Optimization of Sensor Location in Data Center

by

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Dissertation submitted in partial fulfillment of

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

Information Communication and Technology Programme

Universiti Teknologi PETRONAS

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Approved by,

____

(Dr. Low Tan Jung)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

September 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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(Pramita Winata, ID: 13498)

ABSTRACT

The increase demand of data center has been increase significantly due to the rapid growth ICT technology. As a result this brings along the “green” issues in data center such as energy consumption, heat generation and cooling requirements. These issues can be addressed by “Green of/by IT” in the context of operating costs as well as the environmental impacts. To accommodate temperature monitoring system in every corner of data center is cost inefficient. Optimized location for sensor placement is needed to be determined, to reduce the monitoring cost. It needs to be decided which locations to observe in order to most effective results, at minimum cost. Furthermore, it is argued that in depth knowledge of the historical data of the data center’s highly dynamic operating condition will lead to a better management of data center resources. Thus, this project aims to create a wireless temperature monitoring system with location optimization algorithm to optimize temperature sensors deployment/locations. Furthermore, real-time temperature data collection and monitoring can be used to predict the next state of the temperature to detect potential anomaly in heat generation in the data center. Thus quick response for cooling can be invoked – Green by IT.

ACKNOWLEDGEMENT

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I would also like to acknowledge with much appreciation the crucial role of Jun Okitsu, the Hitachi Researcher and also Dr. Nordin Zakaria , as my co-supervisor and Head of High Performance Center (HPC - UTP) for giving me such a great assistance with regards to this project.

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Last but not the least, I wish to express my love and gratitude to my beloved families; for their understanding & support, throughout the duration of my studies.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

LIST OF ABBREVIATIONS

CRAC	: Computer Room Air Conditioning
BTU	: British Thermal Units
EER	: Energy Efficient Ratio
ICT	: Information and Communication Technology

Chapter 1

INTRODUCTION

1.1 Background

Data center is one of the crucial components of society's information technology (IT) infrastructure. It is not an overstatement that in most of the cities, our life relies on the functioning and availability of one or multiple data centers. Most of the things in every segment of human activity such as energy, lighting, telecommunications, internet, transport, urban traffic, banks, security systems, public health, entertainment and even our physical integrity are somehow linked to data centers.

The rapid growth of ICT technology causes an increasing demand of facilities for information processing and data storing. Consequently, this brings along the "green" issues in data center such as energy consumption, heat generation and cooling requirements. These issues can be addressed by "Green of/by IT" in the context of operating costs as well as the environmental impacts. It is argued that in depth knowledge of data centre's highly dynamic operating conditions will lead to a better management of data center resources.

This paper will focus on the usage of wireless sensor network to collect real-time monitoring data of generated heat in a computer lab. Furthermore, analysis on the data gathered to determine the optimize sensor location will be produced.

1.2 Problem Statement

1.2.1 High energy consumption and operating cost of cooling the computers and data storage facilities

The energy consumption in a data center is directly reflected in its electricity costs. For example, a single high performance 200-Watt server; operating 24 hours for a year will consume (24 x 365 x 200 = 1752k) 1725kWh of energy. A cooling unit with a common Energy Efficiency Rating (EER) of 12000 British Thermal Units (BTU) for 1 KWh (1 KWh = 3414 BTU) will consume (3414 x 1752k / 12k ≈ 498) 498 KWh in cooling this server for a year. Assuming electricity costs of 0.45 RM/KWh, the total energy cost to cool this single server would be 224.10 RM/year (this cost does not account for the energy consumed by air circulation and power delivery subsystems). Even though, server does not operate at its maximum power all the time, the cost of electricity for cooling purpose is still concerning for a single server. For a typical data-center rack, this cooling cost has been estimated at U$ 72000 over 10 years [2].

Furthermore, [3] found that in a 30,000 ft2 data center with 1000 standard computing racks, each consuming 10 kW, the initial cost of purchasing and installing the CRAC units is $2-$5 million. With an average electricity cost of $100/MWh, the annual costs for cooling alone are $4-$8 million.

In addition, it is predicted that data center energy consumption in the United States will reach 100 billion kWh/year by the end of 2011 with a corresponding energy bill of approximately US$7.4 billion [4]. As [1] reported IT equipment consumes about 30% of the total power consumption, cooling facilities consume about 45%, and other equipment consumes about 25%. As a result, the cooling facilities in data center will consume 45 billion kWh/year by the end of 2011 with a corresponding energy bill of approximately US$3.33 billion.

From the findings above, it is obvious that an efficient cooling management is an important for a cost efficient data center.

1.2.2 Long response times to transients and emergencies in data centers and computing rooms

Besides a concerning high cooling cost, heat generated in data center can affect the system reliability and availability. Condition in data center is constantly changing Momentary down conditions, which caused by either utilization spike or cooling failure, can result in server downtimes due to slow responses time for fixing the situation [8].

1.2.3 Environmental effect – Green by IT is not fully exploited yet.

One important impact of Computer Room Air Conditioning (CRAC) that should be highly considered is the societal and environmental effect. The following are three significant effects that arise because of CRAC:

1.2.3.1 Increase in CO_2 emissions

The concentration of CO2 in the atmosphere is increasing at an accelerating rate from decade to decade. As a McKinsey study pointed it out, the carbon emissions from data centers will quadruple by 2020 [6].

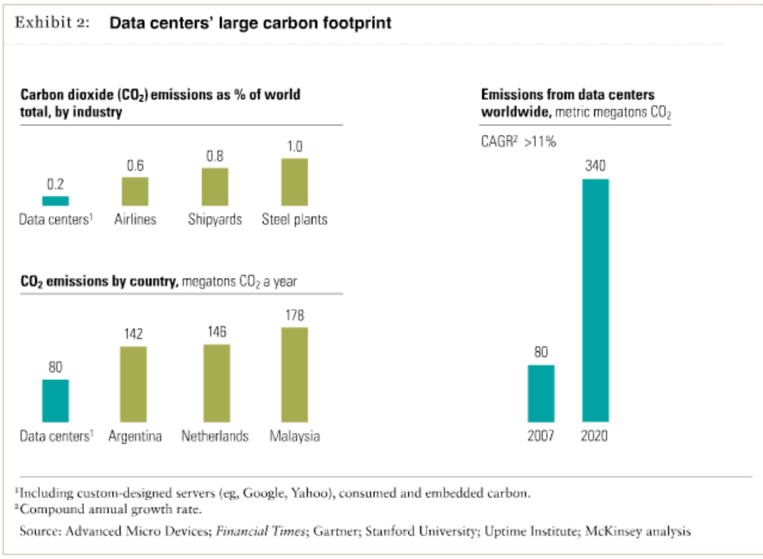


Figure 1 Data centers' large carbon footprint

Data center carbon emissions are a growing global concern. Figure 1 shows the carbon footprint generated by data centers' worldwide.

1.2.3.2 Overload of the electricity supply grid

Air conditioner is one of the most common high power use device. High usage of air conditioners, as it happens in data center for cooling facilities, will result in high usage of energy accordingly. This situation can lead to the overload of the electricity supply grid [8].

1.2.3.3 Rising water usage for cooling leading to water scarcity

In order to cool data centers, a massive amount of water is needed. As [7] pointed out, a 1MW data center operating with water-cooled chillers and cooling towers can consume 18,000 gallons per day to dissipate heat generated by IT equipment. It's worsen as the data center is growing in a rapid manner which can cause water supplies being seriously threatened.

1.3 Objectives and Scope of Study

1.3.1 Objectives

The main objective of this project is to determine the optimized sensor location in data center to sense the heat and humidity for cooling data center efficiently.

Sensor will be deployed to monitor real-time heat and humidity of the data center. In order to make data monitoring efficient wireless sensor network for transmitting data will be used.

In order to find out the optimize location to place the sensor, the raw data gathered will be monitored and analyzed. Sensitivity level of the sensors with each PC will be analyzed based on the data gathered. Further optimization will be reached, by determining a minimum set of sensor needed. An algorithm to do this will be developed.

Thus, in conclusion the objectives of this project are:

- To create a Wireless Temperature Monitoring System (WTMS) with location optimization algorithm to optimize temperature sensors deployment/locations.
- To create an algorithm that can predict the states of temperature
- To integrate WTMS with the existing WSN infrastructure for real-time temperature data collection and monitoring in data center to address the issues of heat generation and cooling requirements.

1.3.2 Scope of Project

The scope of the project will cover:

- implementation of wireless sensor network in data center
- simulation model of data center in a computer laboratory
- Green technology in data center

Geographically, the test bed that will be used for this project will be limited in Data Communication Laboratory at Universiti Teknologi PETRONAS.

Chapter 2

LITERATURE REVIEW

2.1 Data Center Sensing Method

2.1.1 Wired Technology

2.1.1.1 Thermal Images

Thermal imaging, also known as thermography or thermal video, is a way to observe the infrared portion of the color spectrum [13]. Thermal imaging has been used widely in many aspects, such as security, military, navigation, surveillance, industry, science, technology, and medicine. Thermal images, the outcome of thermal imaging, will visualize temperature variation over the camera's view frame.

Relating of data centers, thermal imaging also one of the method for performing data center inspection [12]. Thermal imaging will give real-time and accurate details of heating and cooling patterns. This pattern is an important information to make certain decisions, such as cooling adjustment, infrastructure modification, or layout designs [14].

The main advantage of using thermal imaging in sensing temperature in data center is the detection of thermal anomalies will be easier and faster. Typically, a single thermal image has over 75,000 thousand temperature points [15]. Furthermore, it will help in detecting the actual surface temperature which is useful to spot overheating and fixing it before failure [12]

Even though it will make the job to detect thermal anomaly easier, to practically capturing images throughout data center continuously is very expensive and time consuming.

2.1.1.2 Onboard Sensor

The usage of onboard sensor is to detect the thermal condition of the nearby key server components, such as CPUs, disks, or I/O controllers [16]. However the onboard sensor doesn’t sense the data center’s thermal environment. Even though recent servers have additional sensors to monitor data center’s air intake, this will be a problem for those who do not have [16].

Important element for onboard sensor for data center’s sensing is the communication mechanism. There are two ways of data collection for onboard sensor; in-band data collection and out-of-band data collection. The difference between out-of-band data collection and in-band data collection lies in the location of devices and network. In-band data collection collect the data through the server’s operating system (OS) to the data center wiredly IP network. On the other hand, out-of-band data collection uses a separate devices and separate network to collect the data [16].

2.1.1.2.1 In-band data collection

The advantages of in-band data collection lies in the infrastructure and the deployment cost. The network infrastructure is easier to deploy the network of the server as the data center is directly connected. Moreover, the cost is relatively cheap as it only needs USB-based sensor for additional hardware. Nevertheless, in-band data collection requires the host operating system to be online the time for monitoring the sensor continuously and the joint network might interfere with the data center operations.

2.1.1.2.2 Out-of-band data collection

Out-of-band collection will give more flexibility in placing the sensor as it uses separate devices and interruption in data center operation can be avoided as it uses separate network.

However, the problem will occur in the practical realization.

Deploying a wired network connecting each sensing point will create a chaos in an already cramped data center.

2.1.2 Wireless Technology

There are several radio frequency (RF) transmission protocols being considered. This section will discuss some protocols that are considered to be implemented in data center sensing. .

2.1.2.1 ZigBee

Another wireless technology considered to be implemented in sensing thermal condition in data center is ZigBee technology. ZigBee technology is initiated by the ZigBee Alliance and later joining forces with IEEE 802.15.4. It is a wireless networking protocol targeted towards automation remote control application and sensor networks [20]. The technology is designed to provide low cost and low power connectivity for devices that need long battery life but o not need high data transfer rate. In other words, ZigBee technology aims to target the market of devices that do not need high data transfer rate as in Bluetooth.

The transmission range in ZigBee technology is up to 10 to 75 meters. It is operating in the three unlicensed band worldwide with different data rates: [20]

- 2.4 GHz for global with maximum data rate of 250 kbps
- 915 MHz for Americas with maximum data rate of 40 kbps
- 868 MHz for Europe with maximum data rate of 20 kbps

ZigBee system consists of several components in which the most basic is a device. This device can be either full-function device (FFD) or reduced-function device (RFD). ZigBee system must at least include one FFD as the personal are networl (PAN) coordinator.

Network topologies that are supported by ZigBee include:

- Star topology
- Peer-to-peer topology
- Cluster Tree topology

2.1.2.2 Wi-Fi

The Wi-Fi Technology, a very common protocol nowadays, it continues to be the pre-eminent technology for building general-purpose wireless networks.

Wi-Fi technology transmits at frequencies of 2.4 GHz or 5 GHz. This frequency is considerably higher than the frequencies used for cell phones, walkie-talkies and televisions. The higher frequency allows the signal to carry more data. [21]

The benefits using Wi-Fi is as Wi-Fi has become widely adopted in so many public places that you can expect to find a hotspot almost anywhere you need to get online. However, the short-range of Wi-Fi is the main drawback. Wi-Fi Internet access is available only within a short range of the access point – typically 150 to 300 feet.[22]

2.1.2.3 Wavenis

Another wireless technology being considered used is wavenis. Wavenis, created in 2000 by Coronis Systems, is a two-way wireless connectivity platform. The technology is designed for use by application that needs in long-range transmission to manage small amounts of data with low radio traffic and ultra-low-power management. It is currently used literally by millions devices around in the world, in diverse markets where communication ability and device autonomy present conflicting requirements. These markets include telemetry, industrial automation, remote utility meter monitoring, and etc. [23]

As mentioned in [24], some advantages provided by Wavenis are:

- Long battery life (up to 15 years on primary battery)
- Long range (200m indoor – 1km LOS)

- Smart links (2-way communications)
- Reliable transmissions (FHSS, FEC, data interleaving)
- Connection to WANs (Bluetooth extension capability)
- Networking capabilities (p2p, star, tree, mesh, repeater)
- Low unit cost

2.2 Sensor Board

As the sensor has already been predetermined, this section will discuss the sensor mentioned, which is CornusSens1 produced by Reality.One Pte Ltd in Singapore. CornusSens1 is a multipurpose sensor board that accommodates 2 sensor, temperature and humidity. From the datasheet [25], the features of the sensor board can be referred.

The procurement of the sensor board comes with a firmware, called CornusView.

	CornusView
Server Operating System	Linux
Software Language	Java
Application Server	Glassfish Application Server
Database	Apache Derby

Table 1 CornusView specification

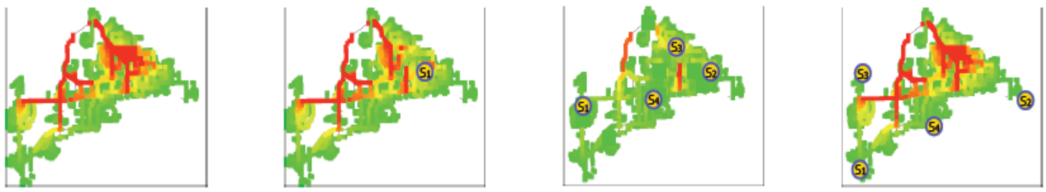
This firmware supports the configuration of the overall Cornus system; backend, database, concentrator, repeater, firmware, network access, VPN, and sensor board configuration.

The configuration of the system can be divided into 2 parts; system and local configuration. System configuration will affect all concentrators, sensor boards and also CornusView application, connecting to this backend. While local configuration is local to one user on one machine running CornusView, for example each machine and also each user on a machine can have a different configuration. The local configuration contains user interface related data and the configuration how to connect to the backend. [26]

It also provides other functionality to retrieve the sensors' data from the network and provide some analysis, such as graphics or diagrams.

2.3 Sensor Location Optimization

Related works have been done to determine the optimized sensor location. In [27] this paper, algorithm to decide sensors location to produce the best outcome is shown. However, the setting of the project is not in data center but in water environment (i.e. lake) for contamination detection purpose. In the following paragraphs more details information about the algorithm will be discussed.



(a) *Impact of contaminations* (b) *After one sensor placed* (c) *Effective placement* (d) *Poor placement*

Figure 2 Impact of contamination events on a large drinking water distribution network. The color of each node indicates the impact severity.

The main objective of sensing optimization is to find out a set of sensor that will give the best result for a minimum possible cost. Initial function is defined:

$$F(A)\ is\ a\ sensing\ quality\ function\ that\ will\ provide\ a\ score \\ for\ selecting\ the\ set\ of\ locations\ A\ out\ of\ the\ possible\ locations\ V.$$

As we want to get a minimum set of sensors, assuming we have k sensors and we want to ensure that $|A| \leq k$, our optimization problem becomes:

$$A^* = argmax\ F(A),\ A \subset V: |A| \leq k$$

In this paper, greedy algorithm is used where this procedure starts by picking the location 1 that provides the most information. Then, iteratively pick elements s_i that provides the most additional information.

The solution provided by the greedy algorithm is at least 63% of the optimal quality [11]. In practice, the performance of the greedy algorithm is much closer to optimal, where it reaches 95% [26][27][11].

2.4 Summary

In conclusion, in order to gather the optimized data, both wired and wireless technology will be used. Thermal imaging is chosen for the wired technology as there is no configuration needed. However, as it is time-consuming and literally impossible to manually capturing the temperature continuously, additional wireless sensor network will be deployed. Wavenis is chosen to be the wireless technology method as it is ultra-low-power consumption, highly sensitive sensing feature, and has much longer transmission distance than other technologies.

Furthermore, as the application software provided by Reality.One is a stand-alone desktop java application, web-based application to monitor the data sensor will be developed for convenient purpose.

Finally, in term of determining the optimized sensor location a historical analysis will be performed. The data gathered from the wireless sensor network will be further analyzed to determine the optimized sensor location by utilizing the sensitivity on each sensor location's with each PC.

Chapter 3

METHODOLOGY

3.1 Introduction

This chapter will cover the details explanation of methodology that is being used to make this project complete and working well. In order to evaluate this project, the methodology based on System Development Life Cycle (SDLC) as shown in Figure 3 will be used.

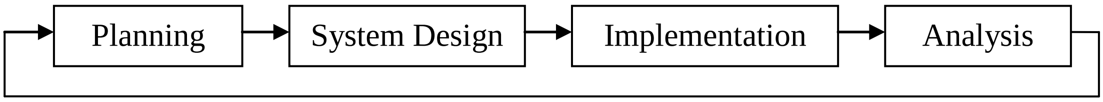


Figure 3 SLDC Phase

Figure 4 shows steps in each phase of the development cycle.

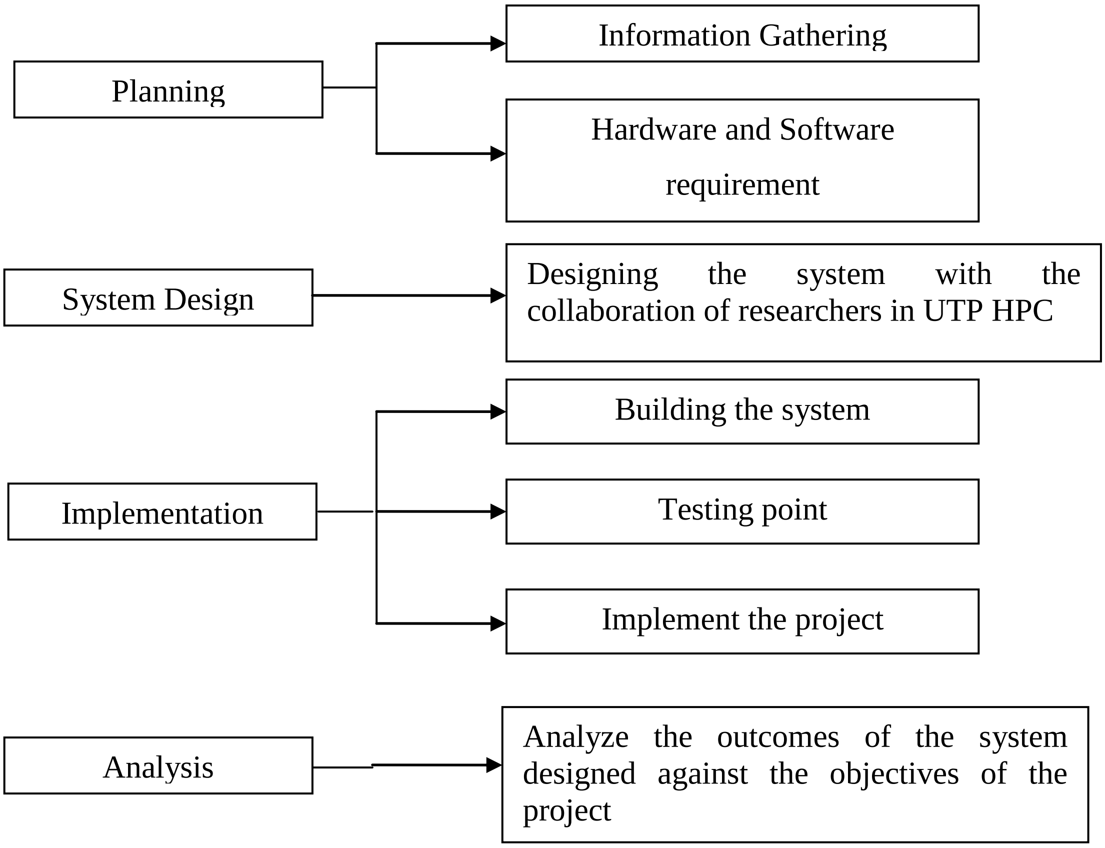


Figure 4 Steps in SLDC Phase

3.2 Planning

In order to obtain all the information requires fulfilling the project’s objectives, project planning must be done in the proper manner.

3.2.1 Information Gathering

In this stage, information on how the project can be carried out is done. Extensive literature studies and meeting is carried out to get a thorough data to design and build the system. The literature studies come from the materials collected from journal and research paper gathered from Internet. Furthermore, meetings with experts also can be done to get more information and suggestions for designing and building the system.

3.2.2 Hardware and Software Requirement

Hardware and software requirements need to be derived to make sure that a suitable hardware can be gathered and suitable software can be developed. However, time and cost constraint must be put as considerations in choosing the hardware and software implementations.

In this project, in addition to extensive literature studies, several meetings and consultations with experts; Dr. Dr. Mohamed Nordin (UTP Lecturer), Dr. Low Tan Jung (UTP lecturer), and Jun Okitsu (Hitachi researcher), has been conducted for better system development.

3.3 Designing

In this stage, the overall system design needs to be selected. As there are many system design can be implemented in temperature monitoring, one particular design that is most effective and efficient must be chosen. Hardware, software, and time limitations also need to be considered in choosing the system design.

3.4 Implementation

3.4.1 Building the system

There are two main activities this stage, which are collecting sensor data and asset management.

a. *Collecting sensing data.*

This stage focuses on the hardware implementation, which includes:

i. Sensor configuration.

The configuration of sensor will include the configuration of the overall wireless network system which includes the server, concentrator, sensor board and the firmware.

ii. Windows Application

A standalone application is built in order to give user friendly environment for analyzing the data gathered from the sensor. This standalone application will come in handy for further implementation of the experiment. The application will be built under the agile development methodology, where it's being developed in incremental, repetitious means.

This cycle of development is repetitive as all sections developed will be review continuously to identify element of enhancement and refinement that comply with project's objectives. Figure below shows the general agile development cycle:

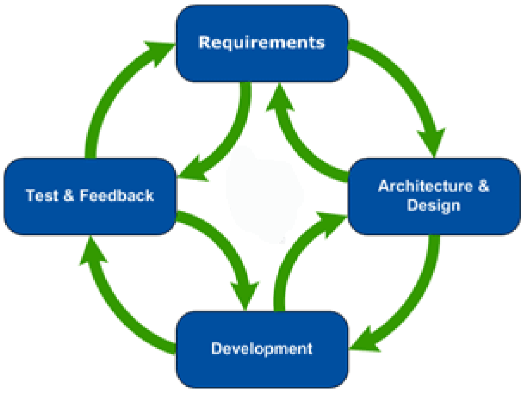


Figure 5 Agile Development

The application is developed under the .NET Framework 3.5 environment using C# as the main programming language.

b. Asset management

Asset management is done by determining the venue where the experiment will be done and listing all equipments (PCs and sensors) and all of their attributes (time, sensors' location, PCs location and PCs specifications).

3.4.2 Testing the point

In order to ensure correctness of the result, the project will do several testing, verification, validation and evaluation. In this stage, the project will be tested. The testing of this project consists of verifying and validating the system.

In this step, all the rules will be rechecked to make sure that the conditions is match with the conditions from information obtained. Otherwise, validation involves testing the system to ensure it is the right system- that it meets the expert's expectation. In this project, the activity involve is to test the overall system in order to make sure the system is working properly for optimum data collection. Some data samples can be derived from the testing experiment for evaluation.

3.4.3 Implement the project

After the system is tested, verified, validated, and evaluated then the system ready to be implemented and used by the users. Implementing the project is the main stage in the development cycle. In this stage, real-time data will be gathered to be analyzed. The following are some steps to be carried out when implementing the project:

- Deploy temperature sensor on the selected location.
- Monitor data generated by the sensor in each hotspot location (see Fig. 6). There will be 9 sensor nodes to be monitored.

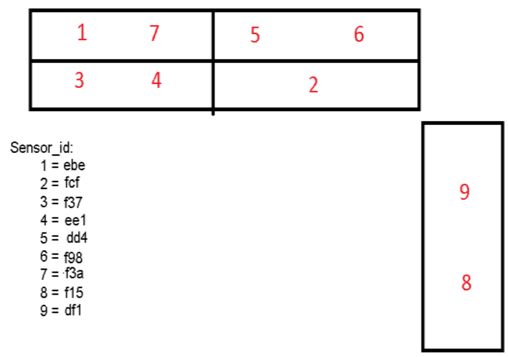


Figure 6 Sensor Layout

3.5 Analysis

The main objective of this phase is to detect the optimized sensor location as shown in Figure 7. The optimized sensor location can be derived by analyzing the data gathered from the experiment.

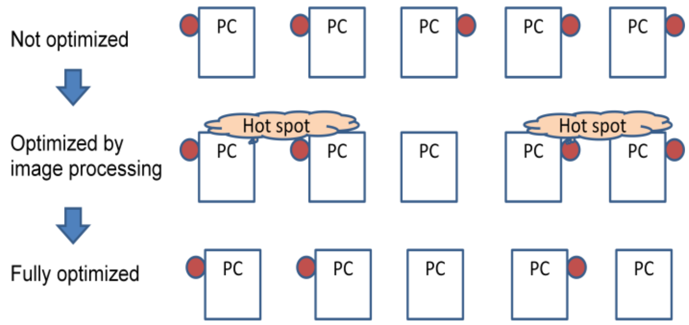


Figure 7 Sensor Location Optimization Overview

3.5.1 Analyze the result

Data gathered in the experiment can be used to select the candidate sensors to detect "thermally-anomaly". "Thermally-anomaly" means that the temperature sensed is not normal which can lead to a probable hotspot. The following are the steps to detect "thermally-anomaly" area:

1. Divide sensors into N groups.(N: number of sensors)

 - use correlation value.

 - use machine learning classification algorithm.

2. Estimate temperature and select sensors using the estimation

 - use slope & intercept to estimate temperature

 - select minimum estimated temperature value sensor in each group.

3.6 Key Milestone

Task	Start Date	End Date
Project Initiation	May 2012	May 2012
Planning Phase	June 2012	July 2012

Construction Phase	July 2012	November 2012
Final Review	November 2012	December 2012
Release	December 2012	December 2012

Table 2 Project Milestone

3.7 Gantt Chart

The project Gant Chart can be found in Appendix A.

Chapter 4

RESULT AND DISCUSSION

This chapter will present the result of the project. It includes result and discussion of the selected system design and the project progress in each stage of system development cycle.

4.1 Selected system design

System design that is chosen to be implemented in this project is shown in Fig 8.. It comprises of 3 main parts, which are the server, concentrator, and the sensor boards.

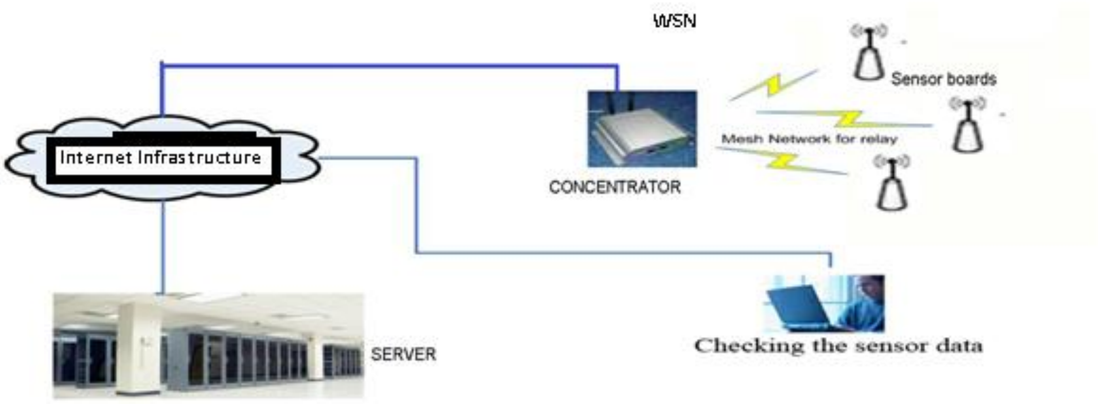


Figure 8 System design

Figure 11 shows the illustration of the system design. This system design is a wireless based distributed computing. It utilizes Client-Server architecture as its architecture with the concentrator acts as the middleware. The concentrator is used to poll among sensor boards to gather the data then transmit the data to the server. The protocol used in data transferring from sensor boards to the concentrator is the Wavenis protocol. Data monitoring can be done via network by accessing the server database.

4.2 System Development Progress

4.2.1 Building the system

4.2.1.1 Collecting sensing data

4.2.1.1.1 Sensor configuration

1. Training

   In order to successfully configure the sensor network, two trainings on the sensor network configuration has been done. The following are the training details:

   a. Singapore Training

      - Date : 12-13th July 2012
      - Venue: RealityOne Pte Ltd, Singapore
      - Objectives :
        - Familiarize with the sensor system
        - Learn to configure the system
        - Learn how to implement the system for the project
        - Observe the ongoing implementation of the sensor system
        - Fetch the sensors purchased

      - Photos taken on the training period can be found in Appendix B.

   b. UTP Sensor Training

      - Date : 28th - 29th September 2012
      - Venue : Data Communication Lab, UTP
      - Objectives :
        - Familiarize with the sensor system
        - Learn to configure the system
        - Learn how to implement the system for the project
      - Result :
        - The demonstration of the system set up was halted due to slow internet connection. For the solution, a system using a local server is made for demonstration purpose. The system was set up

using building01 network. The configuration was done successfully and the demo could go on.

  - In order to learn setting up using a cloud server (as this is what will be implemented), good connection internet in building01 is required. Therefore a prepaid broadband stick is prepared. A new Digi number was purchased and loaded for this purpose.

2. UTP Sensor network configuration (17th July 2012)

- Venue : HPC UTP
- Objective:
  a. Configure the system (server, concentrator, and sensor-boards).
  b. Fetch sample data from the sensor boards.

- Procedure
  a. Video Call through Skype swith the vendor on Singapore to guide through the configuration process.
  b. Purchasing a Digi number to get 3G connection from the concentrator to the server

- Result:
  a. Due to the time constraint to set up a local server in UTP, temporarily Server used will be a cloud server owned by the Singapore vendor.
  b. UTP cloud server will be purchased for long-term used.
  c. Concentrator is successfully configured; 3G communication with the cloud server is successfully made.
  d. Firmware, CornusView, couldn't be connected to the cloud server due to port blocking in UTP internet thus sample data couldn't be fetch from

the sensors.

- Solution:

  Get a broadband to get the firmware successfully connected.
- Photos taken during the configuration can be found in Appendix C.

3. UTP Sensor network configuration (29th Sept 2012)

- Venue : High Performance Center (HPC) UTP
- Objective

  Configure the real monitoring system (server, concentrator, and sensor-boards).
- Procedure

  a. Re-subscribe the concentrator to the internet as internet subscription has been expired.
  b. Reconfigure the concentrator to connect to the cloud server as it was configured to connect to the local server during the training period.
  c. Setting up the sensor network in the HPC (placing the concentrator and sensor boards in the experiment area)
  d. Record the sensor location with its ID for asset management (Fig. 9)
  e. Verify that the system is working properly

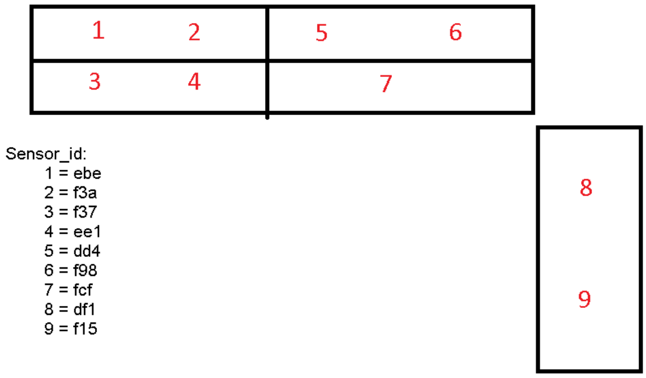


Figure 9 Sensor Network Map

- Result:
  a. Since the cloud server used has been upgraded, the local monitoring application (CornusView) needs to be upgraded as well.
     - Solution:

       The up-to-date application was requested to the vendor and was given within the same day. Thus the new system can be viewed locally using the up-to-date application.

  b. The system was installed successfully afterwards and data can be accessed. (Fig. 10)

Figure 10 Sensor Network

- Photos of the sensor configuration can be found in Appendix D.

4.2.1.1.2 Application Development

- A windows application is built in Visual Studio 2008, using C#, and NET 3.5 Framework.

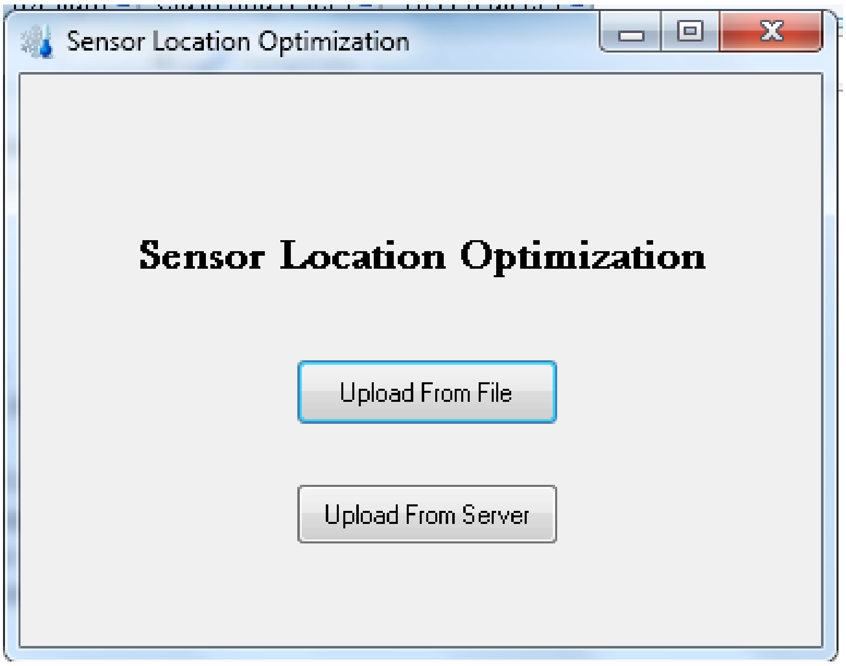


Figure 11 Homepage

- The application is developed for thermal monitoring management system. Thermal data can be collected in two ways, directly from the sensor network created (Figure 11) and from an external file (Figure 12). In getting data directly from the network can be divided in two category live mode and date-specified mode.

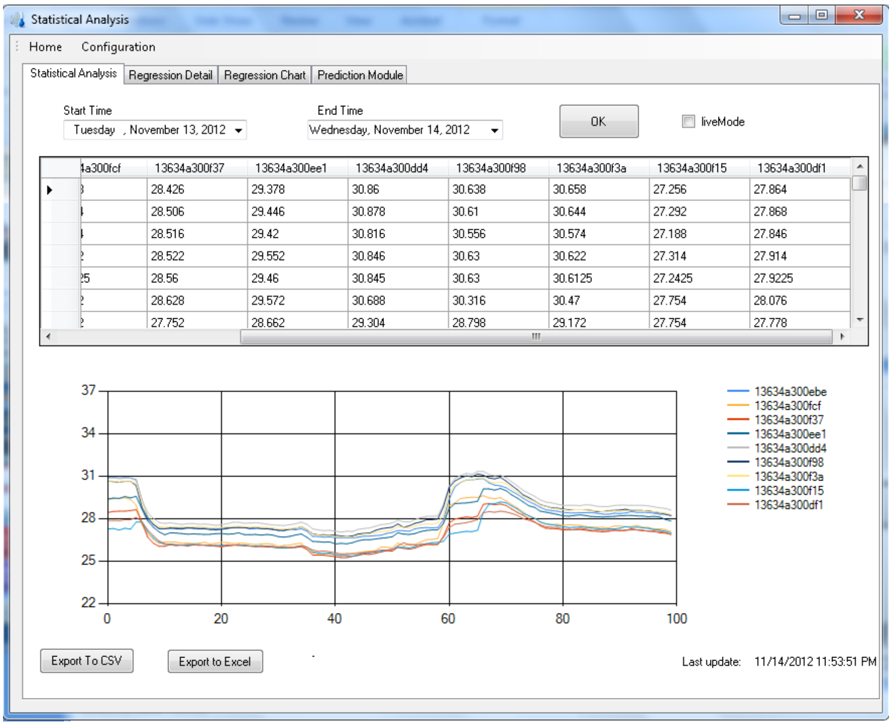


Figure 12 Direct Sensor Data Gathering

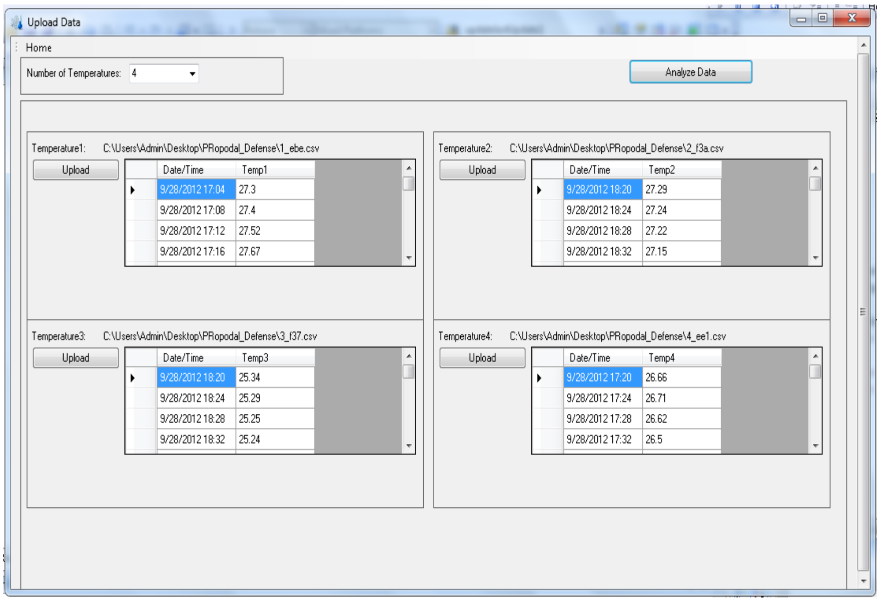


Figure 13 Data Gathering from external file

- The data received will be automatically analyzed.
- The analysis will include the sensor location optimization algorithm, which are
  - Regression detail to get the optimize sensor

location. It will include:

- The correlation between each sensor
- The slope and intercept value of each sensor
- The estimation value of the temperature based on the slope and intercept value.

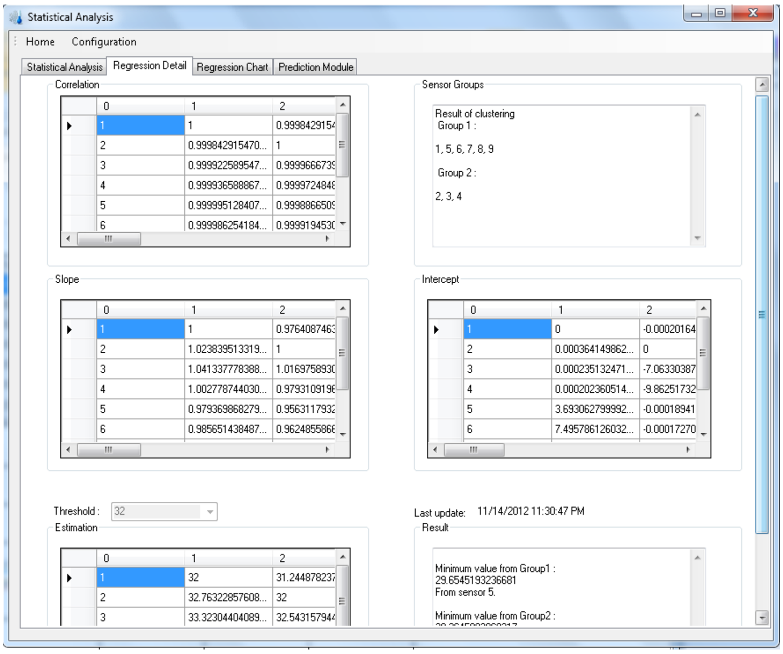


Figure 14 Regression Detail

- Regression chart
  - The regression chart section provides five types of regression (linear, polynomial, exponential, logarithmic, and power). User can freely choose the desired regression to see the result.

Figure 15 Regression Chart

- Prediction module to predict the next state of the network. The prediction module will be resulting in a text file containing the probability (0-1) that room temperature does not exceed threshold temperature.
- In the prediction module, the threshold temperature, prediction interval and prediction period can be specified.

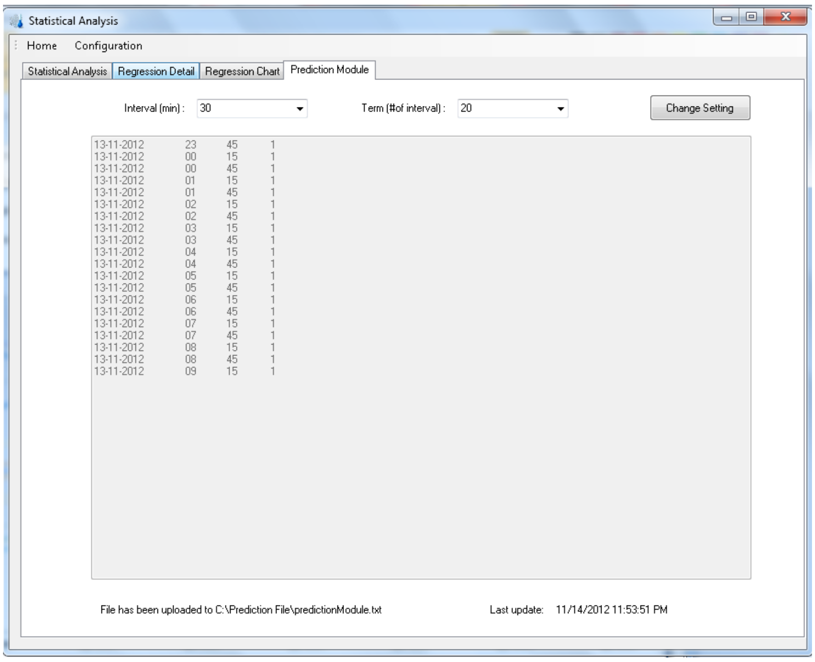


Figure 16 Prediction Module

4.2.1.2 Asset Management

The initial venue that has been agreed to be used as the test bed for the experiment is the Data Communication Lab in Building 02, UTP. However, after a thermal camera experiment done on 27th July 2012, the venue will be moved to High Performance Center UTP and Block 17 lab (17-01-05).

The thermal camera experiment is done by Jun Okitsu on 27th July 2012, Hitachi Researcher, to capture the thermal image of the room. The result shows that the room doesn't have heat circulation, in other words no sensor optimization needed. Thus, the venue is changed to be in HPC.

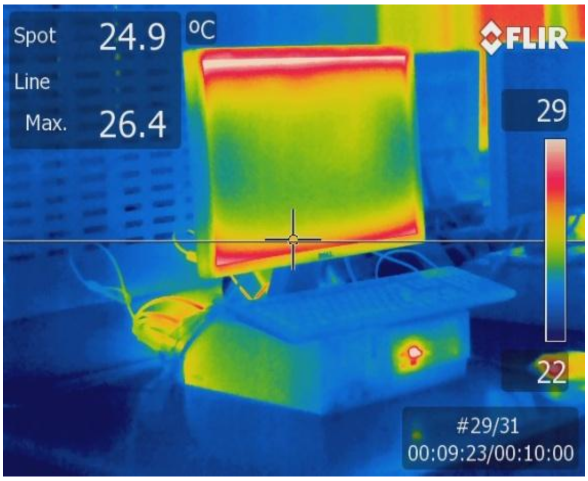


Figure 17 Thermal Image 1

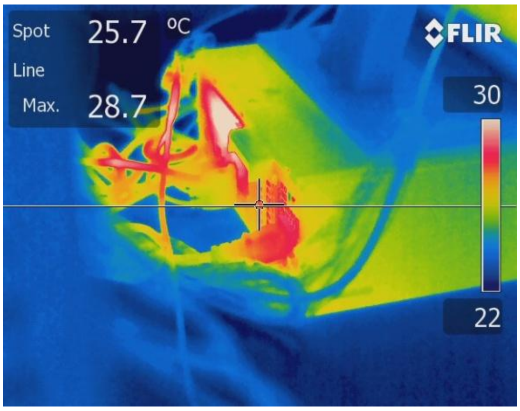


Figure 18 Thermal Image 2

Asset management also included recording the sensor_id and its location (see Fig. 9), and capturing the experiment environment (Appendix D).

4.2.2 Testing point

1. 1st Test Experiment (18th July 2012)

Figure 19 Testing point

- Venue : HPC UTP , Data Communication Lab, Chancellor complex
- Objective:
  a. Get the application to load a random jobs to the computer.
  b. Get permission from the official to install temperature software (CoreTemp) to the lab. CoreTemp will be used to measure the temperature inside the PCs by accessing the temperature sensor on the PC's motherboard.
  c. Install the software to all computers on the lab.
  d. Get the broadband to avoid UTP port blocking.
  e. Configure the firmware to successfully connect to the server database.
  f. Configure sensor-boards to be connected with the system.

- Result:
  a. The application to load random jobs to the computer is received from dr. Nordin and placed to the lab.

b. The PC temperature software (CoreTemp) is installed to all computers on the lab.
c. The firmware is successfully connected to the server database.
d. Sensor-boards are connected with the system.
e. Sample data can be fetched. Sample data can be found in Appendix C.

2. 2nd Test Experiment (19th July 2012)

Figure 20 Sensor Boards

- Venue: Data Communication Lab.
- Objective:
  a. Measuring power consumption of the PC.
  b. Get PC system detail for Asset management.
- Procedure:
  - Consultation:
    a) Phone call to Dell Malaysia.
    b) UTP IT Technician, Mr. Ruslan.
    c) Postgraduate student, Chan Piset.
  - Online research.
- Result:
  a. Joulemeter, an application from research Microsoft, can be used to monitor real-time power consumption of a PC.
  b. WattUp, a device to measure a machine power, need to be used for calibration.

- Solution proposed:
  a. Method 1: Used Manual Calibration on the Joulemeter by referring to the PC datasheet.
  b. Method 2: Used the successfully retrieved core load percentage to measure the power.

- Feedbacks: (23rd July 2012)

  "Method is acceptable. But, value is not acceptable. For example, I think base power 4W is too little, may be around 40W or higher. But it is difficult to estimate without measuring (calibrating) power consumption. I think it is better to suspend estimating power consumption till measurement of power consumption is ready." (Jun Okitsu)

4.2.3 Project Implementation

As the sensor network has been set up successfully in HPC and the application development to retrieve the data has been finished, the experiment is ready to start. The experiment is done as follow:

- Date : 13th November 2012 – 14th November 2012
- Venue : HPC UTP
- Objective :

  Collect sensor data (temperature) from the sensor network and analyze the data gathered.
- Procedure :
  - Data was collected automatically from the windows application that has been made.

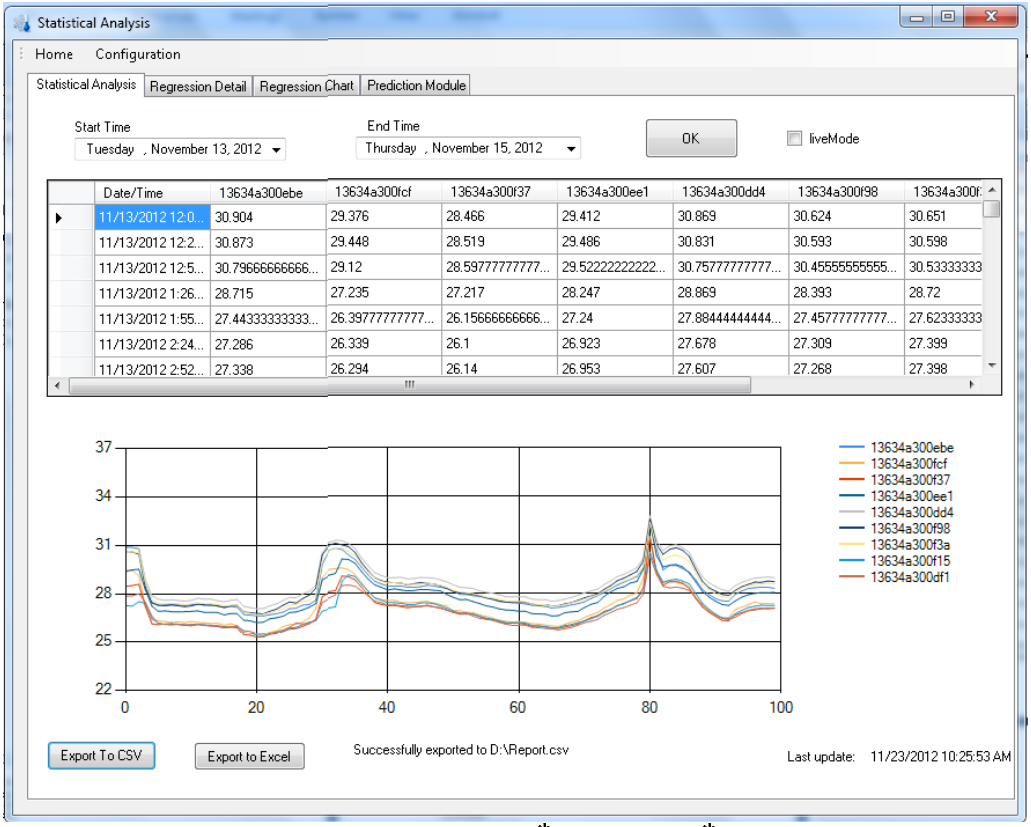


Figure 21 Data gathered on 13th November- 14th November2012

- The overview result of data gathering is shown in Figure 21. CSV file format of the data can be found in Appendix E.

4.3 Analysis

Windows application built will give the analysis result automatically as shown in Figure 22. The following section will explain the analysis in detail.

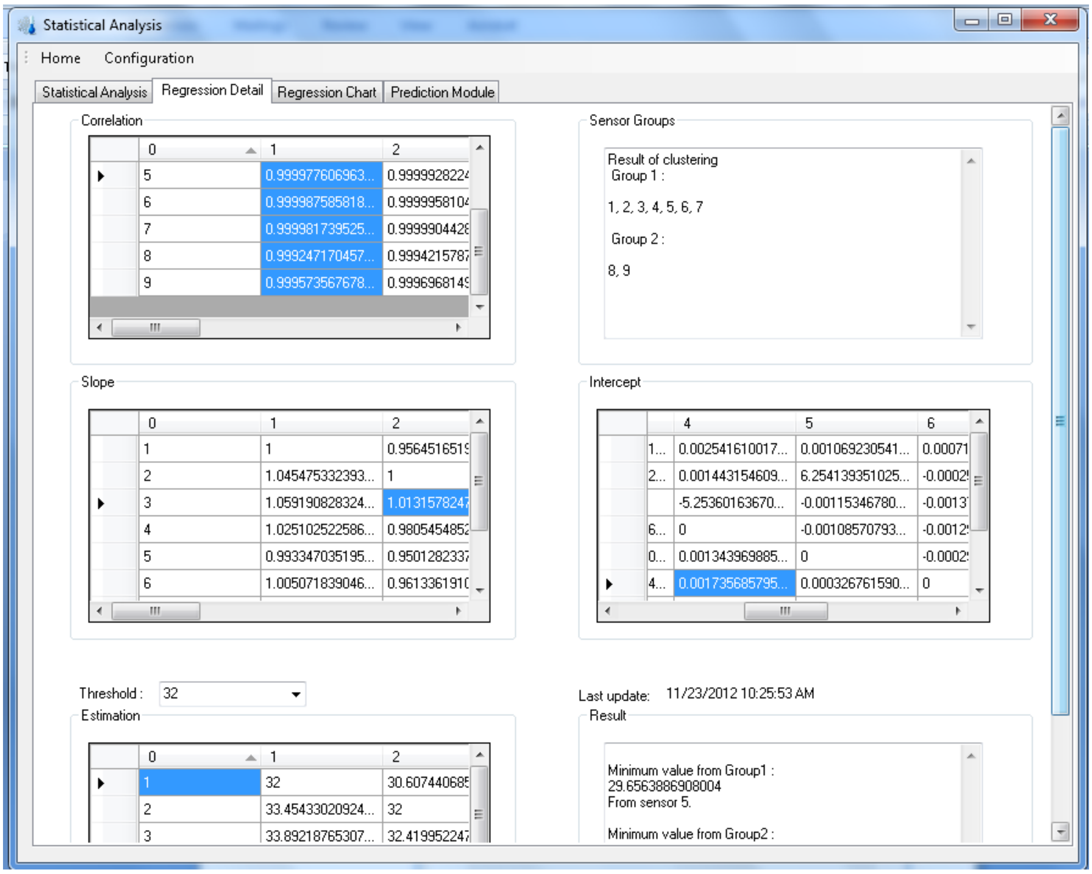


Figure 22 Analysis Result

Based on the data gathered, some analysis is done:

a. Correlation

The correlation is calculated with this formula:

Equation 1 Correlation Equation

$$r = \frac{n\sum xy - \left(\sum x\right)\left(\sum y\right)}{\sqrt{n\left(\sum x^2\right) - \left(\sum x\right)^2}\sqrt{n\left(\sum y^2\right) - \left(\sum y\right)^2}}$$, n = number of sensors

Cor		X								
		#1	#2	#3	#4	#5	#6	#7	#8	#9
Y	#1	1	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
	#2	0.99	1	0.99	0.99	0.99	0.99	0.99	0.99	0.99
	#3	0.99	0.99	1	0.99	0.99	0.99	0.99	0.99	0.99
	#4	0.99	0.99	0.99	1	0.99	0.99	0.99	0.99	0.99
	#5	0.99	0.99	0.99	0.99	1	0.99	0.99	0.99	0.99

	#6	0.99	0.99	0.99	0.99	0.99	1	0.99	0.99	0.99
	#7	0.99	0.99	0.99	0.99	0.99	0.99	1	0.99	0.99
	#8	0.99	0.99	0.99	0.99	0.99	0.99	0.99	1	0.99
	#9	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	1

Table 3 Correlation Table

The resulting correlation calculation of the data is shown in Table 3. Based on this correlation table, hierarchical clustering is performed to divide the sensor into its respective groups:

Group 1: sensor 1, 2, 3, 4, 5, 6, and 7

Group2: sensor 8 and 9

b. Slope and Intercept

Regression Equation(y) = a + bx.

Equation 2 Intercept and Slope equation

$$a = \frac{(\sum y)(\sum x^2) - (\sum x)(\sum xy)}{n(\sum x^2) - (\sum x)^2}$$

$$b = \frac{n(\sum xy) - (\sum x)(\sum y)}{n(\sum x^2) - (\sum x)^2}$$

Where: a= intercept,

b = slope

n = number of sensors

x = first data

y = second data

Slope		X								
		#1	#2	#3	#4	#5	#6	#7	#8	#9
Y	#1	1	0.956	0.944	0.975	1.007	0.995	0.999	0.933	0.94
	#2	1.045	1	0.987	1.02	1.052	1.040	1.044	0.975	0.982
	#3	1.06	1.013	1	1.033	1.066	1.054	1.058	0.988	0.996
	#4	1.025	0.981	0.968	1	1.0329	1.02	1.024	0.957	0.964
	#5	0.993	0.950	0.938	0.969	1	0.989	0.992	0.927	0.933
	#6	1.005	0.961	0.949	0.980	1.011	1	1.004	0.937	0.944
	#7	1.001	0.957	0.945	0.977	1.008	0.996	1	0.934	0.941
	#8	1.071	1.024	1.011	1.045	1.079	1.065	1.07	1	1.007
	#9	1.06	1.017	1.004	1.038	1.071	1.058	1.063	0.993	1

Table 4 Slope Table

Intercept		X								
		#1	#2	#3	#4	#5	#6	#7	#8	#9
Y	#1	0	0.001	0.003	0.003	0.001	0.001	0.001	0.006	0.004
	#2	-0.001	0	0.001	0.001	6.25E-05	-0.002	-4.063	0.004	0.003
	#3	-0.002	-0.001	0	-5.2E-05	-0.001	-0.001	-0.001	0.002	0.001
	#4	-0.002	-0.001	8.5E-05	0	-0.001	-0.001	-0.001	0.002	0.001
	#5	-0.001	-2.09E-05	0.001	0.001	0	-0.00	-7.046E-05	0.004	0.003
	#6	-0.001	0.000	0.002	0.002	0.000	0	0.000	0.005	0.003
	#7	-0.001	5.6E-05	0.001	0.001	7.59E-05	-0.00	0	0.004	0.003
	#8	-0.002	-0.001	-0.001	-0.001	-0.002	-0.002	-0.002	0	-0.00
	#9	-0.002	-0.002	-0.001	-0.001	-0.002	-0.002	-0.002	0.001	0

Table 5 Intercept Table

The resulting slope and intercept calculation of the data is shown in Table 4 and Table 5.

c. Estimation (threshold = 32)

From the calculated slope and intercept, the temperature values of the sensors based on the corresponding threshold can be estimated.

The slope and intercept calculated earlier will form a regression equation for each sensor. The estimation temperature can be calculated by providing the threshold temperature, 32^{o}C.

For example:

If sensor #8 temperature is 32, how much is the estimation temperature of sensor#9?

To be able to answer this question, we need to derive the regression equation of sensor #9 from the slope and intercept table.

Regression equation: y = a + bx, where a = intercept and b = slope

$$y = 0.001 + 0.993x$$

If the threshold temperature is 32 (y = 32)

$$32 = 0.001 + 0.993x$$

$$x = 32.22$$

The complete resulting estimation calculation is shown in Table 6.

Estimation		X								
		#1	#2	#3	#4	#5	#6	#7	#8	#9
Y	#1	32	30.61	30.21	31.21	32.21	31.84	31.97	29.85	30.07
	#2	33.45	32	31.58	32.6	33.68	33.29	33.42	31.21	31.44
	#3	33.9	32.42	32	33.06	34.12	33.72	33.86	31.63	31.86
	#4	32.80	31.38	30.97	32	33.02	32.64	32.77	30.61	30.84
	#5	31.79	30.40	30.01	31.00	32	31.63	31.76	29.66	29.87
	#6	32.16	30.76	30.36	31.38	32.38	32	32.13	30.00	30.22
	#7	32.03	30.64	30.24	31.24	32.25	31.88	32	29.89	30.10
	#8	34.26	32.77	32.36	33.43	34.5	34.1	34.23	32	32.22
	#9	34.03	32.55	32.13	33.20	34.26	33.86	34.0	31.77	32

Table 6 Estimation Table

The minimum estimated temperature value sensor from each group is picked:

Minimum value from Group1: 29.66, from sensor 5.

Minimum value from Group2: 31.77 from sensor 9.

This means that in group 1, sensor 5 is less significant as it gives the minimum estimation result (further from the threshold, less crucial). Furthermore, in group 2, sensor 9 is less significant as it gives the minimum estimation result.

Thus for reducing the cost, removing sensor 5 and sensor 9 from the network will give the minimum impact on the temperature monitoring system.

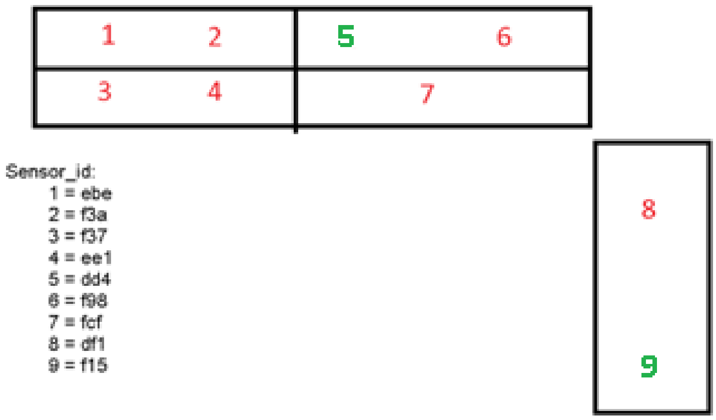


Figure 23 Optimized sensor map

d. Regression Chart

Regression chart also provided to give a better view on the regression equation (see Fig. 24)

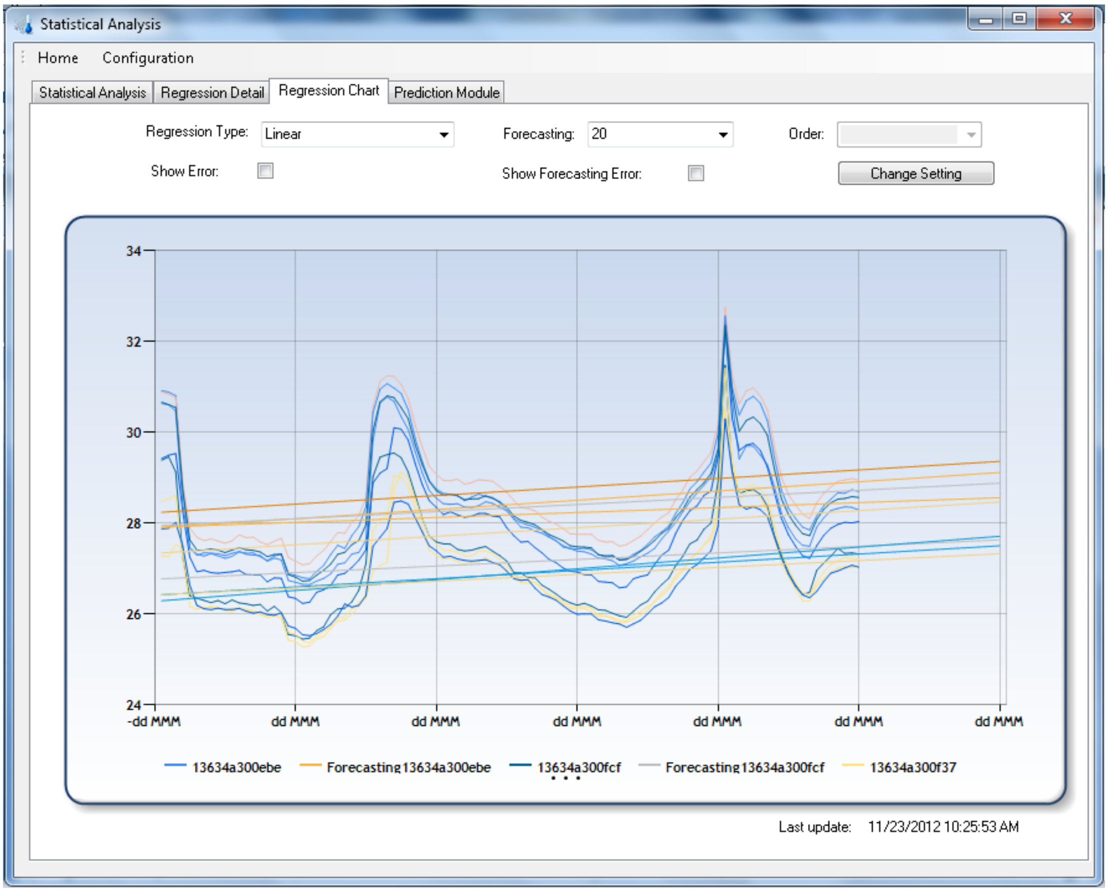


Figure 24 Regression chart (13th November – 14November 2012)

e. Prediction Module

In the prediction module, the threshold temperature is set to 32°C, with interval 30 minutes and period of 20.

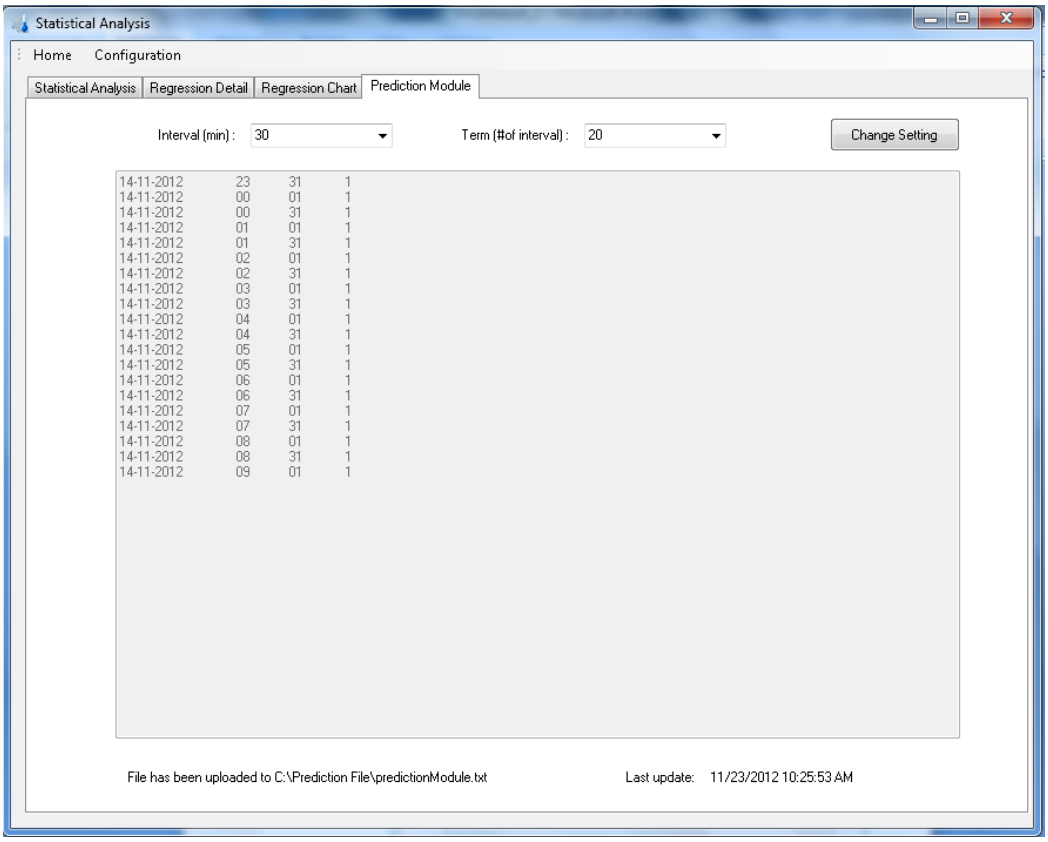


Figure 25 Prediction Temperatures (14th November 2012)

The result is shown above. The file is updated every 10 seconds in "C:\Prediction File\predictionModule.txt", with the newly fetched data. The date and time of the last update can be monitored as well.

Chapter 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The increase demand of data center has been increase significantly due to the rapid growth ICT technology. As a result, this brings along the “green” issues in data center such as energy consumption, heat generation and cooling requirements. These issues can be addressed by “Green of/by IT” in the context of operating costs as well as the environmental impacts. To accommodate temperature monitoring system in every corner of data center is cost inefficient. Optimized location for sensor placement is needed to be determined, to reduce the monitoring cost. It needs to be decided which locations to observe in order to most effective results, at minimum cost. Furthermore, it is argued that in depth knowledge of the historical data of the data center’s highly dynamic operating condition will lead to a better management of data center resources. Thus, this project aims to create a wireless temperature monitoring system with optimized sensor location. A windows application to collect real-time data of generated heat using wireless sensor network will be built to give a user-friendly access for monitoring system. The data monitored will be used to monitors the real-time temperature in data center to predict the next state of the temperature to detect potential anomaly in heat generation in the data center. Thus quick response for cooling can be invoked – Green by IT.

5.2 Recommendation

The wireless temperature monitoring system is a project of high potential and below is some recommendations for future enhancement:

a. Measures more parameters such as humidity, pressure, and flow rate by adding more sensors to the architecture

b. Enhance the notification method, for example an integrated automated mailing system to the administrator if there a thermal-anomaly is detected.
c. Expands the deployment scale to include more rooms/laboratories to be monitored.

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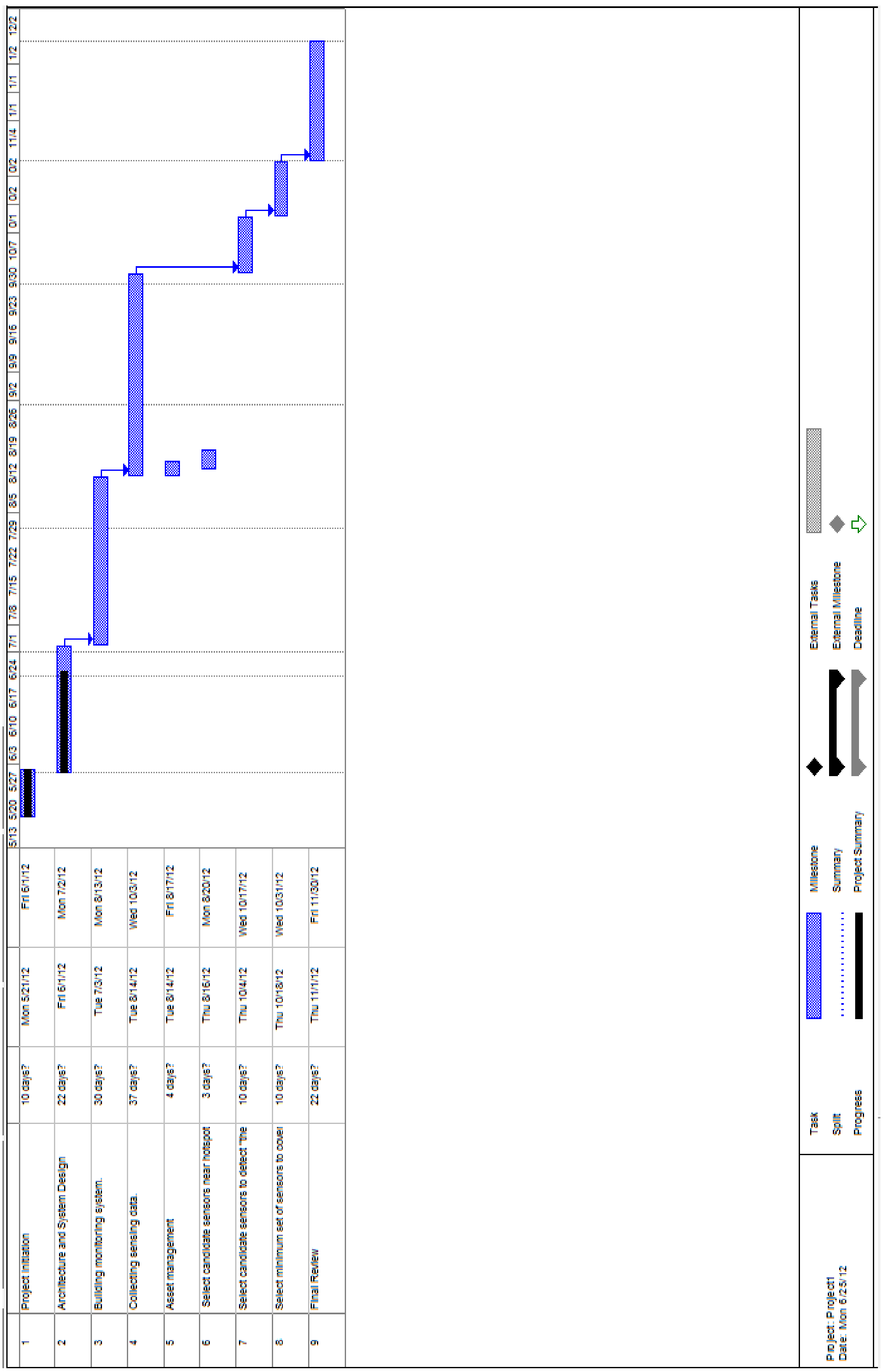
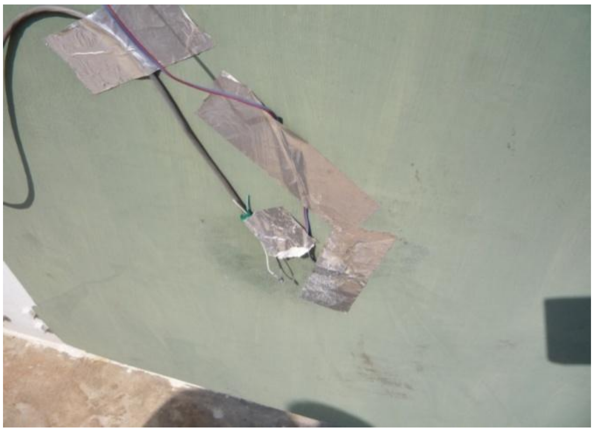
APPENDICES

APPENDIX A

GANTT CHART

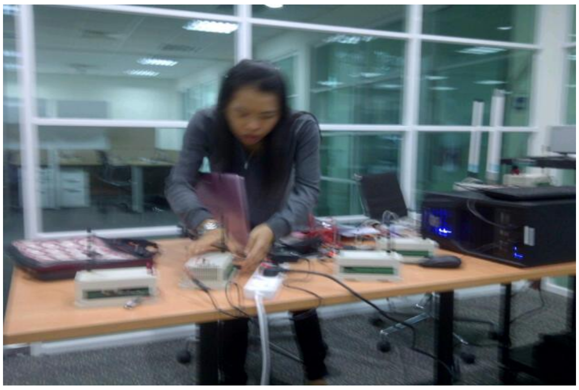


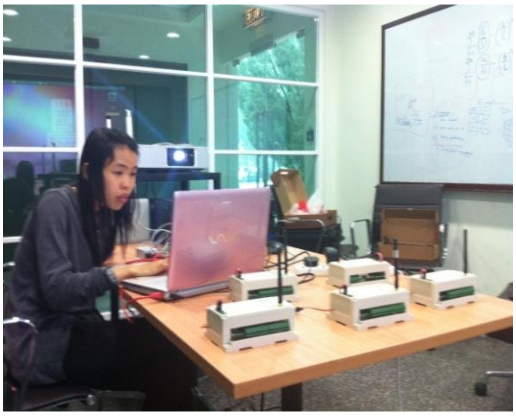
APPENDIX B
SINGAPORE TRAINING PHOTOS



APPENDIX C

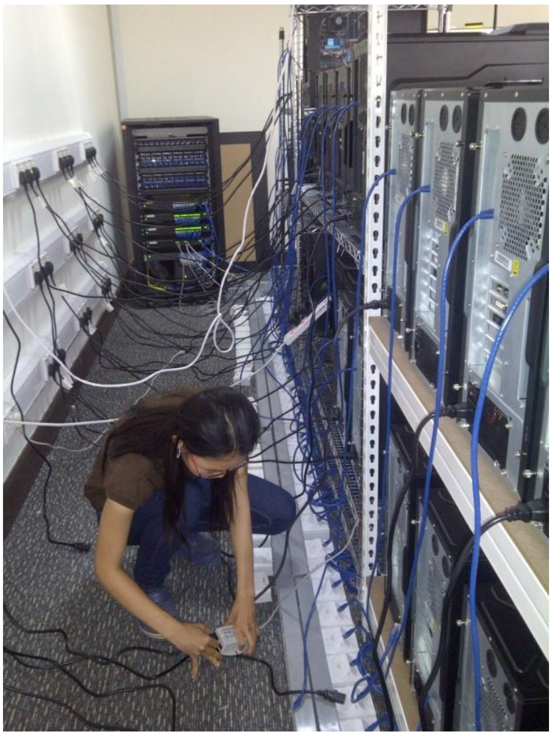
UTP Sensor network configuration (17th July 2012)

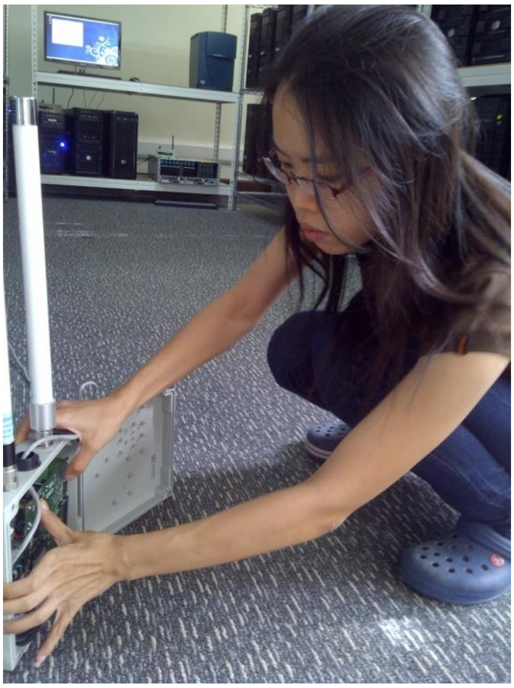


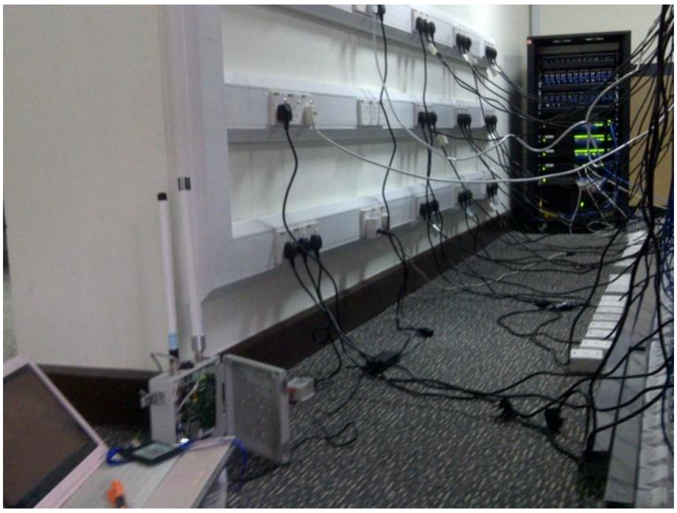




APPENDIX D

UTP Sensor network configuration (29th Sept 2012)







APPENDIX E

EXPERIMENT DATA

Date/Time	13634a300ebe	13634a300fcf	13634a300f37	13634a300ee1	13634a300dd4	13634a300f98	13634a300f3a	13634a300f15	13634a300df1
11/13/2012 0:00	30.904	29.376	28.466	29.412	30.869	30.624	30.651	27.274	27.866
11/13/2012 0:28	30.873	29.448	28.519	29.486	30.831	30.593	30.598	27.251	27.88
11/13/2012 0:57	30.79666667	29.12	28.59777778	29.52222222	30.75777778	30.45555556	30.53333333	27.52666667	28.00777778
11/13/2012 1:26	28.715	27.235	27.217	28.247	28.869	28.393	28.72	27.414	27.491
11/13/2012 1:55	27.44333333	26.39777778	26.15666667	27.24	27.88444444	27.45777778	27.62333333	26.50444444	26.62777778
11/13/2012 2:24	27.286	26.339	26.1	26.923	27.678	27.309	27.399	26.18	26.184
11/13/2012 2:52	27.338	26.294	26.14	26.953	27.607	27.268	27.398	26.117	26.11
11/13/2012 3:21	27.33222222	26.24333333	26.14222222	26.90333333	27.64666667	27.32111111	27.42222222	26.16111111	26.09
11/13/2012 3:50	27.32	26.289	26.118	26.888	27.599	27.273	27.399	26.138	26.121
11/13/2012 4:19	27.27888889	26.22	26.06888889	26.90666667	27.55	27.21777778	27.34333333	26.07555556	26.09333333
11/13/2012 4:48	27.328	26.302	26.034	26.921	27.602	27.263	27.4	26.115	26.09
11/13/2012 5:16	27.367	26.237	26.128	26.952	27.735	27.363	27.452	26.119	26.117
11/13/2012 5:45	27.30777778	26.21555556	26.07555556	26.86111111	27.67333333	27.33111111	27.40666667	26.09	26.05444444
11/13/2012 6:14	27.289	26.182	26.041	26.851	27.684	27.334	27.393	26.064	26.013
11/13/2012 6:43	27.28	26.20444444	25.98444444	26.85444444	27.57777778	27.25333333	27.35666667	26.01888889	26.03888889
11/13/2012 7:12	27.155	26.057	25.924	26.702	27.518	27.169	27.256	25.919	25.982
11/13/2012 7:40	27.223	26.162	25.953	26.788	27.597	27.273	27.303	25.963	25.967
11/13/2012 8:09	27.18222222	26.02444444	25.90444444	26.77777778	27.66111111	27.30444444	27.31111111	26.02444444	26.01777778
11/13/2012 8:38	26.729	25.541	25.416	26.372	27.234	26.88	26.859	25.601	25.729

11/13/2012 9:07	26.69222222	25.51777778	25.38444444	26.33777778	27.15666667	26.84333333	26.80444444	25.54333333	25.67888889
11/13/2012 9:36	26.647	25.442	25.27	26.227	27.074	26.793	26.715	25.4	25.537
11/13/2012 10:04	26.641	25.462	25.286	26.254	27.1	26.771	26.729	25.359	25.516
11/13/2012 10:33	26.71777778	25.62666667	25.44555556	26.46888889	27.26888889	26.93	26.84555556	25.50222222	25.56444444
11/13/2012 11:02	26.776	25.711	25.498	26.526	27.393	27.062	26.955	25.614	25.653
11/13/2012 11:31	26.87888889	25.97777778	25.67555556	26.62333333	27.58777778	27.30444444	27.09	25.71222222	25.76777778
11/13/2012 12:00	27.086	26.103	25.83	26.851	27.787	27.505	27.306	25.898	25.947
11/13/2012 12:28	27.119	26.123	25.862	26.888	27.767	27.435	27.351	25.935	26.214
11/13/2012 12:57	27.31111111	26.26222222	25.99444444	27.01777778	28.00444444	27.71777778	27.52	26.10555556	26.14444444
11/13/2012 13:26	27.349	26.516	26.162	27.177	28.158	27.917	27.611	26.255	26.183
11/13/2012 13:55	27.61333333	27.09666667	26.43	27.40333333	28.54888889	28.35	27.95	26.34444444	26.39666667
11/13/2012 14:24	29.807	29.012	27.828	28.875	30.553	30.423	30.021	26.933	27.483
11/13/2012 14:52	30.636	29.442	28.078	29.09	31.112	30.936	30.657	27.064	27.678
11/13/2012 15:21	30.76333333	29.49777778	28.13	29.19222222	31.23333333	31.06	30.79222222	27.12777778	27.87
11/13/2012 15:50	30.669	29.534	29.033	30.089	31.223	30.962	30.751	28.723	28.45
11/13/2012 16:19	30.33666667	29.43111111	28.99888889	30.06	31.04222222	30.84666667	30.53444444	29.11	28.47888889
11/13/2012 16:48	30.053	29.116	28.793	29.818	30.73	30.486	30.288	28.999	28.412
11/13/2012 17:16	29.565	28.61	28.332	29.302	30.144	29.851	29.718	28.515	28.106
11/13/2012 17:45	29.09666667	28.09333333	27.86444444	28.84	29.66222222	29.34666667	29.28111111	28.09666667	27.8
11/13/2012 18:14	28.708	27.697	27.395	28.486	29.235	28.928	28.908	27.687	27.492
11/13/2012 18:43	28.54	27.57666667	27.28222222	28.33666667	29.06555556	28.74666667	28.70444444	27.54222222	27.38444444
11/13/2012 19:12	28.421	27.538	27.198	28.18	28.931	28.645	28.604	27.394	27.243
11/13/2012 19:40	28.406	27.529	27.216	28.242	28.926	28.625	28.631	27.389	27.264
11/13/2012 20:09	28.42	27.41555556	27.14444444	28.17222222	28.95888889	28.59555556	28.59444444	27.35	27.20444444
11/13/2012 20:38	28.344	27.379	27.079	28.121	28.851	28.486	28.507	27.271	27.172
11/13/2012 21:07	28.33777778	27.39555556	27.13333333	28.14333333	28.88222222	28.56444444	28.52444444	27.26444444	27.15666667
11/13/2012 21:36	28.373	27.442	27.148	28.204	28.944	28.63	28.531	27.37	27.171
11/13/2012 22:04	28.462	27.478	27.236	28.203	28.932	28.577	28.594	27.379	27.19
11/13/2012 22:33	28.42555556	27.37444444	27.13666667	28.14888889	28.91111111	28.55444444	28.53777778	27.32333333	27.12333333
11/13/2012 23:02	28.34	27.277	27.049	28.13	28.795	28.434	28.462	27.2	27.079
11/13/2012 23:31	28.26555556	27.15777778	26.92555556	27.89111111	28.66777778	28.27444444	28.33888889	27.05	26.94

11/14/2012 0:00	28.079	26.903	26.8	27.716	28.492	28.094	28.149	26.873	26.771
11/14/2012 0:28	27.904	26.895	26.682	27.574	28.337	28.005	28.054	26.737	26.734
11/14/2012 0:57	27.89	26.79444444	26.67222222	27.58888889	28.31222222	27.95444444	28.00888889	26.75222222	26.74888889
11/14/2012 1:26	27.821	26.791	26.686	27.455	28.261	27.9	27.956	26.676	26.563
11/14/2012 1:55	27.77	26.62888889	26.54777778	27.33888889	28.12444444	27.83111111	27.84888889	26.54222222	26.42222222
11/14/2012 2:24	27.684	26.537	26.383	27.197	28.033	27.701	27.742	26.43	26.369
11/14/2012 2:52	27.603	26.433	26.332	27.123	27.974	27.607	27.674	26.368	26.297
11/14/2012 3:21	27.46555556	26.31777778	26.21777778	27.00444444	27.87333333	27.49333333	27.6	26.26444444	26.17444444
11/14/2012 3:50	27.432	26.24	26.106	26.935	27.758	27.437	27.494	26.157	26.06
11/14/2012 4:19	27.37666667	26.18666667	26.12555556	26.91888889	27.74666667	27.42222222	27.47111111	26.14666667	25.98888889
11/14/2012 4:48	27.362	26.228	26.117	26.859	27.747	27.439	27.465	26.151	25.996
11/14/2012 5:16	27.312	26.172	26.041	26.858	27.746	27.408	27.449	26.124	25.996
11/14/2012 5:45	27.22444444	26.08666667	25.92555556	26.71111111	27.61222222	27.30222222	27.29888889	25.97888889	25.86555556
11/14/2012 6:14	27.204	26.075	25.954	26.695	27.578	27.244	27.274	25.939	25.84
11/14/2012 6:43	27.16444444	26.01	25.89111111	26.68	27.58333333	27.27777778	27.27555556	25.91666667	25.80111111
11/14/2012 7:12	27.063	25.954	25.785	26.568	27.483	27.192	27.177	25.842	25.773
11/14/2012 7:40	27.099	25.919	25.813	26.59	27.519	27.206	27.193	25.845	25.702
11/14/2012 8:09	27.16111111	26.05666667	25.88888889	26.77	27.61222222	27.30666667	27.26666667	25.97111111	25.77777778
11/14/2012 8:38	27.253	26.193	25.967	26.819	27.707	27.39	27.373	26.044	25.856
11/14/2012 9:07	27.33111111	26.27666667	26.07555556	26.85333333	27.85111111	27.53	27.48	26.15666667	25.99888889
11/14/2012 9:36	27.44	26.481	26.276	27.087	27.995	27.689	27.612	26.258	26.153
11/14/2012 10:04	27.645	26.64	26.463	27.289	28.123	27.799	27.768	26.397	26.235
11/14/2012 10:33	27.82333333	26.78111111	26.59333333	27.39777778	28.22222222	27.93222222	27.88	26.54111111	26.35777778
11/14/2012 11:02	28.014	27.065	26.848	27.772	28.514	28.213	28.12	26.78	26.609
11/14/2012 11:31	28.24333333	27.26555556	26.97	28.05444444	28.72111111	28.44555556	28.29666667	26.94888889	26.77333333
11/14/2012 12:00	28.466	27.537	27.195	28.265	29.002	28.745	28.562	27.212	26.975
11/14/2012 12:28	28.651	27.618	27.345	28.371	29.136	28.9	28.726	27.313	27.082
11/14/2012 12:57	28.83111111	27.85777778	27.51	28.6	29.34	29.11333333	28.88222222	27.51555556	27.23
11/14/2012 13:26	29.002	27.993	27.643	28.702	29.55	29.316	29.085	27.712	27.385
11/14/2012 13:55	29.50444444	28.90555556	28.33	29.46888889	30.16444444	29.96888889	29.62888889	28.05888889	27.92666667
11/14/2012 14:24	32.272	31.463	31.399	32.355	32.743	32.544	32.343	30.497	30.283
11/14/2012 14:52	30.692	29.147	29.313	30.294	31.243	30.993	30.861	29.402	29.127
11/14/2012 15:21	29.40333333	28.65555556	28.46555556	29.59	30.61111111	30.36888889	30.01111111	28.64888889	28.39777778
11/14/2012 15:50	29.691	28.695	28.684	29.707	30.9	30.682	30.247	28.777	28.302
11/14/2012 16:19	29.68444444	28.73444444	28.68222222	29.74555556	30.96444444	30.78333333	30.32666667	28.83666667	28.35222222
11/14/2012 16:48	29.488	28.622	28.563	29.591	30.789	30.623	30.179	28.724	28.287
11/14/2012 17:16	29.279	28.367	28.269	29.225	30.485	30.246	29.928	28.55	28.14
11/14/2012 17:45	28.79	27.71777778	27.63777778	28.66888889	29.67555556	29.43444444	29.18	27.94333333	27.68777778
11/14/2012 18:14	28.215	27.273	27.117	28.093	29.001	28.719	28.523	27.358	27.229
11/14/2012 18:43	27.88888889	26.89	26.80444444	27.73444444	28.61555556	28.31555556	28.18	26.98444444	26.87
11/14/2012 19:12	27.644	26.632	26.542	27.482	28.391	28.095	27.943	26.68	26.598
11/14/2012 19:40	27.503	26.424	26.287	27.275	28.188	27.902	27.76	26.46	26.412
11/14/2012 20:09	27.48333333	26.46888889	26.27555556	27.21888889	28.09666667	27.84111111	27.71666667	26.40555556	26.35111111
11/14/2012 20:38	27.902	26.952	26.627	27.494	28.437	28.147	28.071	26.706	26.489
11/14/2012 21:07	28.11	27.11666667	26.77555556	27.72222222	28.64666667	28.37222222	28.29555556	26.91111111	26.70888889
11/14/2012 21:36	28.269	27.264	26.909	27.879	28.787	28.518	28.438	27.091	26.89
11/14/2012 22:04	28.313	27.436	27.005	27.962	28.912	28.658	28.52	27.163	26.942
11/14/2012 22:33	28.35	27.32666667	27.04666667	28.01	28.94	28.64777778	28.53333333	27.23666667	27.00666667
11/14/2012 23:02	28.339	27.338	27.008	27.997	28.971	28.725	28.574	27.215	27.064
11/14/2012 23:31	28.281	27.311	27.064	28.027	28.934	28.687	28.556	27.211	27.024

APPENDIX F

TECHNICAL PAPER

Optimization of Sensor Location in Data Center

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***A*bstract—The demand of data center has been increasing significantly due to the rapid growth in ICT technology. This brings along the "green" issues in data center such as energy consumption, heat generation and cooling requirements. These issues can be addressed by "Green of/by IT" in the context of operating costs as well as the environmental impacts. To accommodate temperature monitoring system in every corner of data center is cost inefficient. Optimized location for sensor placement is thus needed to reduce the monitoring cost. This project aims to create a wireless temperature monitoring system with location optimization algorithm to optimize temperature sensors deployment/locations. Furthermore, real-time temperature data collection and monitoring can be used to predict the next state of the temperature to detect potential anomaly in heat generation in the data center. Quick response for cooling can be thus invoked – an approach in "Green by IT".**

Keywords—Sensor location optimization, Wireless Sensor Network, Correlation analysis, green by IT.

I. INTRODUCTION *(HEADING 1)*

Data center is one of the crucial components of Information Communication Technology (ICT) infrastructure. It is not an overstatement that in most of the cities, our life relies on the functioning and availability of one or multiple data centers. Most of human activities involve energy, lighting, telecommunications, internet, transport, urban traffic, banks, security systems, public health, entertainment and even our physical integrity are somehow linked to data centers. Consequently, this brings along the "green" issues in data center such as energy consumption, heat generation and cooling requirements. High energy consumption and operating cost of a data center is not new. Environmental effect comes along with it. Increasing CO_2 emission and rising water usage for cooling makes this problem needs to be urgently dealt with.

To mitigate the problems, real-time temperature monitoring system is introduced. Sensors are deployed to monitor real-time heat and humidity in the data center. In order to make data monitoring efficient wireless sensor network for transmitting data is an attractive option.

To find out the optimize location in placing the sensors, the raw data gathered will be monitored and analyzed. Sensitivity level of the sensors is analyzed based on the data gathered. By determining which sensors are of significance, optimized location can be derived.

Furthermore, future prediction of the state of the network will be added to the system to monitor that the temperature doesn't reach the threshold level.

II. LITERATURE REVIEW

A. Data Center Sensing Method

1) Wired Technology

a) Thermal Images

The main advantage of using thermal imaging in sensing temperature in data center is quick and easy detection of thermal anomalies will be easier and faster. Typically, a single thermal image has over 75,000 thousand temperature points [1]. Furthermore, it will help in detecting the actual surface temperature which is useful to spot overheating and fixing it before failure [2]

b) Onboard Sensor

The usage of onboard sensor is to detect the thermal condition of the nearby key server components, such as CPUs, disks, or I/O controllers. However the onboard sensor doesn't sense the data center's thermal environment. Even though recent servers have additional sensors to monitor data center's air intake, this will be a problem for those who do not have [3].

2) Wireless Technology

There are several wireless technologies being considered to be implemented in this network. Wavenis is chosen to be the technology used. As mentioned in [4], some advantages provided by Wavenis are:

- Long battery life (up to 15 years on primary battery)
- Long range (200m indoor – 1km LOS)
- Smart links (2-way communications)
- Reliable transmissions (FHSS, FEC, data interleaving)
- Connection to WANs (Bluetooth extension capability)
- Networking capabilities (p2p, star, tree, mesh, repeater)
- Low unit cost

B. Sensor Board

The specifications of the sensor used are as below: [5]

Table 1SensorBoard Specification

	CornusView
Server Operating System	Linux
Software Language	Java
Application Server	Glassfish Server
Database	Apache Derby

C. Related Work

To obtain optimized sensor set according to an optimization model, several works have been proposed. Kraus et al. have proposed optimization model of water sensor networks [6].

In this paper, greedy algorithm is used where this procedure starts by picking the location 1 that provides the most information. Then, iteratively pick elements that provide the most additional information. The solution provided by the greedy algorithm is at least 63% of the optimal quality [6]. In practice, the performance of the greedy algorithm is much closer to optimal, where it reaches 95% [6][7].

III. METHODOLOGY/PROCEDURE

Methodology based on System Development Life Cycle (SDLC) as shown in Figure 1 is used.

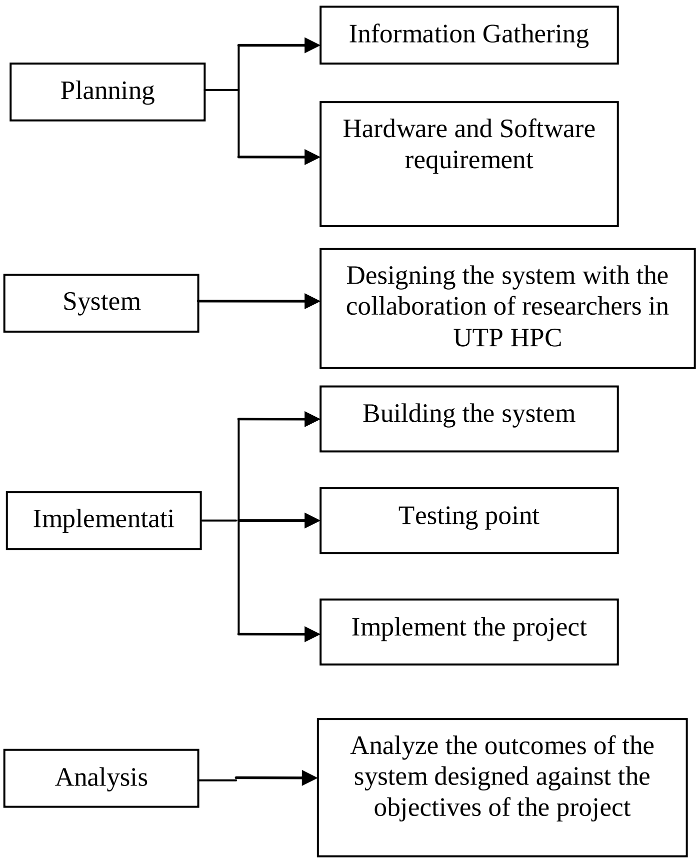

Figure 1 Project Methodology

A. System Architecture

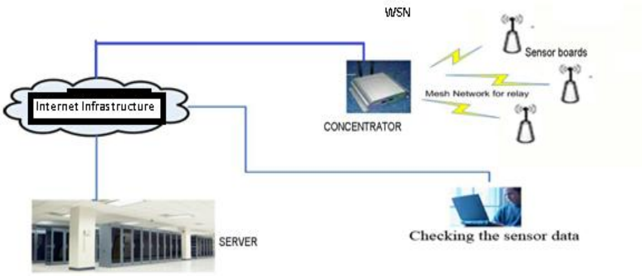

Figure 2 System Architecture

System architecture chosen in this project is shown in Fig. 2. It comprises of 3 main parts, which are the server, concentrator, and the sensor boards. It is basically a wireless based distributed network. It utilizes Client-Server architecture with the concentrator acting as the middleware. The concentrator is used to poll among sensor boards to gather the data then transmit the data to the server. The protocol used in data transferring from sensor boards to the concentrator is the Wavenis protocol. Data monitoring can be accomplished by accessing the server database via the network infrastructure.

B. Application Development

A standalone application is built in order to give user friendly environment for analyzing the data gathered from the sensors. This standalone application will come in handy for further implementation of the experiment. The application is built under the agile development methodology, where it's being developed in incremental, repetitive means. It is based on the .NET Framework 3.5 environment with C# as the main programming language.

C. Optimizing of Sensor Location

Data gathered from the sensors is used to select the candidate sensors to detect "thermally-anomaly". "Thermally-anomaly" means that the temperature sensed is not normal which can lead to a probable hotspot. The following are the steps to detect "thermally-anomaly" area:

- Divide sensors into N groups.(N: number of sensors)
  - Use correlation value to measure the relationship strength of the sensors

The correlation is calculated with this formula:

$$r = \frac{n\sum xy - \left(\sum x\right)\left(\sum y\right)}{\sqrt{n\left(\sum x^2\right) - \left(\sum x\right)^2}\sqrt{n\left(\sum y^2\right) - \left(\sum y\right)}} \quad (1)$$

where,

x = data for first sensor
y = data for second sensor
n = number of sensors

- Use machine learning classification algorithm to cluster the sensors

- Estimate temperature based on the linear equation and select the minimum value from each clustered group
  - Use slope & intercept to make the linear equation for each sensor (y = ax + b)

$$a = \frac{(\sum y)(\sum x^2) - (\sum x)(\sum xy)}{n(\sum x^2) - (\sum x)^2} \quad (2)$$

$$b = \frac{n(\sum xy) - (\sum x)(\sum y)}{n(\sum x^2) - (\sum x)^2} \quad (3)$$

where,

a = intercept

b = slope

  - Select minimum estimated temperature value sensor in each group. This sensor represents the least important sensor in its group.

IV. EXPERIMENT

A sensor network has been set up successfully in High Performance Center (HPC), Universiti Teknologi PETRONAS (UTP) and the application is developed to retrieve the data. The experiment is ready to start.

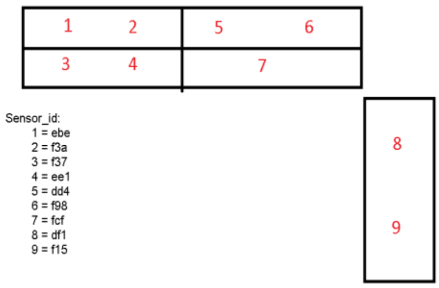

Figure 3 Sensor Network Layout

The experiment is done in 2 two-level racks and 1 one-level rack with 5 CPUs occupied each level in each rack. In the layout, the racks are represented as a rectangle. There are 9 sensors deployed in this experiment. Each sensor are represented as number.

The experiment is done to collect sensor data (temperature) from the sensor network and analyze the data gathered. The data was collected automatically from the windows application that was developed.

Figure 4 and 5 show the screenshots of the results obtained from the application.

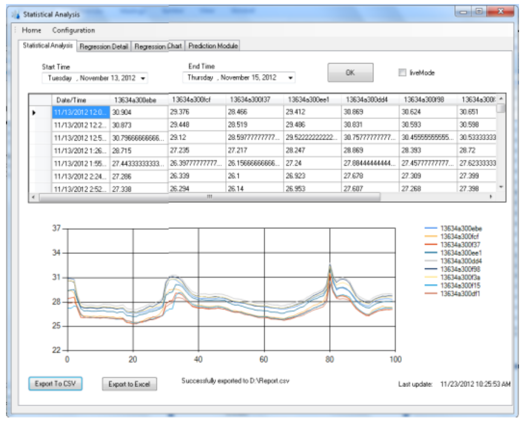

Figure 4 Data gathered on 13th- 14th November 2012

Showing the analysis of the data gathered

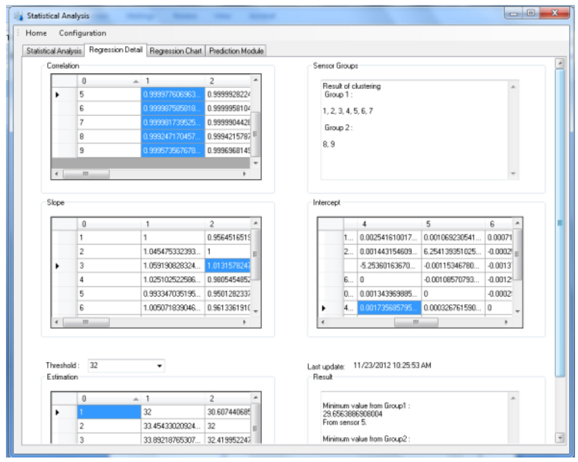

Figure 5 Analysis of the Result

From the data gathered, some analysis is performed:

- Correlation

Table 2 Correlation Table based on Equ. (1)

Cor		X								
		#1	#2	#3	#4	#5	#6	#7	#8	#9
Y	#1	1	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
	#2	0.99	1	0.99	0.99	0.99	0.99	0.99	0.99	0.99
	#3	0.99	0.99	1	0.99	0.99	0.99	0.99	0.99	0.99
	#4	0.99	0.99	0.99	1	0.99	0.99	0.99	0.99	0.99
	#5	0.99	0.99	0.99	0.99	1	0.99	0.99	0.99	0.99
	#6	0.99	0.99	0.99	0.99	0.99	1	0.99	0.99	0.99
	#7	0.99	0.99	0.99	0.99	0.99	0.99	1	0.99	0.99
	#8	0.99	0.99	0.99	0.99	0.99	0.99	0.99	1	0.99
	#9	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	1

The resulting correlation calculation of the data is shown in Table 2. This correlation coefficient measures the strength linear relationship between two sensors. A correlation greater than 0.8 is generally described as strong, whereas a correlation less than 0.5 is generally described as weak. Based on the calculated correlation, the sensors are strongly correlated to each other.

Based on this correlation table, hierarchical clustering is performed to divide the sensor into its respective groups:

Group 1: sensor 1, 2, 3, 4, 5, 6, and 7
Group2: sensor 8 and 9

- Slope and Intercept

Table 3 Slope Table based on Equ. (2)

Slope		X								
		#1	#2	#3	#4	#5	#6	#7	#8	#9
Y	#1	1	0.956	0.944	0.975	1.007	0.995	0.999	0.933	0.94
	#2	1.045	1	0.987	1.02	1.052	1.040	1.044	0.975	0.982
	#3	1.06	1.013	1	1.033	1.066	1.054	1.058	0.988	0.996
	#4	1.025	0.981	0.968	1	1.0329	1.02	1.024	0.957	0.964
	#5	0.993	0.950	0.938	0.969	1	0.989	0.992	0.927	0.933
	#6	1.005	0.961	0.949	0.980	1.011	1	1.004	0.937	0.944
	#7	1.001	0.957	0.945	0.977	1.008	0.996	1	0.934	0.941
	#8	1.071	1.024	1.011	1.045	1.079	1.065	1.07	1	1.007
	#9	1.06	1.017	1.004	1.038	1.071	1.058	1.063	0.993	1

Table 4 Intercept Table based on Equ. (3)

Intercept		X								
		#1	#2	#3	#4	#5	#6	#7	#8	#9
Y	#1	0	0.001	0.003	0.003	0.001	0.001	0.001	0.006	0.004
	#2	-0.001	0	0.001	0.001	6.25E-05	-0.002	-4.063	0.004	0.003
	#3	-0.002	-0.001	0	-5.2E-05	-0.001	-0.001	-0.001	0.002	0.001
	#4	-0.002	-0.001	8.5E-05	0	-0.001	-0.001	-0.001	0.002	0.001
	#5	-0.001	-2.09E-05	0.001	0.001	0	-0.00	-7.046E-05	0.004	0.003
	#6	-0.001	0.000	0.002	0.002	0.000	0	0.000	0.005	0.003
	#7	-0.001	5.6E-05	0.001	0.001	7.59E-05	-0.00	0	0.004	0.003
	#8	-0.002	-0.001	-0.001	-0.001	-0.002	-0.002	-0.002	0	-0.00
	#9	-0.002	-0.002	-0.001	-0.001	-0.002	-0.002	-0.002	0.001	0

- Estimation

Table 5 Estimation Table

Estimation		X								
		#1	#2	#3	#4	#5	#6	#7	#8	#9
Y	#1	32	30.61	30.21	31.21	32.21	31.84	31.97	29.85	30.07
	#2	33.45	32	31.58	32.6	33.68	33.29	33.42	31.21	31.44
	#3	33.9	32.42	32	33.06	34.12	33.72	33.86	31.63	31.86
	#4	32.80	31.38	30.97	32	33.02	32.64	32.77	30.61	30.84
	#5	31.79	30.40	30.01	31.00	32	31.63	31.76	29.66	29.87
	#6	32.16	30.76	30.36	31.38	32.38	32	32.13	30.00	30.22
	#7	32.03	30.64	30.24	31.24	32.25	31.88	32	29.89	30.10
	#8	34.26	32.77	32.36	33.43	34.5	34.1	34.23	32	32.22
	#9	34.03	32.55	32.13	33.20	34.26	33.86	34.0	31.77	32

The slope and intercept calculated earlier will form a regression equation for each sensor. The estimation temperature can be calculated based on the threshold temperature of 32^{o}C.

The sensor with minimum estimated temperature value sensor from each group is picked. First group contains 6 sensors (#1, #2, #3, #4, #5, and #6) and second group contains 2 sensors (#8 and #9). From the calculated estimation temperature, the minimum estimation temperature from Group1: 29.66, from sensor 5and minimum estimation temperature from Group2: 31.77 from sensor 9.

This means in group 1, sensor 5 is less significant as it gives the minimum estimation result (further from the threshold, less crucial). Furthermore, in group 2, sensor 9 is less significant as it gives the minimum estimation result.

Thus for reducing the cost, removing sensor 5 and sensor 9 from the network will give the minimum impact on the temperature monitoring process.

- Prediction Module

In the prediction module, the threshold temperature is set to 32^{o}C, with interval of 30 minutes and period of 20. The file is updated every 10 seconds in the local directory, with the newly fetched data. This prediction represents the probability of the network reaching the threshold. Thus, necessary actions can be taken to manage this situation.

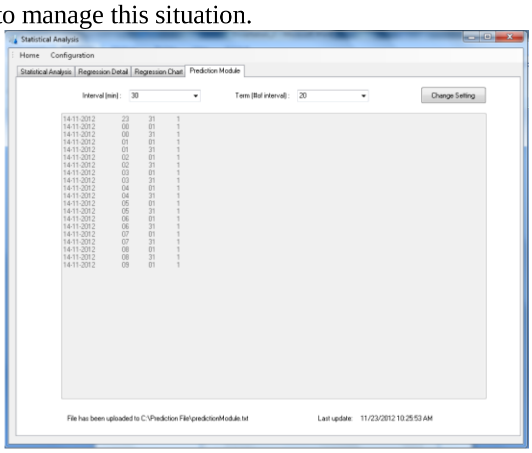

Figure 6 Prediction Module Output

V. CONCLUSION

Location for sensors can be optimized by the developed algorithm through the analysis of the historical data collected via the sensors in a wireless sensor network.

Wireless Temperature Monitoring System that monitors the real-time temperature in data center can be used to predict the next state of the temperature to detect potential anomaly in heat generation in the data center. Thus quick response for cooling can be invoked. This is an approach for Green by IT.

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