for calculating height value is orderly light wave having with certain direction (beam of light). It is the beam of light with high intensity. The laser that was used in this experiment is laser diode.

Laser diode consists of 3 parts, namely (Somsak, 1986)

1) Laser medium was made from semi-inductor substance which made from compound.

2) Energy pumping for the object's substance which is the laser medium in stimulating condition.

3) Optical Cavity for light amplification

Mechanism of laser generating can be divided into 2 phases

First phase is stimulation emision. Atom system or molecules will abosorb light when energy was sent in to make atom or molecule be in the high-energy level. It is required radiation into atom or molecules system which have equel energy to the difference of both energy level. However, the radiation will not be absorbed, but light will stimulate atom or molecule to regurgitate light before time. Radiated light with stimulating light from the system at the same time have equal energy and simultaneousness in moving direction and phase of wave light.

Second phase is light amplification. When stimulating radiation in object’s substance which is used to make laser, atom or molecule of object’s substance is in being stimulating state. Light moving through will stimulate light regurgitation. Therefore, light intensity increases which is called photon. When photon moves through object’s substance, a number of photon will increase respectively. The increased photon which derives from stimulating radiation is required to have enough amounts. Thus, light amplification is needed by letting the light moves back and fourth through object laser’s substance several times. By using 2 pieces of mirror which placed horizontally at the end of the 2 mirrors to reflect the light back and fourth, the 2 horizontal mirrors is called optical cavity. It functions as a light amplification to increase light intensity to be high over gain and prevail loss of the system and the beam of laser will spew out on the mirror side where there are light reflection below 100%

The taken laser diode uses 625 nm wave lengths with 5 mW. It connects to 3 of 1.5 v. batteries and switch to help open and close.

In angle value displaying part, the structure is made from hair spray’s cover. The diameter is 7 centimeters and 4 centimeters thick. In order to make both angle of elevation and angle of depression’s scale, it can be done in Adobe Pagemaker 7.0 program. Both angle of elevation and angle of depression scale writing should be in the half length of circumference of hair spray’s cover, print in sticker paper, and attach to the rim of hair spray can, and then check the accuracy of angle value scale by comparing to the diameter.

In order to comprising the angle measurement part, the laser will be implanted with hair spray’s cover by fixing the laser in the line of diameter of hair spray's cover at 90 degree position of angle elevation. While the battery will stick to inner wall of the main structure and implant switch with hair spray's cover to make it easy to open and close the laser

4.1.3. Compute and display section; the distance between the observers to target object, up risen angle, bend angle will be taken to compute for the height and display the results, This section comprises of;

- Computing circuit and display circuit, the two circuits have been designed by Protel Programme as the details shown in Appendix A
- Microcontroller used in this experiment is ATMEGA8515L. The calculation programme of Microcontroler was design by CodeVisionAVR programme. The details shown in Appendix B then connect to 4x3 Matrix keypad, using 7 bit Microcontroller. The keypad has totally 12 keys as shown in figure 4-1

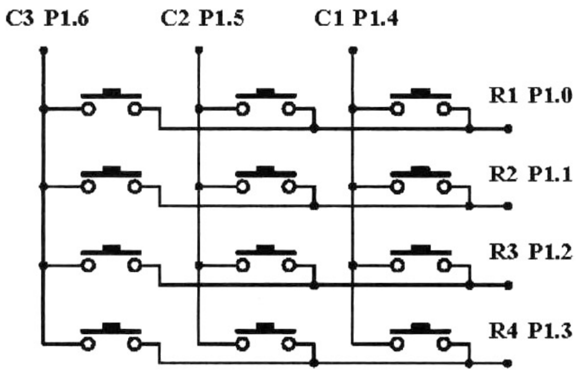


Figure 4-1 4x3 Metrix keypad

From the above figure, the password of each keypad had to be obtained for programme design and control of external equipments. The password of each keypad can be obtained as follows.

Table 4-1 The output of scan results for Column No.1

Numeric	Digital Data		Port
	Column	Row	
1	1110	1110	EEH
4	1110	1101	EDH
7	1110	1011	EBH
*	1110	0111	E7H

Table 4-2 The output of scan results for Column No.2

Numeric	Digital Data		Port
	Column	Row	
2	1101	1110	DEH
5	1101	1101	DDH
8	1101	1010	DBH
0	1101	0111	D7H

Table 4-3 The output of scan results for Column No.3

Numeric	Digital Data		Port
	Column	Row	
3	1011	1110	BEH
6	1011	1101	BDH
9	1011	1011	BBH
#	1011	0111	B7H

From the scan results of column 1-3, the password of each keypad can be obtained as shown below.

1	2	3
4	5	6

EE	DE	BE
ED	DD	BD

7	8	9
*	0	#

Numeric

EB	DB	BB
E7	D7	B7

Passwords of keypads

Figure 4-2 Passwords of keypads

The Equipment used to connect with Microcontroller is monitor. Liquid Crystal Display module or LCD module was used to display the number. The set of commands to control display module were design and applied. This module was connected to Data bus of LCD 8 pins (DO-D7) and R/W bus to choose commands or write data for LCD or connect with E bus and send the pulse signal to activate LCD to work.

The composition of LCD module comprises of 3 sections as follows.

1. Display section in LCD module; this section comprises of liquid crystal therefore display process have to be taken from outside by adjusting the view angle for the visibility of display module.

2. Controller section, this section will receive the data and compute to control LCD module. For example display font, move font, and clear the data.

3. Data section; receive the signal from Controller for LCD module to display the results

Table 4-4 LCD module bus, size 16 font, and single line

Bus	**Symbol**	**Description**
1	VSS	Ground (GND)
2	VCC	Electric (+ 5V)
3	VO	Adjust brightness (+ V)
4	RS	Register Select
5	R/W	Read and Write data
6	E	Enable
7-14	DB0-DB7	Data Bus

Details of LCD module bus, size 16 font, and single line are shown below.

- 1st bus (VSS) connect to ground

- 2^{nd} bus (Vcc) connect to electric line 5 voltage
- 3^{rd} bus (Vo), input bus to receive electromotive force to adjust the brightness of display section
- 4^{th} bus (Rs): input bus; if input bus logic is zero, the input data will be the command. If input bus logic is one, the input data will be results to display.
- 5^{th} bus (R/W): input bus, if input bus logic is zero, it is the writing data into LCD module. If input bus logic is one, it is the reading process from LCD module.
- 6^{th} bus(E): enable bus for the LCD module
- 7^{th} -14^{th} bus (Do-D7), the transmittal bus between LCD module and external equipments, size 8 bits.

The test of computing and display were conducted by input the distance between an observer to a target object, up risen angle and bend angle into Microcontroller through keypad to calculate the height and compare the reliability of the height obtaining from invented instrument with the height obtaining from manual calculator.

4.1.4 The main structures will comprise 3 sub-parts which are

- The main structure part is made of 2 plywoods 0.5 centimeters thick, 14.3 x 14.8 centimeters size (head /end side), and 0.5 centimeters 2 plywoods with 19.8 x 14.3 centimeters (side). 0.5 centimeters of 2 plywoods (top/low side) composed into square box which has wide x long x high equal 14.4 x 21 x 15.1 centimeter. The high top of the box will attached to hinge so that it can be opened and closed.

- Level measurement part will use mosquito larva to measure that the instrument is in the position that is parallel to ground because high measurement by using trigonometry principle is variable factor which is important for correct calculation of height. Therefore, the instrument should always be parallel to the ground in order to find angle value so that it can be used to calculate as much accurate as possible by sticking to the cover of the main structure.

While tripod for reduce an inaccuracy of height measurement needs to be motionless so that finding of angle value and distant is the most accurate to calculate height value. The tripod, brand Vertex, s211 model, was used in this experiment. It attaches to the below part of the main structure. When stretching out the tripod, it will be higher to the ground 1 meters.

How to use

1. Stretch out the tripod tool in the position where you can see a clear spot needed for tree measurement.
2. Adjust the level of the instrument in horizontal position to the ground with mosquito larva level measurement and when opening the instrument, it will ask for distant value.
3. Measure the distant between the observation point with measurement tape and input distant value in meters through keypad, press Enter (#), and then the instrument will ask for angle of elevation value.
4. Measure angle of elevation by turning angle measurement part and point the laser to the wanted level, read the result at the scale, input angle of elevation value through keypad and press Enter(#), then the instrument will ask for angle of depression value
5. Measure angle of depression by turning angle measurement part and to point the laser to the wanted level, read the result at the scale, input angle of depression through keypad and press Enter (#), then the instrument will display height value via LCD display.

4.2 Experimental results instrument of tree-height created

4.2.1 Experimental results of height with certain height value

Results from testing material at 2-20 meters high, the testing results are as follows: The minimum percentage of error is 0.010% at 15 meters high (average height is 15.001 meters), the maximum percentage of error is 4.857% at 2 meters high (average height is 2.097 meters) and average percentage of error is 1.698%.

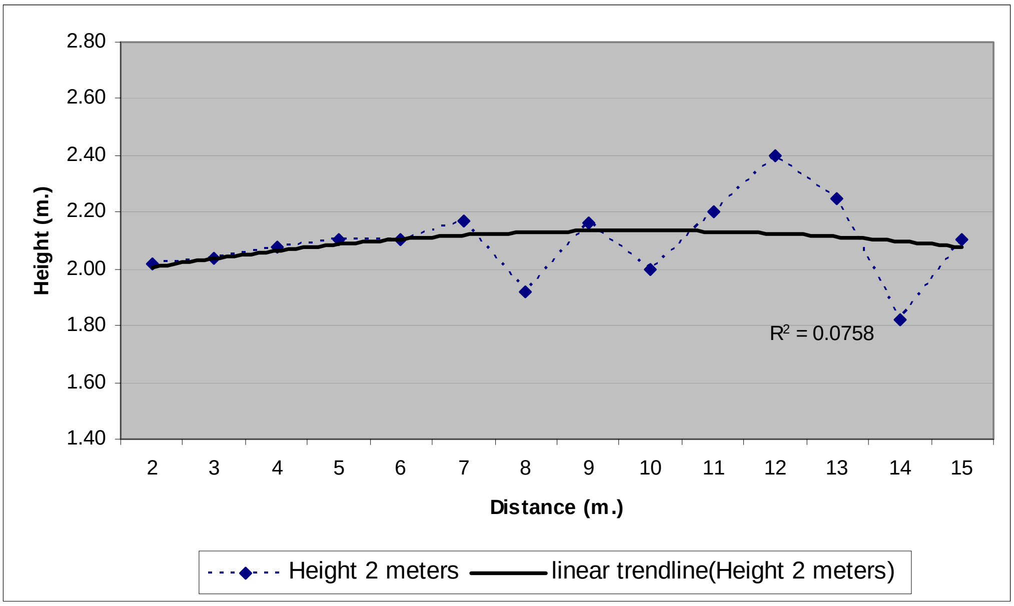
Table 4-5 Average height value from experimental at 2 – 20 meters height.

Distance (m.) / Height(m.)	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Average (m.)	Percentage Error(%)
2	2.02	2.04	2.08	2.10	2.10	2.17	1.92	2.16	2.00	2.20	2.40	2.25	1.82	2.10	2.097	4.857
3	2.96	2.97	2.97	3.10	3.15	3.22	3.04	3.06	3.10	2.97	3.24	3.12	2.80	3.60	3.093	3.095
4	4.16	4.04	4.06	4.05	4.06	4.06	4.00	4.14	4.20	4.18	4.08	4.03	3.78	4.65	4.106	2.661
5	5.06	5.07	5.12	5.20	5.10	5.07	5.04	4.98	5.00	5.06	5.04	4.94	4.90	5.25	5.059	1.186
6	5.90	6.15	6.03	5.85	6.03	6.02	6.16	6.03	6.30	6.04	6.00	6.04	6.02	6.05	6.044	0.738
7	7.10	7.11	7.07	7.05	7.15	7.28	7.04	7.06	7.20	7.04	6.96	7.02	7.14	7.05	7.091	1.296
8	7.92	8.10	8.08	8.10	8.08	7.98	8.00	7.96	8.20	7.92	8.04	8.10	7.84	8.10	8.030	0.375
9	8.98	8.97	9.15	9.35	8.95	8.94	8.96	9.00	9.30	9.08	9.24	9.36	9.10	9.00	9.098	1.093
10	10.36	10.17	10.08	10.10	10.08	9.87	10.11	9.90	10.00	10.23	9.84	10.01	9.80	9.75	10.021	0.212
11	12.30	11.34	11.25	10.95	11.10	11.34	10.96	11.15	11.00	11.15	11.16	10.66	11.34	11.25	11.211	1.916
12	12.75	12.99	12.18	11.90	12.06	12.18	12.05	12.33	12.10	12.10	12.00	12.09	12.04	12.15	12.209	1.740
13	13.80	14.15	13.66	12.60	13.20	13.09	13.28	13.23	12.90	13.23	13.11	13.00	13.02	12.90	13.226	1.740
14	14.50	15.00	14.58	14.40	14.19	14.14	14.16	14.15	13.70	14.19	13.88	14.25	13.86	13.95	14.211	1.505
15	15.18	15.06	15.04	14.40	14.60	15.33	15.04	15.32	14.70	15.07	15.38	15.21	14.84	14.85	15.001	0.010
16	17.85	15.18	16.66	16.89	15.60	16.66	15.96	16.10	15.18	16.17	16.44	16.08	15.96	15.90	16.188	1.174
17	17.85	17.85	17.89	17.60	16.20	16.66	16.22	17.25	17.00	17.38	17.64	16.87	17.08	17.10	17.185	1.088
18	19.98	19.98	18.72	18.80	19.20	18.70	18.72	17.82	18.30	18.23	17.96	17.89	18.20	18.30	18.629	3.492
19	19.95	21.00	19.92	19.92	19.70	19.87	18.72	18.60	18.90	19.46	18.96	19.23	19.60	18.30	19.438	2.305
20	21.00	22.29	20.50	20.70	20.30	20.16	20.56	19.35	19.80	20.13	20.40	20.34	19.60	19.88	20.358	1.789
														Average		1.698

4.2.2 The output of Polynomial trend lines and R-squared value at 2-20 meters

4.2.2.1 The output of Polynomial trend lines and R-squared value at 2 meter.

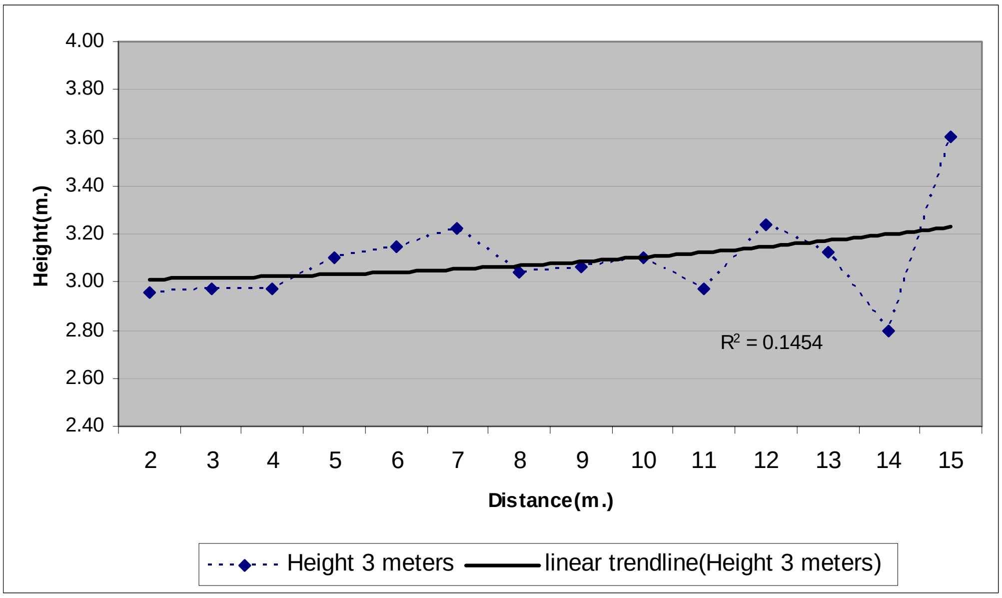
The results of measurement the height from the ground to the height at 2 meter of each distance at 2 -15 meter were used to plot the graph and find the Polynomial trendlines. The R-squared is 0.0758 and the appropriate distance between the observer to object is 2 meter.



Figures 4-3 Measuring results of material height at 2 meter.

4.2.2. The output of Polynomial trend lines and R-squared value at 3 meter.

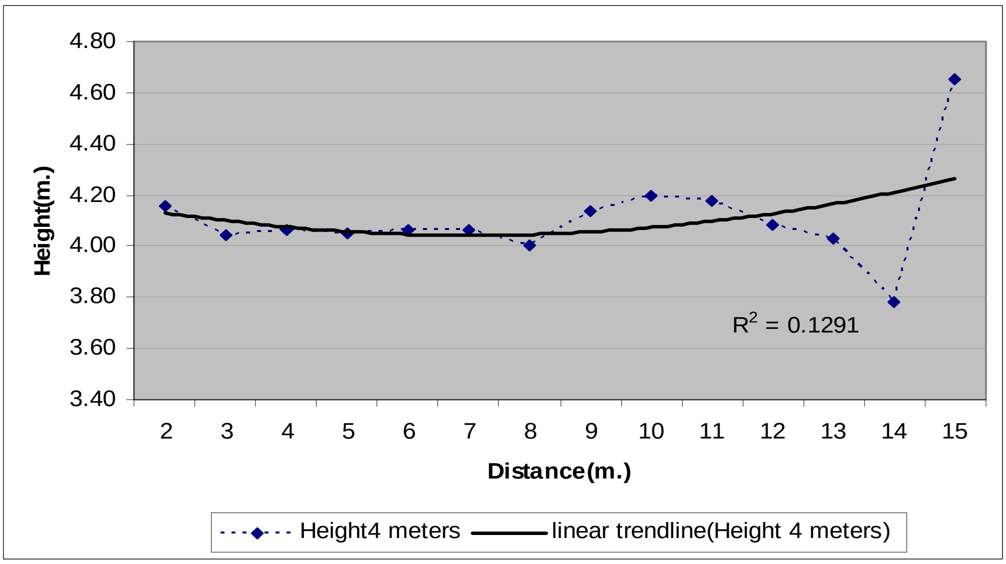
The results of measurement the height from the ground to the height at 3 meter of each distance at 2 -15 meter were used to plot the graph and find the Polynomial trendlines. The R-squared is 0.1454 and the appropriate distance between the observer to object is 2 meter.



Figures 4-4 Measuring results of material height at 3 meter.

4.2.2.3 The output of Polynomial trend lines and R-squared value at 4 meter.

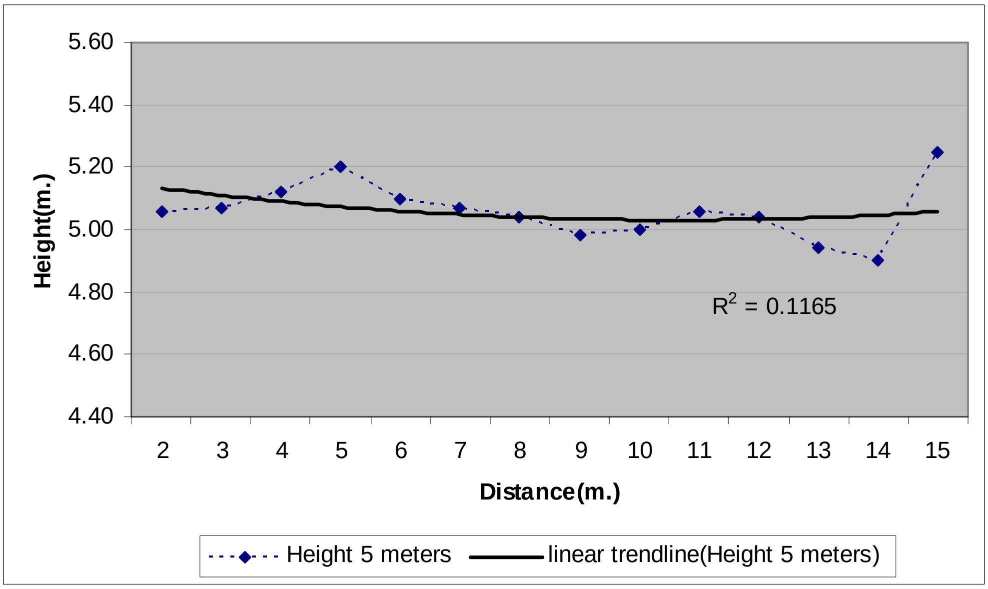
The results of measurement the height from the ground to the height at 4 meter of each distance at 2 -15 meter were used to plot the graph and find the Polynomial trendlines. The R-squared is 0.1291 and the appropriate distance between the observer to object is 7 meter.



Figures 4-5 Measuring results of material height at 4 meter.

4.2.2.4 The output of Polynomial trend lines and R-squared value at 5 meter.

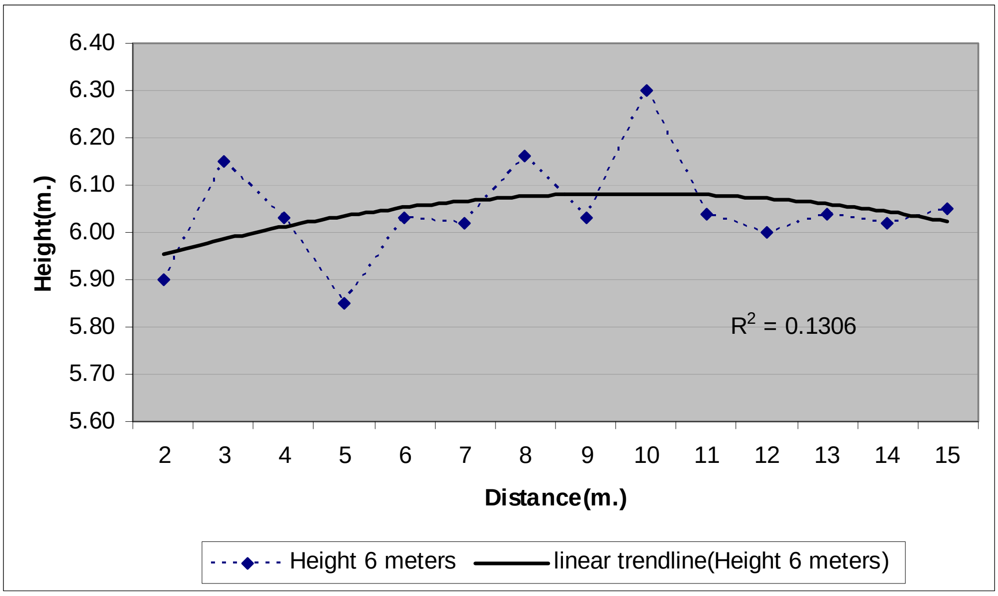
The results of measurement the height from the ground to the height at 5 meter of each distance at 2 -15 meter were used to plot the graph and find the Polynomial trendlines. The R-squared is 0.1165 and the appropriate distance between the observer to object is 10 meter.



Figures 4-6 Measuring results of material height at 5 meter.

4.2.2.5 The output of Polynomial trend lines and R-squared value at 6 meter.

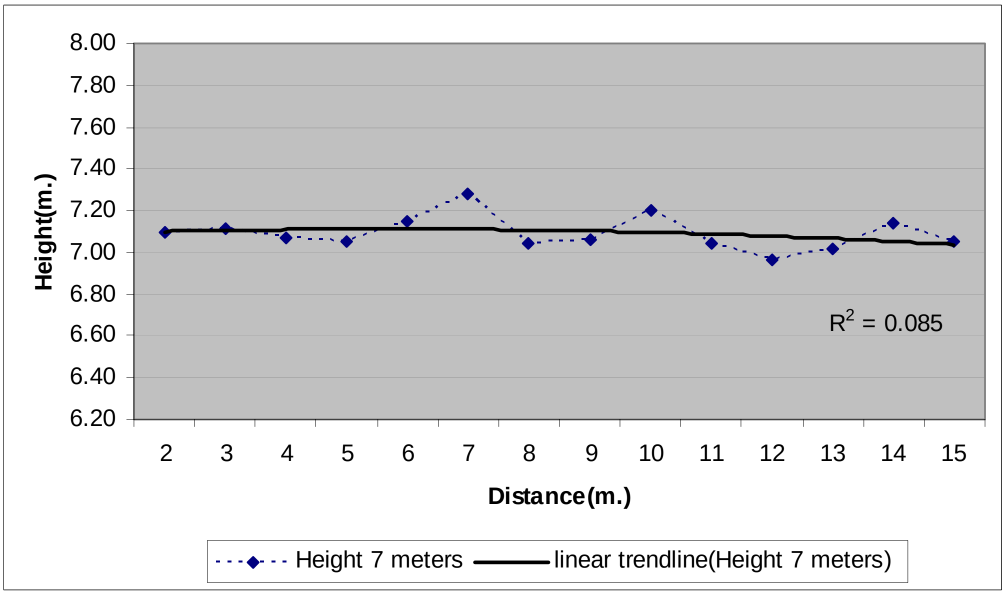
The results of measurement the height from the ground to the height at 6 meter of each distance at 2 -15 meter were used to plot the graph and find the Polynomial trendlines. The R-squared is 0.1306 and the appropriate distance between the observer to object is 3.5 meter.



Figures 4-7 Measuring results of material height at 6 meter.

4.2.2.6 The output of Polynomial trend lines and R-squared value at 7 meter.

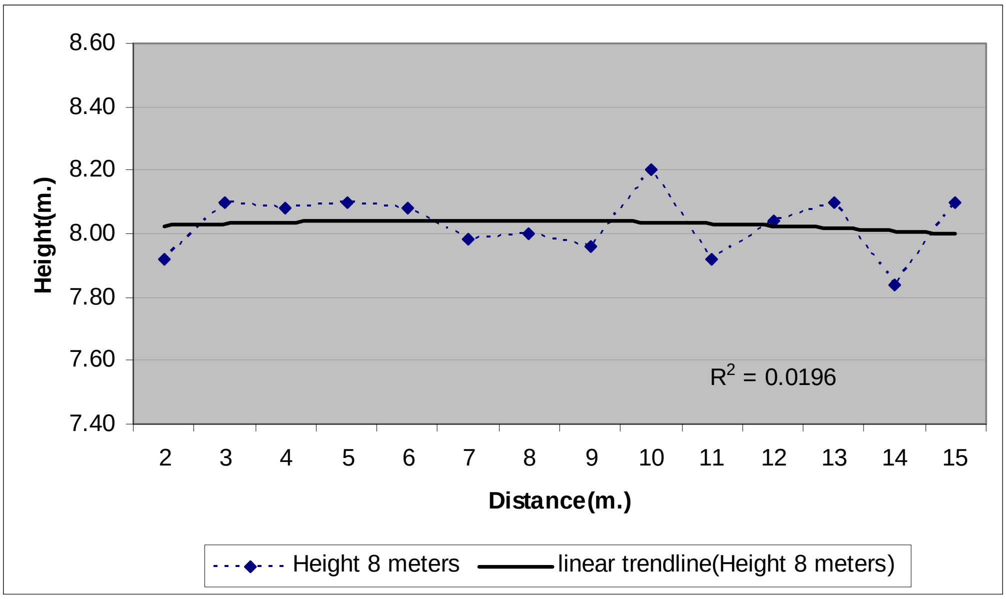
The results of measurement the height from the ground to the height at 7 meter of each distance at 2 -15 meter were used to plot the graph and find the Polynomial trendlines. The R-squared is 0.0085 and the appropriate distance between the observer to object is 15 meter.



Figures 4-8 Measuring results of material height at 7 meter.

4.2.2.7 The output of Polynomial trend lines and R-squared value at 8 meter.

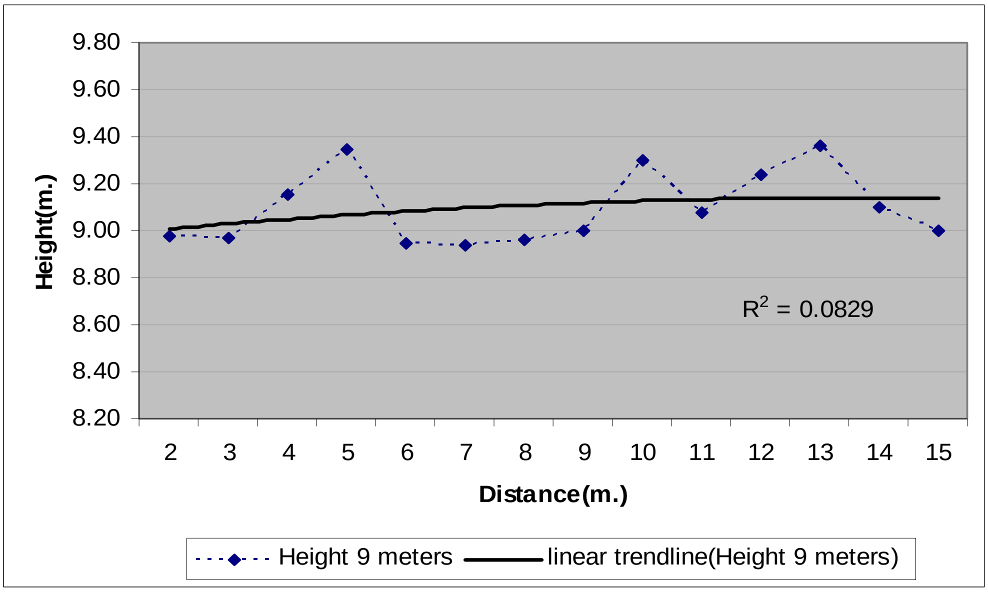
The results of measurement the height from the ground to the height at 8 meter of each distance at 2 -15 meter were used to plot the graph and find the Polynomial trendlines. The R-squared is 0.0196 and the appropriate distance between the observer to object is 15 meter.



Figures 4-9 Measuring results of material height at 8 meter.

4.2.2.8 The output of Polynomial trend lines and R-squared value at 9 meter.

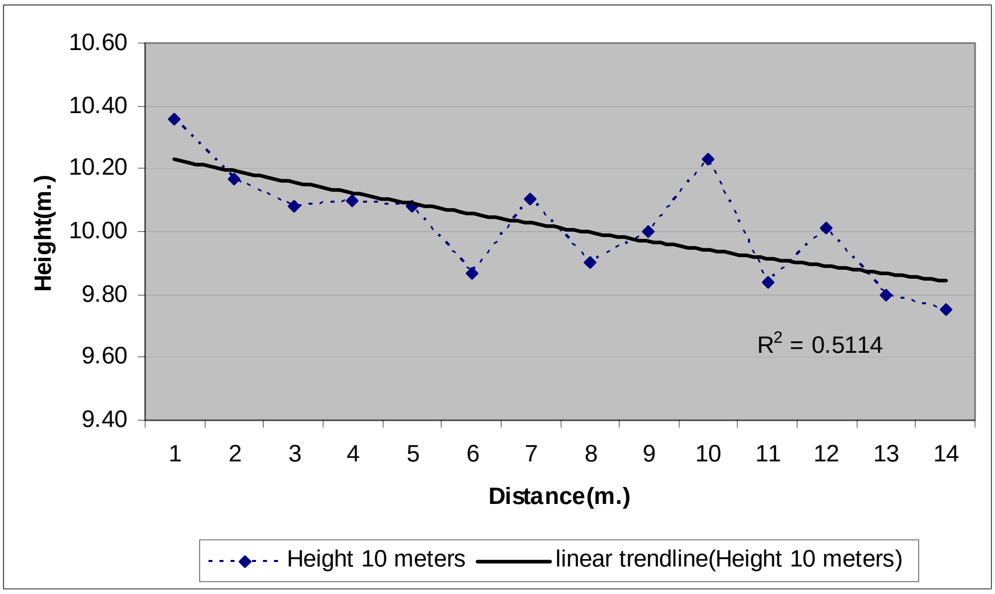
The results of measurement the height from the ground to the height at 9 meter of each distance at 2 -15 meter were used to plot the graph and find the Polynomial trendlines. The R-squared is 0.0829 and the appropriate distance between the observer to object is 2 meter.



Figures 4-10 Measuring results of material height at 9 meter.

4.2.2.9 The output of Polynomial trend lines and R-squared value at 10 meter.

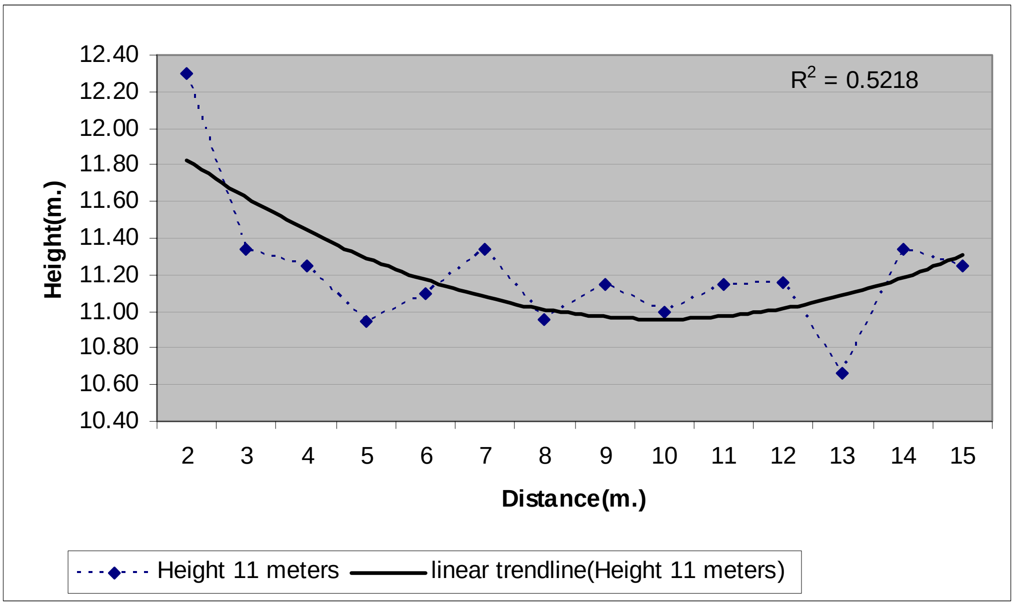
The results of measurement the height from the ground to the height at 10 meter of each distance at 2 -15 meter were used to plot the graph and find the Polynomial trendlines. The R-squared is 0.5114 and the appropriate distance between the observer to object is 8 meter.



Figures 4-11 Measuring results of material height at 10 meter.

4.2.2.10 The output of Polynomial trend lines and R-squared value at 11 meter.

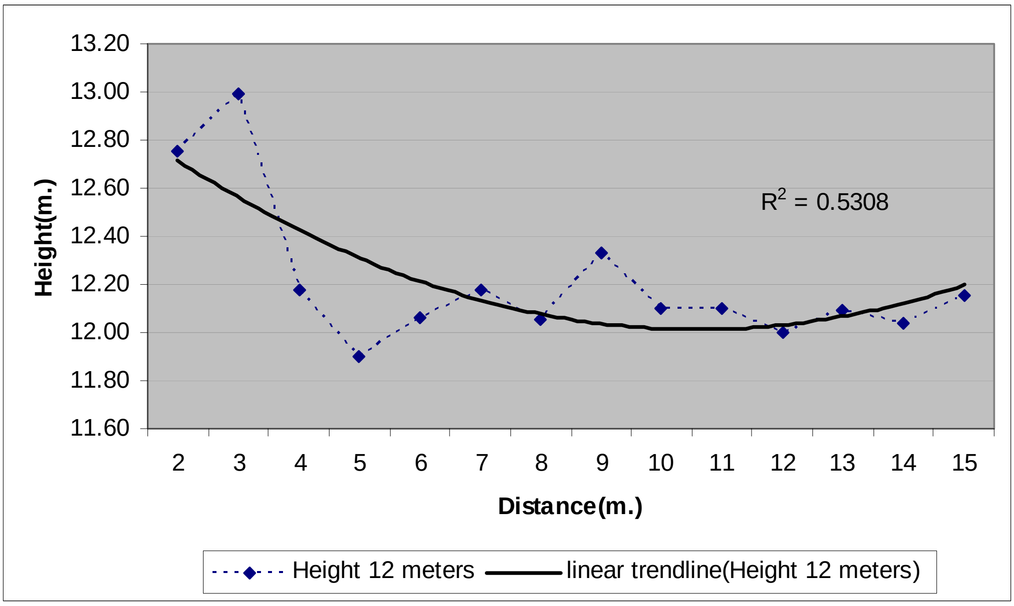
The results of measurement the height from the ground to the height at 11 meter of each distance at 2 -15 meter were used to plot the graph and find the Polynomial trendlines. The R-squared is 0.5218 and the appropriate distance between the observer to object is 8 meter and 11.5 meter.



Figures 4-12 Measuring results of material height at 11 meter.

4.2.2.11 The output of Polynomial trend lines and R-squared value at 12 meter.

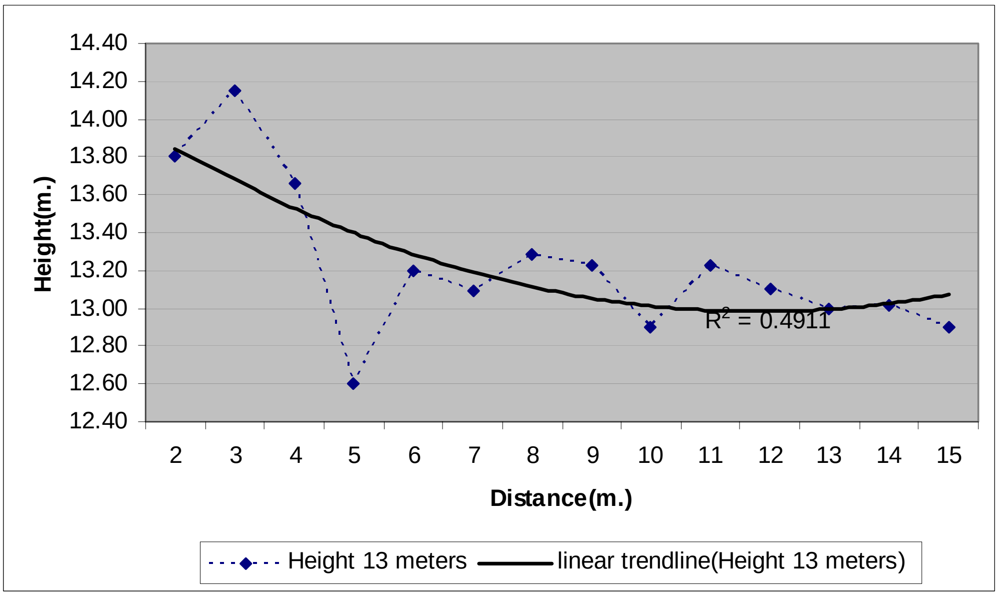
The results of measurement the height from the ground to the height at 12 meter of each distance at 2 -15 meter were used to plot the graph and find the Polynomial trendlines. The R-squared is 0.5308 and the appropriate distance between the observer to object is 10 meter and 11 meter.



Figures 4-13 Measuring results of material height at 12 meter.

4.2.2.12 The output of Polynomial trend lines and R-squared value at 13 meter.

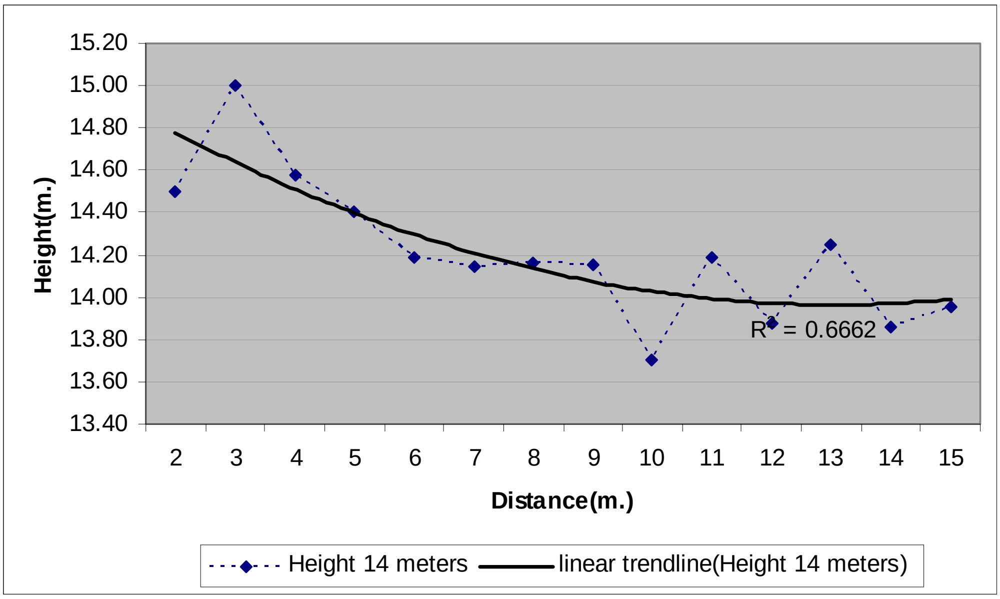
The results of measurement the height from the ground to the height at 13 meter of each distance at 2 -15 meter were used to plot the graph and find the Polynomial trendlines. The R-squared is 0.4911 and the appropriate distance between the observer to object is 11 meter and 13 meter.



Figures 4-14 Measuring results of material height at 13 meter.

4.2.2.13 The output of Polynomial trend lines and R-squared value at 14 meter.

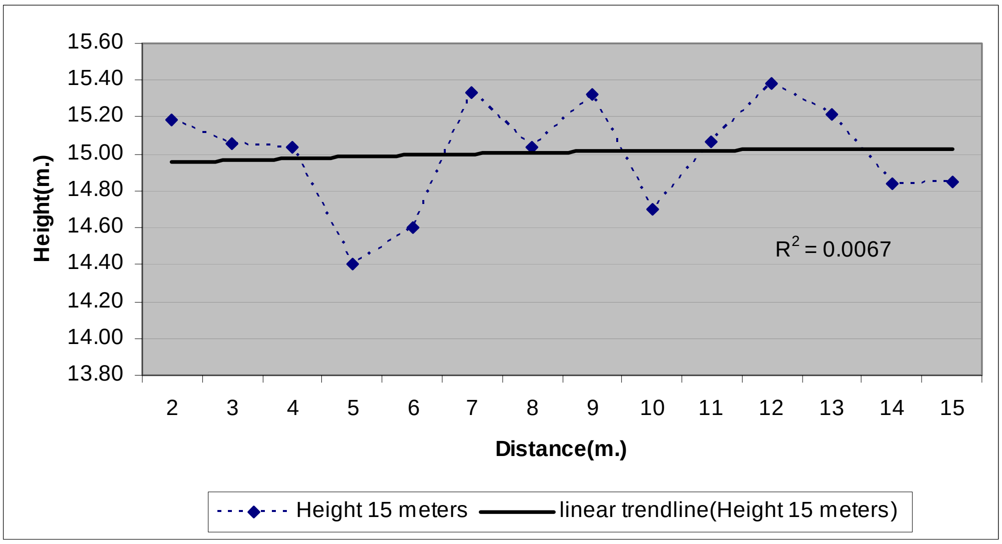
The results of measurement the height from the ground to the height at 14 meter of each distance at 2 -15 meter were used to plot the graph and find the Polynomial trendlines. The R-squared is 0.6662 and the appropriate distance between the observer to object is 11 meter.



Figures 4-15 Measuring results of material height at 14 meter.

4.2.2.14 The output of Polynomial trend lines and R-squared value at 15 meter.

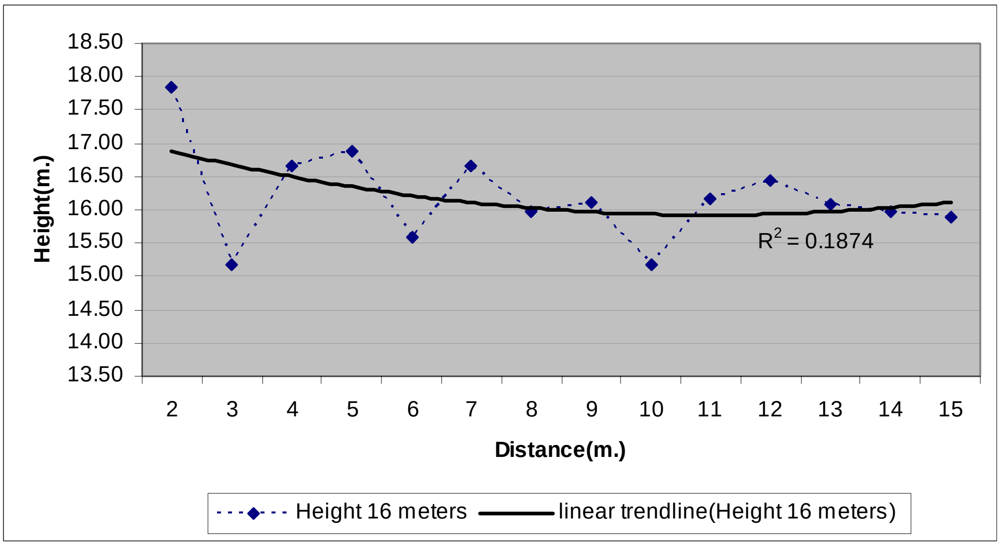
The results of measurement the height from the ground to the height at 15 meter of each distance at 2 -15 meter were used to plot the graph and find the Polynomial trendlines. The R-squared is 0.0067 and the appropriate distance between the observer to object is 8 meter.



Figures 4-16 Measuring results of material height at 15 meter.

4.2.2.15 The output of Polynomial trend lines and R-squared value at 16 meter.

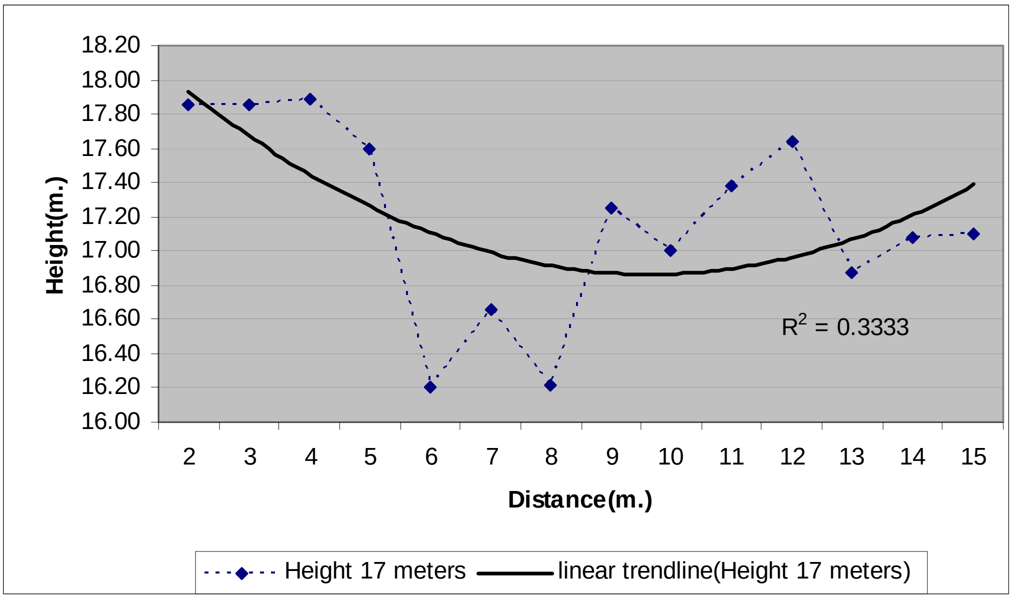
The results of measurement the height from the ground to the height at 16 meter of each distance at 2 -15 meter were used to plot the graph and find the Polynomial trendlines. The R-squared is 0.1874 and the appropriate distance between the observer to object is 8 meter and 13 meter.



Figures 4-17 Measuring results of material height at 16 meter.

4.2.2.16 The output of Polynomial trend lines and R-squared value at 17 meter.

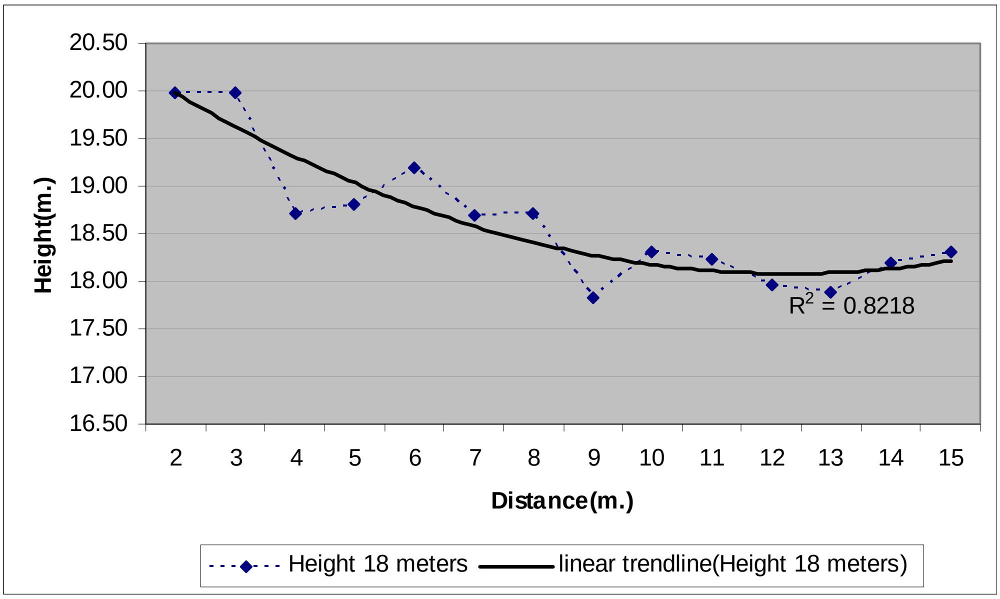
The results of measurement the height from the ground to the height at 17 meter of each distance at 2 -15 meter were used to plot the graph and find the Polynomial trendlines. The R-squared is 0.3333 and the appropriate distance between the observer to object is 7 meter and 12.5 meter.



Figures 4-18 Measuring results of material height at 17 meter.

4.2.2.17 The output of Polynomial trend lines and R-squared value at 18 meter.

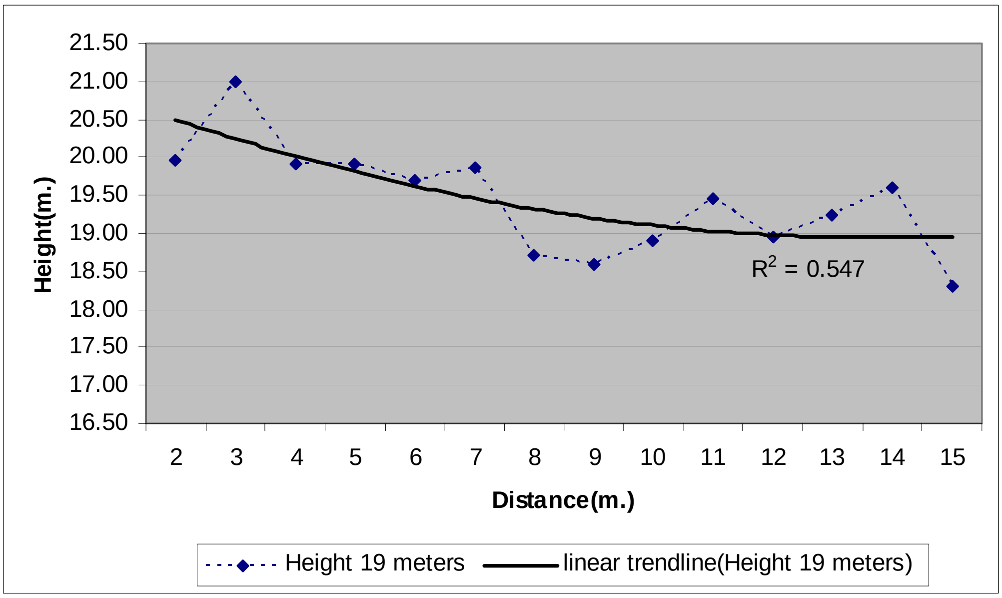
The results of measurement the height from the ground to the height at 18 meter of each distance at 2 -15 meter were used to plot the graph and find the Polynomial trendlines. The R-squared is 0.8212 and the appropriate distance between the observer to object is 12 meter.



Figures 4-19 Measuring results of material height at 18 meter.

4.2.2.18 The output of Polynomial trend lines and R-squared value at 19 meter.

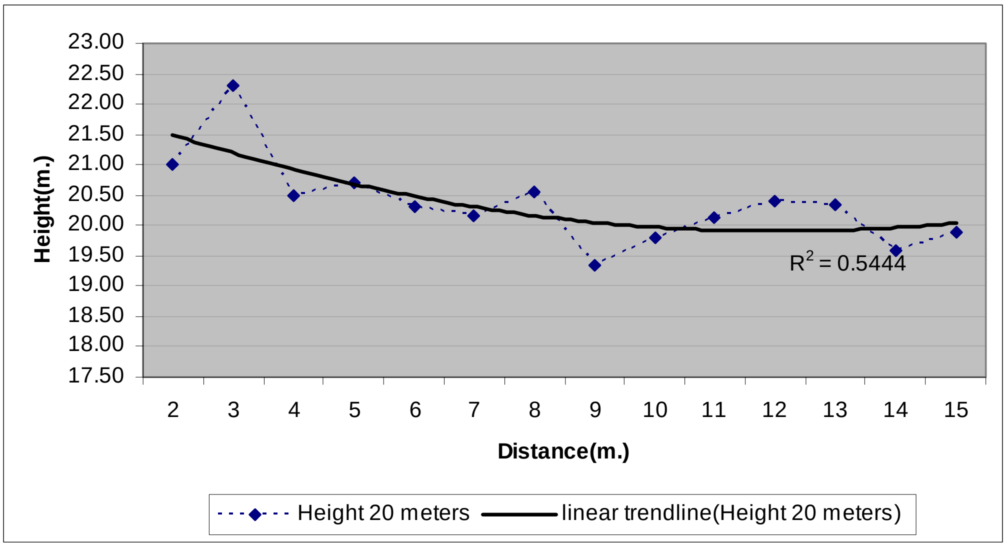
The results of measurement the height from the ground to the height at 19 meter of each distance at 2 -15 meter were used to plot the graph and find the Polynomial trendlines. The R-squared is 0.547 and the appropriate distance between the observer to object is 12 meter.



Figures 4-20 Measuring results of material height at 19 meter.

4.2.2.19 The output of Polynomial trend lines and R-squared value at 20 meter.

The results of measurement the height from the ground to the height at 20 meter of each distance at 2 -15 meter were used to plot the graph and find the Polynomial trendlines. The R-squared is 0.5444 and the appropriate distance between the observer to object is 10 meter and 15 meter.



Figures 4-21 Measuring results of material height at 20 meter.

The analysis of polynomial trend lines to obtain the distance between observer to appropriate object for height measurement at 2-20 meters are shown in the following table.

Table 4-6 The distance between the observer to an appropriate object for height measurement at 2-20 meters

At the height (meter)	Average Height (m.)	Percentage error (%)	R-Squared (R^2)	Best distance (m.)
2	2.097	4.857	0.076	2
3	3.093	3.095	0.145	2
4	4.106	2.661	0.129	7
5	5.059	1.186	0.117	10
6	6.044	0.738	0.131	3.5
7	7.091	1.296	0.085	15
8	8.030	0.375	0.020	15
9	9.098	1.093	0.083	2
10	10.021	0.212	0.511	8
11	11.211	1.916	0.522	8,11.5
12	12.209	1.740	0.531	10,11
13	13.226	1.740	0.491	11,13
14	14.211	1.505	0.666	11
15	15.001	0.010	0.007	8
16	16.188	1.174	0.187	8,13
17	17.185	1.088	0.333	7,12.5
18	18.629	3.492	0.822	12
19	19.438	2.305	0.547	12
20	20.358	1.789	0.544	10,15
Average		**1.698**		

From the table, at 15 meter, the height obtained from the instrument has the least percentage error equal 0.01% and at the 2 meter, the height obtained has the highest percentage error equal 4.857%. The average percentage error equal 1.698.

The reliable distance to measure the height at each level were used to plot the graph to obtain the polynomial trend line as shown below.

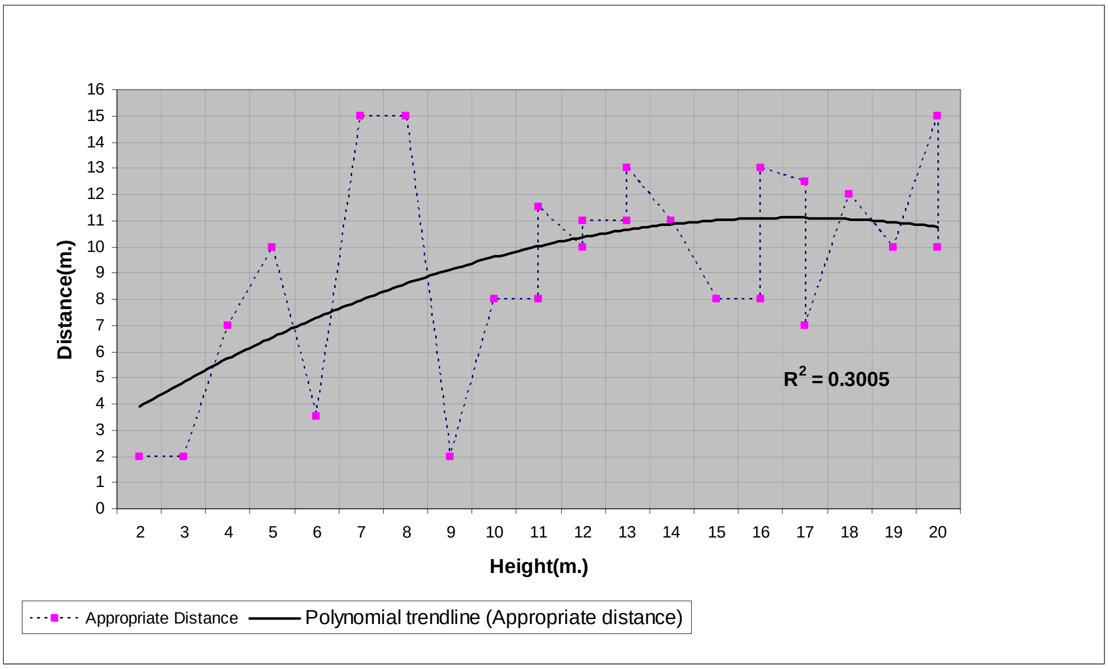


Figure 4-22 The Polynomial trend line of invented instrument

The test result of invented instrument, the analysis of the polynomial trend line and R-squared value (0.3005) shown that appropriate distance from the object to observer for height measurement is 11-11.5 meter. The reliable height obtained range from 13.75 to 20 meter.

4.2.2 Testing result of real tree height measuring

From measuring 28 real trees, the testing results are as follows:

Table 4-7 Testing results from real tree-height measuring

Tree no.	Tree-height value obtained from Pole (m)	Tree-height value obtained from standard instrument (m)	% of error from standard instrument (%)	Tree-height value obtained from instrument invented (m)	% of error from instrument invented (%)
1	3.300	3.403	3.135	3.400	3.030
2	3.350	3.380	0.884	3.470	3.582
3	3.180	3.203	0.713	3.220	1.258
4	3.050	3.112	2.030	2.890	-5.246
5	3.150	3.280	4.115	2.950	-6.349
6	3.750	3.602	-3.956	3.650	-2.667
7	3.600	3.574	-0.709	3.470	-3.611
8	4.200	4.199	-0.029	4.350	3.571
9	4.100	4.338	5.795	4.310	5.122
10	3.460	3.421	-1.116	3.500	1.156
11	4.450	4.540	2.018	4.540	2.022
12	5.550	5.702	2.734	5.720	3.063
13	7.130	7.318	2.633	7.010	-1.683
14	4.650	4.735	1.828	4.450	-4.301
15	4.650	4.662	0.262	4.575	-1.613
16	6.330	6.464	2.118	6.280	-0.790
17	5.620	5.593	-0.480	5.560	-1.068
18	8.125	7.902	-2.748	8.240	1.415
19	6.690	6.649	-0.620	6.700	0.149
20	6.780	6.666	-1.683	6.880	1.475
21	6.760	6.791	0.464	6.670	-1.331
22	3.080	2.994	-2.800	3.120	1.299
23	4.520	4.476	-0.969	4.670	3.319
24	4.660	4.468	-4.113	4.780	2.575
25	5.160	5.085	-1.449	5.320	3.101
26	5.190	5.145	-0.872	5.320	2.505
27	5.760	5.752	-0.137	5.870	1.910
28	4.770	4.760	-0.218	4.560	-4.403

In the step of analysis to search differentiated value between efficiency (% error percentage) obtained from standard instrument with instrument invested by measuring the tree-height for 28 trees found that tree-height value obtained from standard instrument has minimum error of -0.029 % (real tree-height value obtained from measuring pole; that is 4.2 meters, tree-height value measured from standard instrument is 4.199 meters). And tree-height value obtained from with maximum error of 5.795% (real tree-height value obtained from measuring pole is 4.100 meters; tree-height value measured from standard instrument is 4.338 meters)

Tree-height value obtained from instrument invented has minimum error of 0.149 % (real (real tree-height value measured from measuring pole; that is 6.690 meters, tree-height value measured from standard instrument is 6.700 meters). And tree-height value obtained from standard instrument with maximum error of -6.349 % (real tree-height value obtained from measuring pole is 3.150 meters; tree-height value measured from standard instrument is 2.950 meters)

From the analtsis of correlation coefficient between real heights with height value which is measured at 2 to 15 meters by using Pearson correlation coefficient for culculation, it was found that.

In the step of analysis for differentiated value between the efficiency (% error) obtained from standard instrument invented using Independent-samples T-test found that:

Table 4-8 Calculation T-test from error percentage.

Instrument	**N**	**$\overline{X}$**	**SD**	**t**	**Sig.**
Standard instrument	28	0.146	2.339	0.032	0.974
Invented instrument	28	0.341	3.023		

It can be construed that the standard instrument has its error percentage averagely at 0.146, standard deviation is at 2.339 while the invented instrument has its error percentage averagely at 0.341, and standard deviation is at 3.023, when testing efficiency difference (percentage of error) of standard and invented instruments, there are no difference at the level of confidence at 0.05.

CHAPTER V
CONCLUSION AND RECOMMENDATION

From the study in chapter 4, we can discuss the result of making result, instrument testing, as well as difference of the of tree-height measurement efficiency with standard instruments as follows.

5.1 Making and testing of the instrument

5.1.1 Making the instrument step

Due to most of tree height measurements in Thailand, like Haga causes inaccurate result. While the accurate height measurement tool by using laser principle is very expensive. Therefore tree high measurement development in this study, the height measurement which applies both principles with the same measurement efficiency as measurement instrument from aboard, but use equipment that is available in Thailand, cheap and easy to repair and maintain.

The built tree height instrument is developed on height instrument basis which uses trigonometry principle. This kind of tree height measurement requires distant value between the observer to tree and angle value. In order to find height value, it needs to fix the exact spot of tree foot and tree top, but instrument using at present needs aiming with the eyes which triggers lots of errors. Thus, the experimenter uses laser principle, which is the distinctive light origin, it other word, it is the wave orderly light with certain direction (beam) has high-intense and precise wave length, to point reference angle value in order to find tree height value. The experimenter also uses program to calculate tree height value by inputting angle of elevation value, angle of depression and distant through keypad, as a result finding the distant between the observer and the tree is not need to precisely determine.

5.1.2 Built instrument testing step

From the test results of the invented instrument and the analysis of the polynomial trend line and R-squared value equal 0.3005, the polynomial trend lines show that the distance from the observer to appropriate object for height measurement at difference distances because at those distances, the observer can see the clear reference location of up risen angle and bend angle.

5.2 Testing of the efficiency difference of standard tree height measurement and build tree height measurement instrument

The standard instrument is not the tree height measurement instrument, but it is distant measurement instrument which used non-function laser principle to calculate height. However, distant value from the instrument is highly accurate. (Distant measurement between 0.2-100 meter has accurate value at +/3 millimeters. So the experimenter used it as a standard instrument in this study by using distant value from standard value to calculate height value. Due to distant value from standard instrument gives highly correct result, obtained tree height value has less mistake percentage.

According to statistical test, in the comparison of efficiency difference in tree height value of standard instrument with the built instrument, it founds that the 2 types of instrument have no difference because the using of built tree height measurement instrument relies on experiment result in testing step. Built instrument becomes a part of decision making in choosing the distant from observation point to tree, that in tree measurement is needed to see the position of tree top and tree foot clearly. Therefore, tree height value has less inaccurate percentage.

5.3 Instrument limit and suggestion

5.3.1 Scale used in angle measurement is small and difficult to read. Also it contains only integral number, causing the calculated height value is incorrect.

5.3.2 Laser pointing reference position in finding angle has weak power. Thus, it is hard to see height measurement in highly sunny time.

5.3.3 Material used for making measurement tape in this study is heavy steel, causing an error in distant measurement. Thus, this is the reason that obtained height value is incorrect.

5.3.4 In order to write the height-value calculating program for Microcontroller, the experimenter has inputted angle value, specific information for integral number, causing height value calculation which is not integral number is inaccurate.

5.4 Suggestions in the next researcher

5.4.1 Creating scale with more details to one-place decimal level and easy to read is advised. Because the right height measurement needing observation angle a lot (80 degrees) triggers mistake easily and requires high definition.

5.4.2 Laser used for reference position in finding angle has weak power and it is hard to see when it is too sunny. It had better find laser with much more power (more than 5mW) and it is easy to spot.

5.4.3 In order to write calculating program for Microcontroller, it is necessary to determine detailed angle value to one-place decimal.

5.4.4 It should design the instrument to be able to measure the tree that is higher; it is lower than the observation point.

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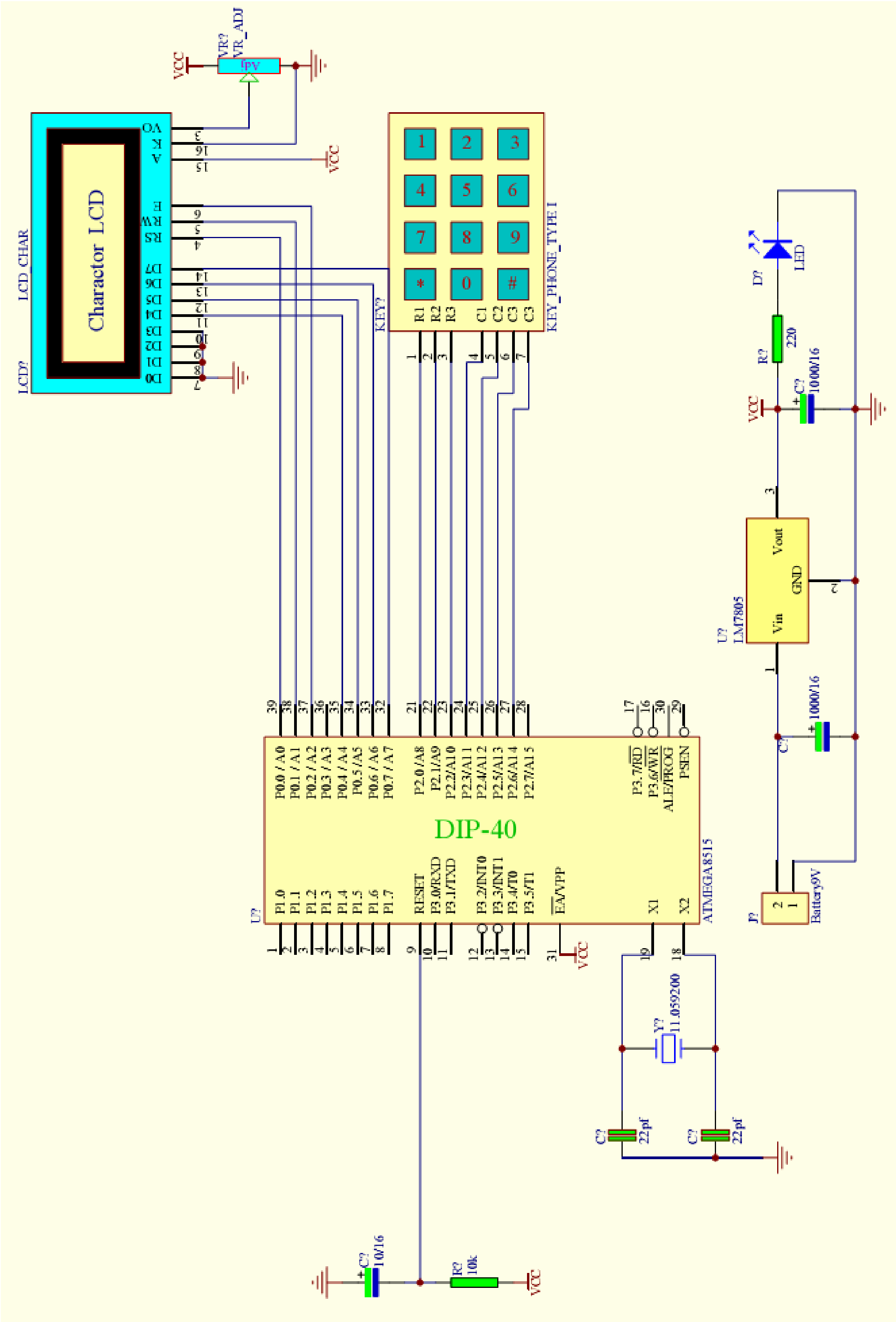
APPENDIX

APPENDIX A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LCD CHAR
Charactor LCD
VR?
VR_ADJ
VCC
KEY?
KEY_PHONE_TYPE I
DIP-40
ATMEGA8515
U?
LM7805
Vin
GND
Vout
LED
D?
R?
220
1000/16
Battery9V
Y?
11.059200
22pf
10k
10/16
RESET
P3.0/RXD
P3.1/TXD
EA/VPP
PSEN
ALE/PROG
X1
X2

APPENDIX B

This program was produced by the CodeWizardAVR V1.24.8b Professional Automatic Program Generator ค Copyright 1998-2006 Pavel Haiduc, HP InfoTech s.r.l. http://www.hpinfotech.com

```
Chip type          : ATmega8515
Program type       : Application
Clock frequency    : 11.059200 MHz
Memory model       : Small
External SRAM size : 0
Data Stack size    : 128
***************************************************/
#include <mega8515.h>
#include <delay.h>
#include <stdlib.h>
#include <delay.h>
#include <ctype.h>
#include <stdarg.h>
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <math.h>
//#include <stat.h>

#define  Col1 PORTC.6
#define  Col2 PORTC.5
#define  Col3 PORTC.4
#define  Row1  PINC.3
#define  Row2  PINC.2
#define  Row3  PINC.1
#define  Row4  PINC.0
#define time_kb 800

char   lcdbuf[8]={0};
char   DataBuf[8]={0};
char  index=0;
char   keybuffer=0;
float  KEYB=0,Q1=0,Q2=0,SUM=0,H1=0,H2=0;
float  Compare1=0,Compare2=0;
// Alphanumeric LCD Module functions
```

```
#asm
   .equ __lcd_port=0x1B ;PORTA
#endasm
#include <lcd.h>

#define RXB8 1
#define TXB8 0
#define UPE 2
#define OVR 3
#define FE 4
#define UDRE 5
#define RXC 7

#define FRAMING_ERROR (1<<FE)
#define PARITY_ERROR (1<<UPE)
#define DATA_OVERRUN (1<<OVR)
#define DATA_REGISTER_EMPTY (1<<UDRE)
#define RX_COMPLETE (1<<RXC)

// USART Transmitter buffer
#define TX_BUFFER_SIZE 8
char tx_buffer[TX_BUFFER_SIZE];

#if TX_BUFFER_SIZE<256
unsigned char tx_rd_index,tx_counter;
#else
unsigned int tx_wr_index,tx_rd_index,tx_counter;
#endif

// USART Transmitter interrupt service routine
interrupt [USART_TXC] void usart_tx_isr(void)
{if (tx_counter)
   {--tx_counter;
   UDR=tx_buffer[tx_rd_index];
   if (++tx_rd_index == TX_BUFFER_SIZE) tx_rd_index=0;};}

#ifndef _DEBUG_TERMINAL_IO_
// Write a character to the USART Transmitter buffer
#define _ALTERNATE_PUTCHAR_
#pragma used+
void putchar(char c)
{lcd_putchar(c);/*
while (tx_counter == TX_BUFFER_SIZE);
```

```
#asm("cli")
if (tx_counter || ((UCSRA & DATA_REGISTER_EMPTY)==0))
   {tx_buffer[tx_wr_index]=c;
   if (++tx_wr_index == TX_BUFFER_SIZE) tx_wr_index=0;
   ++tx_counter,}
else
   UDR=c;*/
#asm("sei")}
#pragma used-
#endif

// Standard Input/Output functions
#include <stdio.h>

// Declare your global variables here
void delay_kb (unsigned int count)  //11.0592MHz
              { // mSec Delay
    unsigned int ii;
    while (count)
                        {ii = 50;
                        while (ii>0) ii--;
                        count--;}
}

float check_val(int Val)
 {
      switch  (Val)
       {
            case 0 : return(0); break;
            case 1 : return(0.017); break;
            case 2 : return(0.03); break;
            case 3 : return(0.052); break;
            case 4 : return(0.069); break;
            case 5 : return(0.087); break;
            case 6 : return(0.10); break;
            case 7 : return(0.123); break;
            case 8 : return(0.14); break;
            case 9 : return(0.158); break;
            case 10 : return(0.17); break;
            case 11 : return(0.19); break;
            case 12 : return(0.21); break;
            case 13 : return(0.23); break;
            case 14 : return(0.24); break;
```

```
case 15 : return(0.26); break;
case 16 : return(0.28); break;
case 17 : return(0.30); break;
case 18 : return(0.32); break;
case 19 : return(0.34); break;
case 20 : return(0.36); break;
case 21 : return(0.38); break;
case 22 : return(0.4); break;
case 23 : return(0.42); break;
case 24 : return(0.44); break;
case 25 : return(0.46); break;
case 26 : return(0.48); break;
case 27 : return(0.50); break;
case 28 : return(0.53); break;
case 29 : return(0.55); break;
case 30 : return(0.57); break;
case 31 : return(0.60); break;
case 32 : return(0.62); break;
case 33 : return(0.65); break;
case 34 : return(0.67); break;
case 35: return(0.70); break;
case 36 : return(0.72); break;
case 37 : return(0.75); break;
case 38 : return(0.78); break;
case 39 : return(0.81); break;
case 40 : return(0.83); break;
case 41 : return(0.87); break;
case 42 : return(0.9); break;
case 43 : return(0.93); break;
case 44 : return(0.96); break;
case 45 : return(1); break;
case 46 : return(1.03); break;
case 47 : return(1.07); break;
case 48 : return(1.11); break;
case 49 : return(1.15); break;
case 50 : return(1.19); break;
case 51 : return(1.23); break;
case 52 : return(1.27); break;
case 53 : return(1.33); break;
case 54 : return(1.37); break;
case 55 : return(1.43); break;
case 56 : return(1.48); break;
case 57 : return(1.54); break;
case 58 : return(1.6); break;
case 59 : return(1.66); break;
case 60 : return(1.73); break;
```

```
        case 61 : return(1.80); break;
        case 62 : return(1.88); break;
        case 63 : return(1.96); break;
        case 64 : return(2.05); break;
        case 65 : return(2.14); break;
        case 66 : return(2.24); break;
        case 67 : return(2.36); break;
        case 68 : return(2.47); break;
        case 69 : return(2.61); break;
        case 70 : return(2.74); break;
        case 71 : return(2.90); break;
        case 72 : return(3.07); break;
        case 73 : return(3.27); break;
        case 74 : return(3.48); break;
        case 75 : return(3.73); break;
        case 76 : return(4.01); break;
        case 77 : return(4.33); break;
        case 78 : return(4.7); break;
        case 79 : return(5.14); break;
        case 80 : return(5.67); break;
        case 81 : return(6.31); break;
        case 82 : return(7.11); break;
        case 83 : return(8.14); break;
        case 84 : return(9.51); break;
        case 85 : return(11.43); break;
        case 86 : return(14.3); break;
        case 87 : return(19.08); break;
        case 88 : return(28.6); break;
        case 89 : return(57.29); break;
        case 90 : return(0); break;
         default : return(9);
    }
}
unsigned char scankey(void)
{
        char KEY=255;
        PORTC=0xff;
        KEY=255;
        PORTC.6=0;
        delay_kb(50);
        if (PINC.3==0)  {KEY='1';delay_kb(time_kb);}
        else if (PINC.2==0)  {KEY='4';delay_kb(time_kb);}
        else if (PINC.1==0)  {KEY='7';delay_kb(time_kb);}
```

```
        else if (PINC.0==0)  {KEY='#';delay_kb(time_kb);}
        PORTC.6=1;
    PORTC.5=0;
        delay_kb(50);
        if (PINC.3==0)  {KEY='2';delay_kb(time_kb);}
        else if (PINC.2==0)  {KEY='5';delay_kb(time_kb);}
        else if (PINC.1==0)  {KEY='8';delay_kb(time_kb);}
        else if (PINC.0==0)  {KEY='0';delay_kb(time_kb);}
        PORTC.5=1;
        PORTC.4=0;
        delay_kb(50);
        if (PINC.3==0)  {KEY='3';delay_kb(time_kb);}
        else if (PINC.2==0)  {KEY='6';delay_kb(time_kb);}
        else if (PINC.1==0)  {KEY='9';delay_kb(time_kb);}
        else if (PINC.0==0)  {KEY='.';delay_kb(time_kb);}
        return(KEY);
}
void clear(void)
{
    lcdbuf[0]=0;
    lcdbuf[1]=0;
    lcdbuf[2]=0;
    lcdbuf[3]=0;
    lcdbuf[4]=0;
    lcdbuf[5]=0;
    lcdbuf[6]=0;
    lcdbuf[7]=0;
}
void main(void)
{
// Declare your local variables here
// Input/Output Ports initialization
// Port A initialization
// Func7=In Func6=In Func5=In Func4=In Func3=In Func2=In Func1=In Func0=In
// State7=T State6=T State5=T State4=T State3=T State2=T State1=T State0=T
PORTA=0x00;
```

```
DDRA=0x00;
// Port B initialization
// Func7=In Func6=In Func5=In Func4=In Func3=In Func2=In Func1=In Func0=In
// State7=T State6=T State5=T State4=T State3=T State2=T State1=T State0=T
PORTB=0x00;
DDRB=0x00;
// Port C initialization
// Func7=In Func6=In Func5=In Func4=In Func3=In Func2=In Func1=In Func0=In
// State7=T State6=T State5=T State4=T State3=T State2=T State1=T State0=T
PORTC=0xff;
DDRC=0x00;
DDRC.6=1;
DDRC.5=1;
DDRC.4=1;
DDRC.3=0;
DDRC.2=0;
DDRC.1=0;
DDRC.0=0;
// Port D initialization
// Func7=In Func6=In Func5=In Func4=In Func3=In Func2=In Func1=In Func0=In
// State7=T State6=T State5=T State4=T State3=T State2=T State1=T State0=T
PORTD=0x00;
// Port E initialization
// Func2=In Func1=In Func0=In
// State2=T State1=T State0=T
PORTE=0x00;
DDRE=0x00;
// Timer/Counter 0 initialization
// Clock source: System Clock
// Clock value: Timer 0 Stopped
// Mode: Normal top=FFh
// OC0 output: Disconnected
TCCR0=0x00;
TCNT0=0x00;
OCR0=0x00;

// Timer/Counter 1 initialization
```

```
// Clock source: System Clock
// Clock value: Timer 1 Stopped
// Mode: Normal top=FFFFh
// OC1A output: Discon.
// OC1B output: Discon.
// Noise Canceler: Off
// Input Capture on Falling Edge
// Timer 1 Overflow Interrupt: Off
// Input Capture Interrupt: Off
// Compare A Match Interrupt: Off
// Compare B Match Interrupt: Off
TCCR1A=0x00;
TCCR1B=0x00;
TCNT1H=0x00;
TCNT1L=0x00;
ICR1H=0x00;
ICR1L=0x00;
OCR1AH=0x00;
OCR1AL=0x00;
OCR1BH=0x00;
OCR1BL=0x00;

// External Interrupt(s) initialization
// INT0: Off
// INT1: Off
// INT2: Off
MCUCR=0x00;
EMCUCR=0x00;

// Timer(s)/Counter(s) Interrupt(s) initialization
TIMSK=0x00;

// USART initialization
// Communication Parameters: 8 Data, 1 Stop, No Parity
// USART Receiver: Off
// USART Transmitter: On
// USART Mode: Asynchronous
// USART Baud rate: 9600
UCSRA=0x00;
UCSRB=0x48;
```

```
UCSRC=0x86;
UBRRH=0x00;
UBRRL=0x47;

// Analog Comparator initialization
// Analog Comparator: Off
// Analog Comparator Input Capture by Timer/Counter 1: Off
ACSR=0x80;

// LCD module initialization
lcd_init(16);

// Global enable interrupts
#asm("sei")
lcd_gotoxy(0,0);
KEYB=11.05;
ftoa(KEYB,2,DataBuf);
printf("%s",DataBuf);
delay_ms(500);
while (1)
    {
     index=0;
     KEYB=0.00;
     clear();
     lcd_gotoxy(0,0);printf("        ");
     lcd_gotoxy(0,1);printf("        ");

     lcd_gotoxy(0,0);
     printf("Distance");
     lcd_gotoxy(0,1);
     printf(" = ");
     keybuffer=255;
     while(keybuffer!='#')
      {
          keybuffer = scankey();
          if ((keybuffer != 255) && (keybuffer!='#'))
          {
               lcdbuf[index] =  keybuffer;
               KEYB = atof(lcdbuf);
               lcd_putchar(lcdbuf[index]);
               delay_ms(200);
```

```
                index++;
                //lcdbuf[index]=0;
            }
        }
        lcd_gotoxy(0,0);printf("        ");
        lcd_gotoxy(0,1);printf("        ");
        lcd_gotoxy(0,0);
        ftoa(KEYB,2,DataBuf);
        printf("Distance");
        lcd_gotoxy(0,1);
        printf("=%s",DataBuf);
        delay_ms(3000);
       //*****************  Q1 **********************
       clear();
       Q1=0.00;
       lcd_gotoxy(0,0);printf("        ");
       lcd_gotoxy(0,1);printf("        ");
       lcd_gotoxy(0,0);
       printf("Angle1");
       lcd_gotoxy(0,1);
       printf(" = ");
       index=0;
       keybuffer=255;
       while(keybuffer!='#')
        {
            keybuffer = scankey();
            if ((keybuffer != 255) && (keybuffer!='#'))
            {
                lcdbuf[index] =  keybuffer;
                Q1 = atof(lcdbuf);
                lcd_putchar(lcdbuf[index]);
                delay_ms(200);
                index++;
                //lcdbuf[index]=0;

            }

        }
```

```
lcd_gotoxy(0,0);printf("        ");
lcd_gotoxy(0,1);printf("        ");
lcd_gotoxy(0,0);

ftoa(Q1,2,DataBuf);
printf("Angle1 "); lcd_gotoxy(0,1);
printf(" =%s",DataBuf);
delay_ms(3000);

if (check_val(Q1)==9)
{
     Compare1 = check_val(Q1+1);
}
else   Compare1 = check_val(Q1);

clear();

(float)H1 = (float)Compare1 * KEYB;

lcd_gotoxy(0,0);printf("        ");
lcd_gotoxy(0,1);printf("        ");
lcd_gotoxy(0,0);

ftoa(H1,2,DataBuf);
printf("Height1=");
lcd_gotoxy(0,1);
printf("%s",DataBuf);
delay_ms(3000);
Q2=0.00;
lcd_gotoxy(0,0);printf("        ");
lcd_gotoxy(0,1);printf("        ");
lcd_gotoxy(0,0);
printf("Angle2");
lcd_gotoxy(0,1);
printf(" = ");

index=0;
keybuffer=255;
while(keybuffer!='#')
{
      keybuffer = scankey();
      if ((keybuffer != 255) && (keybuffer!='#'))
      {
```

```
            lcdbuf[index] =  keybuffer;
            Q2 = atof(lcdbuf);
            lcd_putchar(lcdbuf[index]);
            delay_ms(200);
            index++;

        }

    }
    lcd_gotoxy(0,0);printf("        ");
    lcd_gotoxy(0,1);printf("        ");
    lcd_gotoxy(0,0);

    ftoa(Q2,2,DataBuf);
    printf("Angle2 ");
    lcd_gotoxy(0,1);
    printf("=%s",DataBuf);
    delay_ms(3000);
    clear();

     if (check_val(Q2)==9)
    {
         Compare2 = check_val(Q2+1);
    }
    else   Compare2 = check_val(Q2);

    (float)H2 = (float)Compare2 * KEYB ;
    lcd_gotoxy(0,0);printf("        ");
    lcd_gotoxy(0,1);printf("        ");
    lcd_gotoxy(0,0);
    //H1 = 25.2*4;
    ftoa(H2,2,DataBuf);
    printf("Height2=");
    lcd_gotoxy(0,1);
    printf("=%s",DataBuf);
    delay_ms(3000);

    (float)SUM = (float)H1+(float)H2;
    lcd_gotoxy(0,0);printf("        ");
    lcd_gotoxy(0,1);printf("        ");
    lcd_gotoxy(0,0);
    printf("Total H ",DataBuf);
```

```
        lcd_gotoxy(0,1);
        ftoa(SUM,2,DataBuf);
        printf("= %s",DataBuf);
        keybuffer=255;
        while(keybuffer!='#')
        {
                keybuffer = scankey();

        }
        keybuffer=255;
        delay_ms(1000);
      };
}
```

APPENDIX C

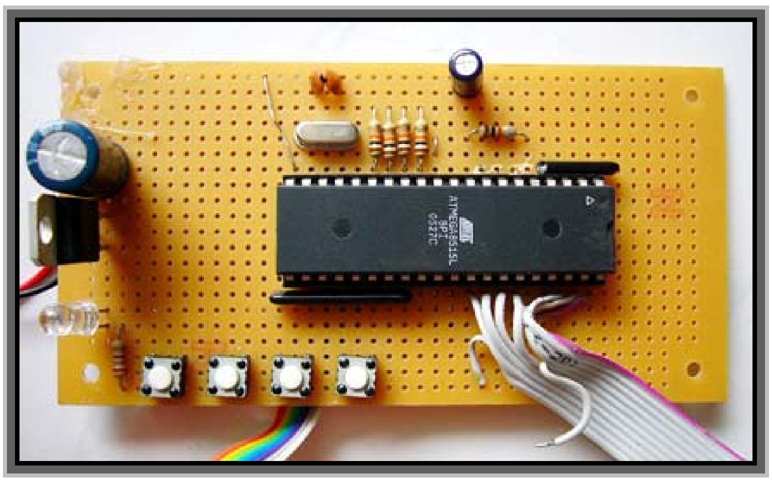
Angle measurment part

Level measurement part

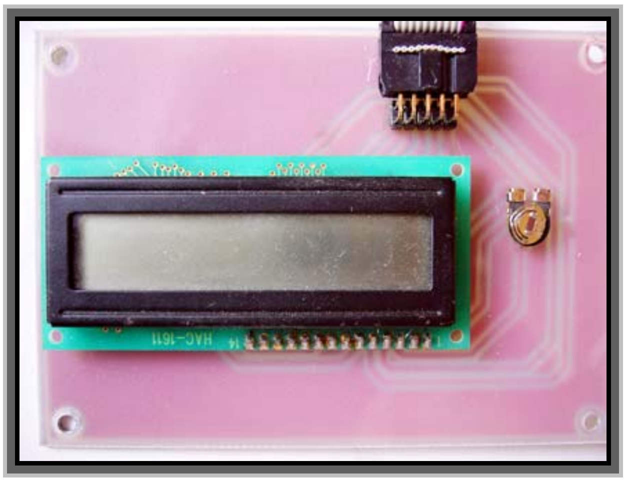
Distance measurement

Tripod

Keypad



Codifying part



Displaying part

Invented instrument

BIOGRAPHY

NAME	Mr. Prawit Raya
DATE OF BIRTH	September 4, 1980
PLACE OF BIRTH	Chanthaburi, Thailand
INSTITUTIONS ATTENDED	King Mongkut's Institute of Tecnology North Bangkok,1999-2003: Bachelor of Science (Agro-Industrial)
	Mahidol University, 2005-2008: Master of Science (Appropriate Technology For Resources and Environmental Development)