# AN INTELLIGENT WIRELESS MULTI-SENSOR TEMPERATURE CONTROL SYSTEM USING A SELF-TUNING PID CONTROLLER WITH NEURAL NETWORK

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| Advisor | Asst. Prof. Dr. Wimol San-Um |

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SOMSAK THAICHAROEN : AN INTELLIGENT WIRELESS MULTI-SENSOR TEMPERATURE CONTROL SYSTEM USING A SELF-TUNING PID CONTROLLER WITH NEURAL NETWORK ADVISOR : ASST. PROF. DR. WIMOL SAN-UM, 67 PP.

This paper presents an intelligent temperature control system that provides a fully automatic air conditioner operation for a stable room temperature. The proposed technique employs the multi-sensor temperature sensing system with wireless data transmission in order to obtain accurate temperature measurement over a wide area. The control system is a PID controller with self-tuning feature using an artificial neural network. The wireless control system is designed using temperature sensor model DHT11, Arduino microcontroller and the transceiver model nRF24L01. The controller provides a control signal to VSD model VF-nC3 to control speed of motor compressor. The experimental results show a fast and stable setting of any specifically set temperatures. The proposed temperature control system offers a stable temperature for industrial plant, energy saving, and long life time of air conditioner.

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| Field of Engineering Technology | Advisor's Signature ........................................... |
| Academic Year 2013 | |

# Acknowledgements

The author wishes to express his profound gratitude and to respectfully dedicate this work to his parent and family members for their endless encouragements, love and sacrifices. The author is most grateful to his advisor, Asst. Prof. Dr. Wimol San-Um, for his valuable supervision, supports and encouragements throughout the study. Grateful acknowledgements are also made to Asst. Prof. Dr. Wipawadee Wongsuwan, the director of master of engineering technology program for her supports. In addition, grateful acknowledgements are made to Assoc. Prof.Worapong Tangsrirat, Dr.Kanthicha Kitipeerachon, Dr.Phaisarn Sudwilai, members of thesis committee, for their valuable suggestions and comments. The author also wishes to acknowledge Thai-Nichi Institute of Technology for a great opportunity of master study and financial supports internships in Japan. The author sincerely appreciates all of his friends in Intelligent Electronic Systems Research laboratory for their friendships and goodwill.

Somsak Thaicharoen

# Table of Contents

# Table Contents (Continued.)

# List of Table

# List of Figures

## List of Figures (Continued.)

## List of Figures (Continued.)

# Chapter 1
# Introduction

## 1.1 Background

Air conditioning system typically controls the temperature in a closed area at a constant value and the temperature deviation should not exceed 2 $^{0}$C as for generally acceptable temperature criteria in industrial plants. The typically and commercially available on-off temperature control system operates by sensing temperature and sending the control signals to stop the compressor when the temperature is higher than the present value. Consequently, the temperature is not stable due to start-stop operation, resulting in the short life-time of compressor motor. In addition, such a system also consumes much energy for starting the motor repeatedly.

As a potential alternative to the on-off control system for air conditioner, the use of a Proportional-Integral-Derivative (PID) controller still remains as a common control algorithm in industry. The PID controller offers versatility, high reliability and ease of operation [1]. Nonetheless, the performance of PID controller degrades during operational time owing to process non-linearity or process time varying parameters, and consequently retuning process is ultimately required [2]. Moreover, Retuning such a PID controller is mostly performed through a trial-and-error procedure which is a time consuming process and only skillful operators could effectively adjust to suitable operational conditions. As a results, there has been extensive research attempts to find the effective tuning procedures for PID controllers.

## 1.2 Motivation

1.2.1 The accuracy of temperature controlling as a typical control of air conditioner was utilized only one sensor for detected temperature in area of controlling at return air flow, So that the air temperature is not real temperature of area controlling. This thesis to proposed multi sensors temperature detecting to collected real temperature in each position then make calculate for find out final average temperature that is real of area temperature controlling.

1.2.2 The automatic self-tuning of PID controller as a typical that was done by manual in some condition to slow for responsible. The artificial neural network is the best system to introduce for increase fastest responsible of PID controller by automatic tuning.

1.2.3 The speed controlling of motor compressor as a typical a motor compressor was operated by direct starting with full speed. The frequency for start stop was effect to life time of motor compressor and electric energy consume. The inverter is equipment to introduce for increase life time, save cost and save energy.

## 1.3 Objective

1.3.1 To design a detection system with temperature sensors and position feedback control systems with PID controllers.

1.3.2 To design control systems to tune the proportional, integral and derivative gain automated neural network.

## 1.4 Research Scope

The research scope of temperature control system with multiple temperature sensors to detect the position and PID controller combined with a neural network in this research, focusing on the big air. Requiring up to 120,000 BTU air conditioner the temperature sensor type is RTD (Resistance Temperature Detector) for measurement with PID controller to adjust the motor speed by VSD (Vary Speed Drive) to simulate the operation of the air conditioning system using neural networks to tune the error signal of PID controller. Using Software for simulation (MATLAB SIMMULINK) in the simulation compared with the old system and the new system offered by configuration errors no more than two degrees Celsius.

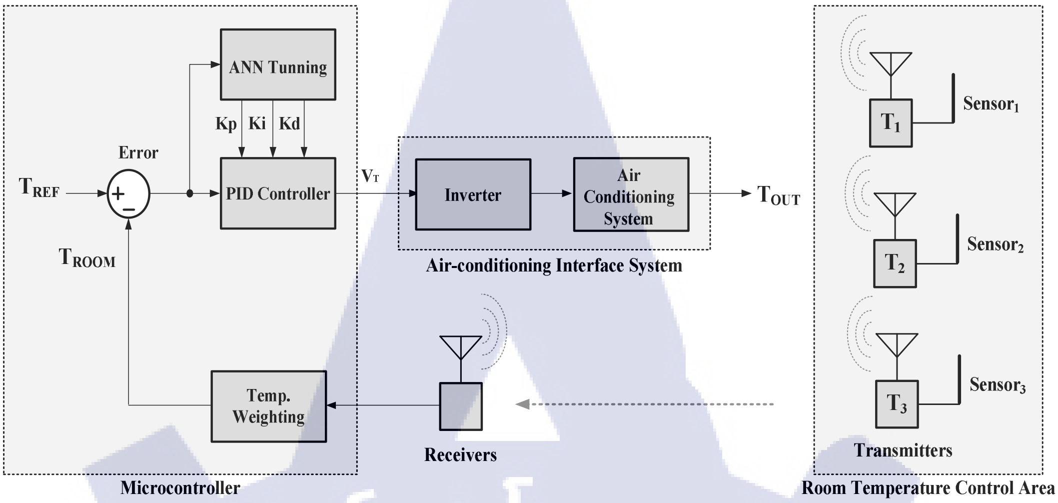



**Figure 1.1** Overall wireless multui-sensor industrial temperature control system.

## 1.5 Expected Outcome

1.5.1 To achieve the multi temperature sensor detection for PID feedback control system.

1.5.2 To achieve the automatic self-tuning of proportional, Integral and divertive time by neural network

1.5.3 Able applies this research to commercial air conditioner by control error temperature to meet set point, decrease maintenance cost and energy saving.

## 1.6 Definitions

1. The resistance thermometer RTD (Resistant Temperature Detector) is defined as a measure of temperature change principles to change the resistance of the metal of which the resistance will be the eye increases with temperature. The resistance of the metal rose is called. Positive temperature coefficient changes (Positive Temperature Coefficient) is the temperature of -270 to 850 ° C, which is popular metal used for metal and platinum RTD is specified, the PT and PT-10, PT-100

2. The Controlled (PID Controller) represents a feedback control system is used widely. Depends on three variables: the proportion, integral and derivative in which the PID. It is widely used in industrial control systems.

3. Inverter (Vary Speed Drive) refers to an electronic device used to control the speed. Of induction which is called Synchronous speed (Ns) = (120 * f) / P of the formula is that the translation of speed is the frequency (f) and the polarity of the motor (P), which basically induction motors are electrodes fixed. So, it is a device that acts VSD to adjust the speed to optimal.

4. Neural Network ANN (Artificial Neural Network) refers to a form of mathematics or computer simulation of the nervous system of the human brain. Learn Practice and decision making in command and control is a complex task.

5. MATLAB is advanced computer program (High-level Language) for technical computing that includes numerical computation. Complex graphics And replication to visualize the image is simple and clear name MATLAB stands for Matrix Laboratory original MATLAB program is written to use in the calculation of matrix or a matrix software which MATLAB is a program developed unceasingly. The program is easy to understand. And complex programming When put to use, and can see the results quickly. For this reason it makes MATLAB program has been used extensively in various fields.

# Chapter 2

# Related Theories and Literature Reviews

## 2.1 Introduction

This chapter concerns with the related theories and literature reviews. The related theories focus on the on off control system of air conditioner. The PID control system. The architectural of artificial neural network and the related of researching.

## 2.2 Related Theories

2.2.1 On – Off control

On-off control is perhaps the simplest type of feedback control strategy. The strategy is similar to that of a relay. The following equations define the output of on-off controller. The output of the controller 'Output when ON' if the controller is in the ON state 'Output when OFF' if the controller is in the OFF state. The below is on off control equation.

$$e = \mathrm{SV} - \mathrm{PV} \tag{1}$$

Where

$e$ : Error

SV : Set point variable

PV : Process variable

Figure 2.1and Figure 2.2 shows the behavior of control systems and air conditioning systems - off the air conditioning control is generally to be On-Off is when the actual temperature is below the desired Compressor was running and cutting. When the temperature is higher than the desired Compressor will be run again. This behavior, which will result in the value of the temperature control unstable. And frequency of the On-Off Compressor will result in renewal applications maintenance costs and energy consumption.

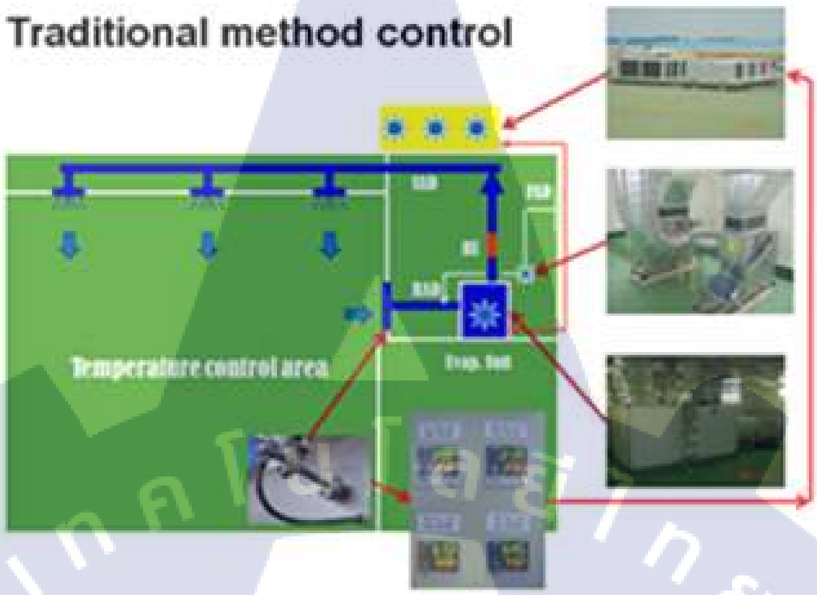



**Figure 2.1** Air conditioner system

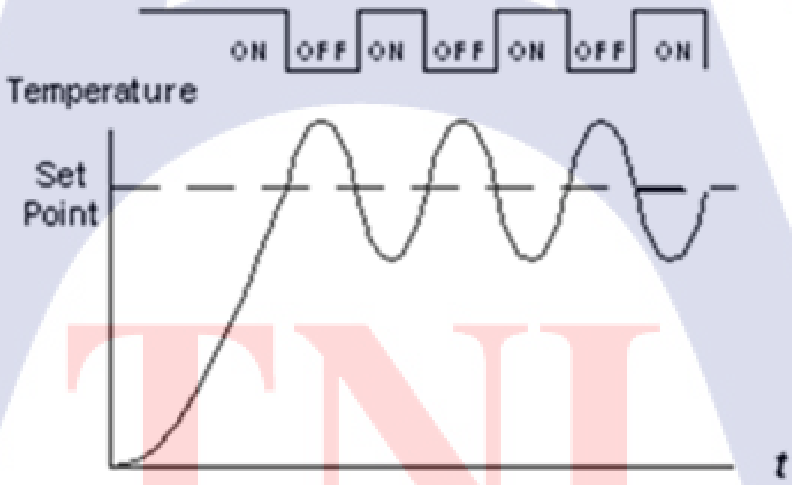



**Figure 2.2** On-off control pattern

<u>2.2.2 Proportional controller</u>

The proportional term produces an output value that is proportional to the current error value. The proportional response can be adjusted by multiplying the error by a constant $K_p$, called the proportional gain constant. The proportional term is given by:

$$Pout = Kpe(t) \tag{2}$$

A high proportional gain results in a large change in the output for a given change in the error. If the proportional gain is too high, the system can become unstable (see the section on loop tuning). In contrast, a small gain results in a small output response to a large input error, and a less responsive or less sensitive controller. If the proportional gain is too low, the control action may be too small when responding to system disturbances. Tuning theory and industrial practice indicate that the proportional term should contribute the bulk of the output change.

Because a non-zero error is required to drive it, a proportional controller generally operates with a steady-state error, referred to as droop. Droop is proportional to the process gain and inversely proportional to proportional gain. Droop may be mitigated by adding a compensating bias term to the set point or output, or corrected dynamically by adding an integral term.

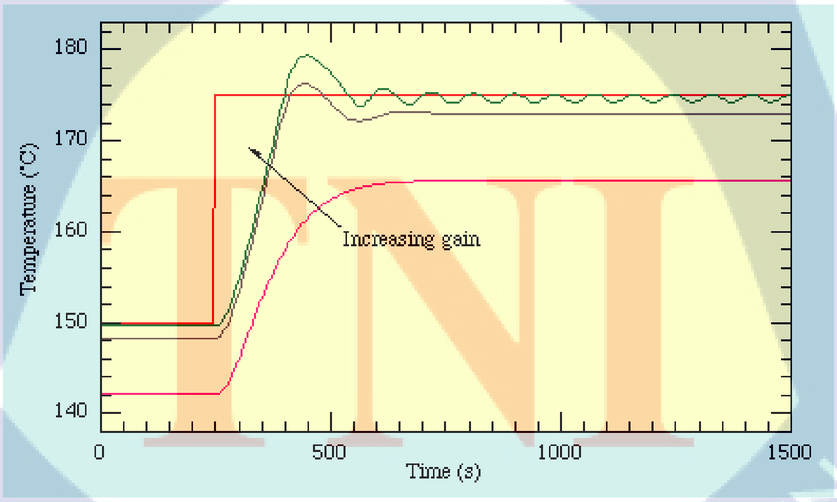



**Figure 2.3** Proportional control pattern

2.2.3 Integral controller

The contribution from the integral term is proportional to both the magnitude of the error and the duration of the error. The integral in a PID controller is the sum of the instantaneous error over time and gives the accumulated offset that should have been corrected previously. The accumulated error is then multiplied by the integral gain (Ki) and added to the controller output. The integral term is given by:

$$Iout = Ki\int_0^t e(t)dt \tag{3}$$

The integral term accelerates the movement of the process towards set point and eliminates the residual steady-state error that occurs with a pure proportional controller. However, since the integral term responds to accumulated errors from the past, it can cause the present value to overshoot the set point value (see the section on loop tuning)

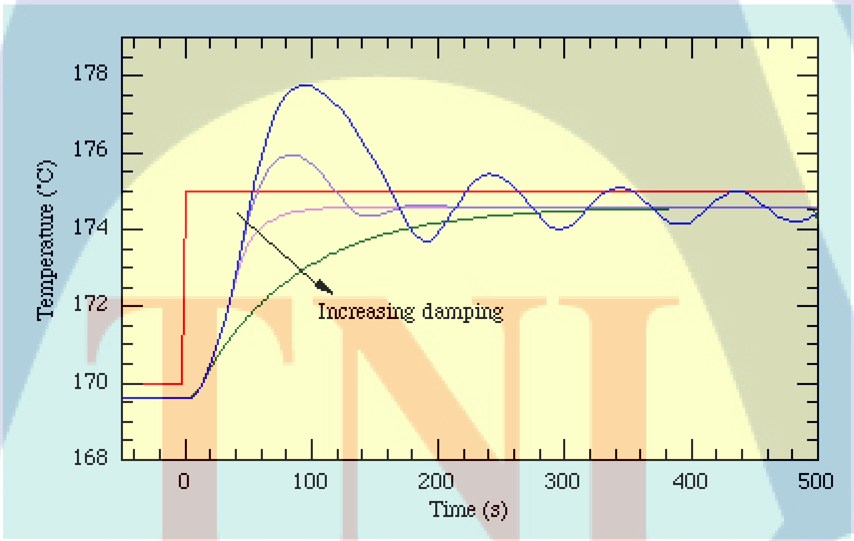



**Figure 2.4** Integral control patterns

2.2.4 Derivative controller

The derivative of the process error is calculated by determining the slope of the error over time and multiplying this rate of change by the derivative gain Kd. The magnitude of the contribution of the derivative term to the overall control action is termed the derivative gain, Kd. The derivative term is given by:

$$Dout = Kd \frac{d}{dt} e(t) \tag{4}$$

Derivative action predicts system behavior and thus improves settling time and stability of the system.

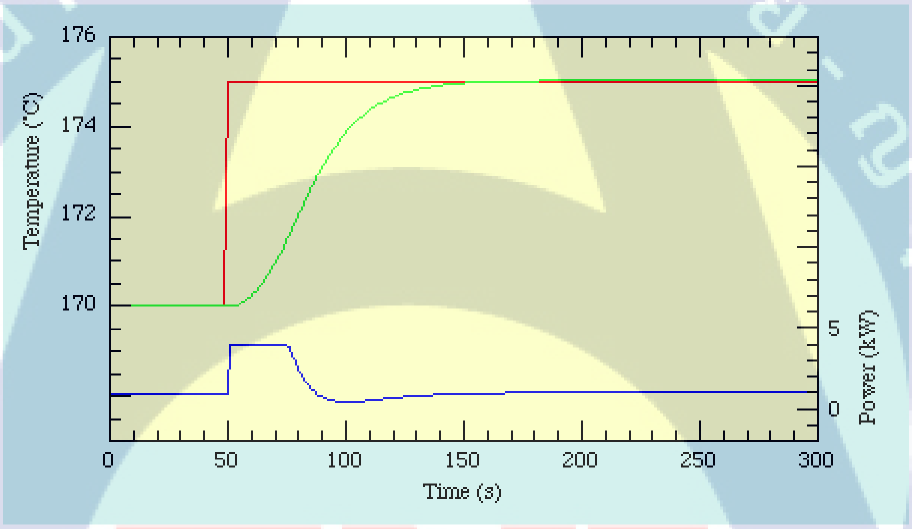



**Figure 2.5** Derivative control pattern

2.2.5 Proportional Integral and Derivative controller

Proportional integral derivative controller (PID controller) is a generic control loop feedback mechanism (controller) widely used in industrial control systems. A PID controller calculates an "error" value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process control inputs.

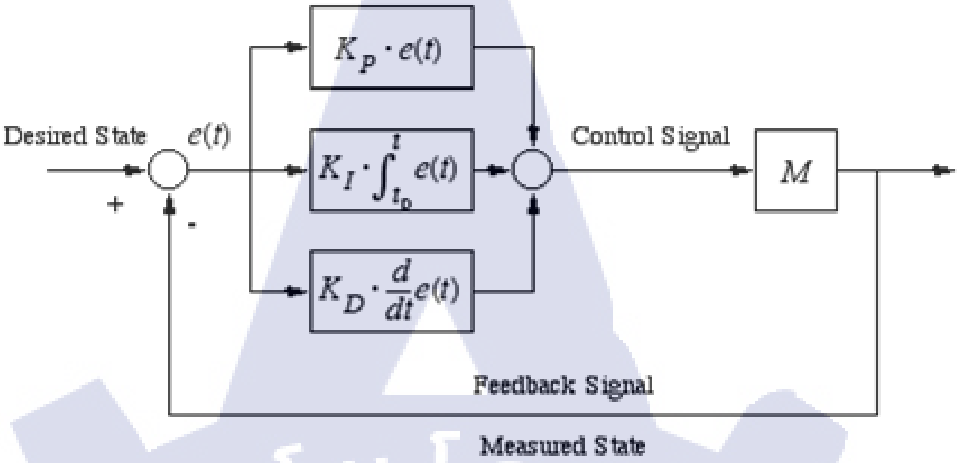



**Figure 2.6** PID control box diagram

The proportional Integral and Derivative is given by equation below.

$$u(t) = MV(t) = Kpe(t) + Ki \int_{0}^{t} e(\tau)dt + Kd \frac{d}{dt} e(t) \qquad (5)$$

Where

*Kp* : Proportional gain, a tuning parameter

*Ki* : Integral gain, a tuning parameter

*Kd* : Derivative time, gain, a tuning parameter

*e* : Error = SV-PV

*t* : Time or instantenousu time (the present)

τ : Variable of integration, take on values from time values 0 to the present *t*

The PID controller calculation algorithm involves three separate constant parameters, and is accordingly sometimes called three-term control: the proportional, the integral and derivative values, denoted P, I, and D. Heuristically, these values can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve, a damper, or the power supplied to a heating element.

In the absence of knowledge of the underlying process, a PID controller has historically been considered to be the best controller. By tuning the three parameters in the PID controller algorithm, the controller can provide control action designed for specific process requirements. The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the set point, and the degree of system oscillation. Note that the use of the PID algorithm for control does not guarantee optimal control of the system or system stability.

Some applications may require using only one or two actions to provide the appropriate system control. This is achieved by setting the other parameters to zero. A PID controller will be called a PI, PD, P or I controller in the absence of the respective control actions. PI controllers are fairly common, since derivative action is sensitive to measurement noise, whereas the absence of an integral term may prevent the system from reaching its target value due to the control action.

2.2.6 Neural Network

2.2.6.1 Principle

Neural network or often referred to as a neural network. Is one of the techniques of data mining the mathematical model for information processing and computing applications connector zionists to simulate the performance of neural networks in the human brain with the objective to create a tool which is capable of learning, pattern recognition and the creation of new knowledge as well as the capabilities of the human brain. The initial concept of this technique is derived from the study of biological electricity network. In the brain, as shown in Figure 2.5, which consists of nerve cells or "neurons" and "synapses" Each neuron consists of a tip on how to get the nerve called "dendrites" as input and late delivery nerve called "an Amazon", which is like the output of cells activated by electrochemical reactions. When stimulated by an external stimuli or stimulating cells together. Nerve runs through the dendrites to the nucleus, which will determine the need to stimulate other cells or not enough nerve. Nucleus, it will stimulate other cells through its hidden action. Most researchers agree that the present neural network has a structure different from the network in the brain. But I still like the brain In the sense that the neural network. Is the integration of the processor sub- parallel and this connection is the major cause of network intelligence. Considering brain size is larger than the neural network significantly. Including neurons are more complex than subunits network. However, an important function of the brain, such as learning, can still be easily simulated by this neural network

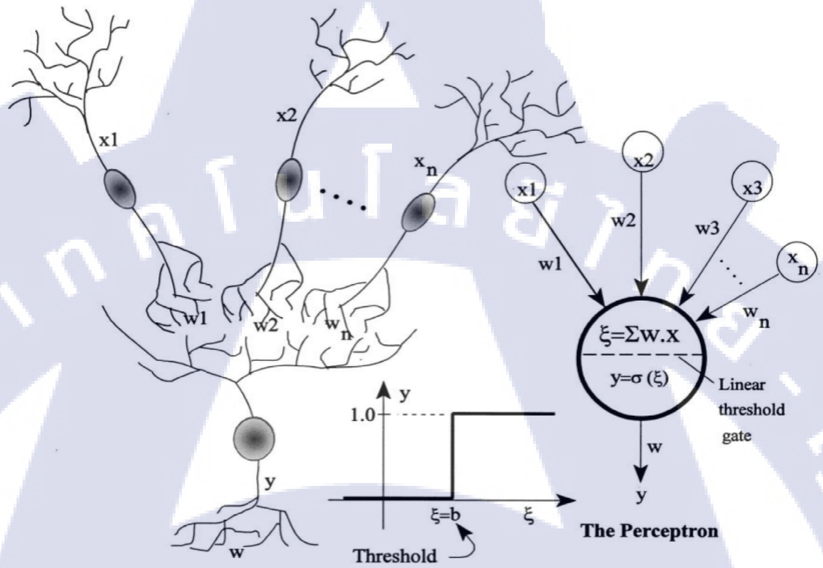



**Figure 2.7** Neurons and the simulation of mathematical models.

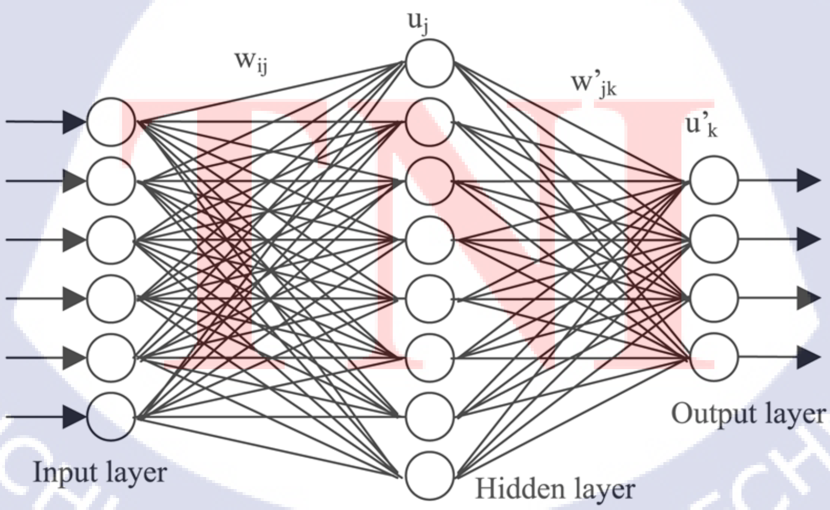



**Figure2.8** Architecture reverse the spread of neural networks.

2.2.6.2 Architectural and functional

For computer Neurons consist of input and output as well as simulation input, each with a weight determines the weight of the input by neuron, each unit will have a threshold value determines the total weight of input to how much you can send the output to when the neuron to other neurons, each unit together to collaborate in this work, it is the same as the logical reaction that occurs in the brain. Only on the computer, everything is numbers only. The performance of the Neural Networks is when input into the network, it took input multiplied by the weight of each leg, the result of input every leg of the neuron to put them together, then compare with threshold defined if the sum. is greater than threshold then it sends output to the output neuron will be sent to the input of the other neuron connections in the network, if the value is less than the threshold, it will not be output. It is important for us to know the weight and threshold for what we want to make the computer recognized. Which is the Uncertain I can set the computer to adjust those values by teaching it to recognize the pattern of what we want to give it recognition called "back propagation" which is the reverse process of recognition for training feed-forward Neural Networks with the use of those algorithms . Back-propagation In order to improve weight points of the network. (Network Weight) After inserting the data model for training the network each time it is received (output) of the network is compared to the expected results. Then calculate the error which the error is being sent back into the network to modify the weight ratings.

Learning for neural networks. There are two types Supervised Learning or learning to teach. It is the class that has the answers to the neural network adaptation. The data of teaching neural networks will have the answers you'll verify that neural networks provide the right answer or not answer incorrectly, neural network, it adapts itself to provide an answer, the better. This is Unsupervised Learning without teaching or learning. The study recommended no there is no right or wrong answer. Neural networks are organized according to the nature of the data structure itself. The results of neural networks are able to categorize of the data.

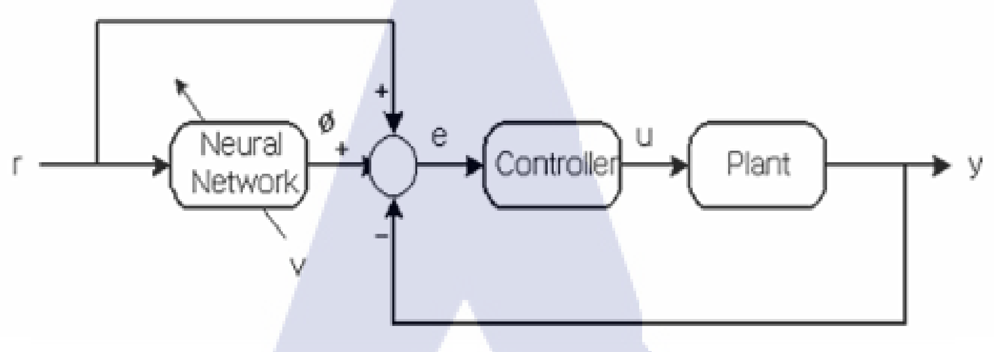



**Figure 2.9** Control box diagrams

The figure 2.9 show the design of configuration control system. The designing system consist of process plant, controller and neural network by the function whenever process have change the controller will respond and suddenly take action by send the control signal to adjust the process to be as controlling target. Anyway the respond time control is depend on the accuracy of turning system of PID controller. The neural network is one of system witch high performance for utilization for automatic tuning of PID controller.

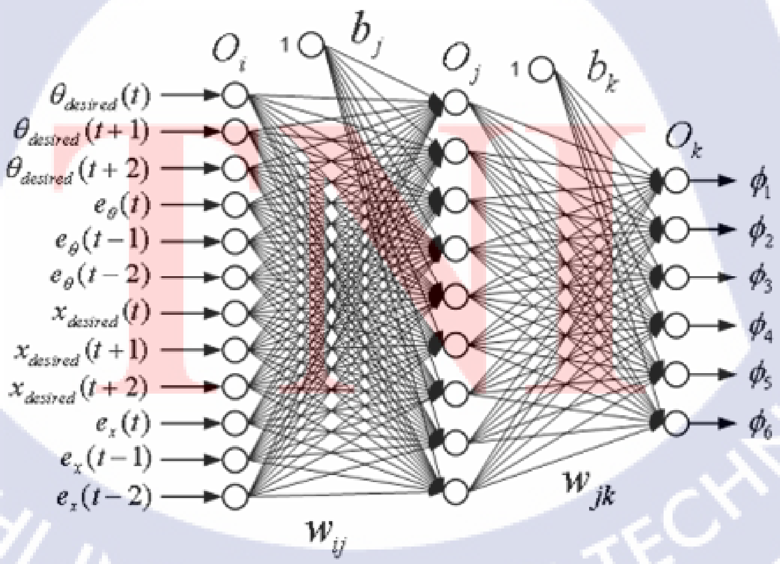


**Figure 2.10** Architecture reverse the spread of neural networks

Figure 2.10 show the  design of neural netwok control system. The designing system consist of input process layer, hidden layer and output layer. The quantity of each layer depend on the purpose of utilization and accuracy.

**Table 2.1** Research on the neural network controller and PID controller.

| **Items** | **Related Research** | **The Techniques Presented In This Research.** |
|---|---|---|
| [1] | Man Gyun Na (2001) | Auto Tuned PID Controller Using a Model Predictive Control Method for the Steam Generator Water Level |
| [2] | Sung-Su Kim; and Seul Jung (2006) | Hardware Implementation of a Neural Network Controller an MCU and an FPGA Nonlinear System. |
| [3] | Jin Woo Moon;Sung Kwon Jung; and Jong- Jin Kim  (2009) | Application of ANN (Artificial Neural Network in Residential Thermal Control |
| [4] | Xuepeng Liu; Dongmei zhao;and Jianxin Wu (2009) | Frequency Variable Air Conditioner Controller Using Neural Network |
| [5] | Woo-yong Han; Jin-wook Han; and Chang-goo Lee (1999) | Development of a Self-tuning PID Controller based on Neural Network for Nonlinear Systems |
| [6] | Leila Fallah Araghi; M. Habibnejad Korayem; Amin Nikoobin; and  Farbod Setoudeh (2008) | Discrete PID Controller Tuning Using Piecewise-Linear Neural Network |
| [7] | Petr Dolezel; Ivan Taufer; and Jan Mares (2012) | An artificial neural network approach of load frequency control in a multi area interconnected power system |
| [8] | V.Shanmuga Sundaram; and T.Jayabarathi (2011) | Application of ANN (Artificial Neural Network in Residential Thermal Control |
| [9] | Neerparaj Rai; and Bijay Rai (2013) | Neural Network based Closed loop Speed Control of  DC Motor using Arduino Uno. |

## 2.3 Literature Reviews

Table 2.1 summarizes research on the neural network controller and PID controller which has a total of twenty first trials. Be seen from the table that the development of design in two areas: the use of neural network function mimics PID controller and the neural network that works with PID control. However, these studies focused on the control of General Motors. But research in the outline aspects of this research project is primarily focused on temperature detection.

Man Gyun Na (2001) [1] proposed to control the gain of the PID controller of automated control over model (model predictive control) was the first attempt to find out the techniques of automatic control are also covered. in the control boiler industry , which is the fourth model of the functional test is found. The system can automatically control itself well. And the gain of the PID controller works automatically.

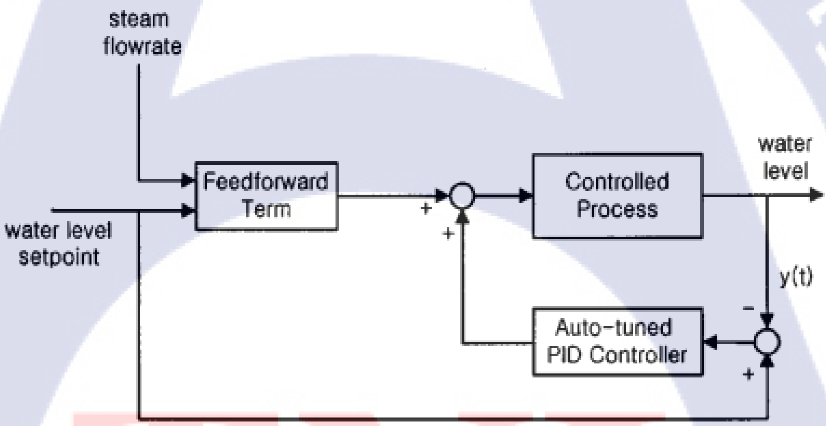



**Figure 2.11** Control box diagrams with MPC.

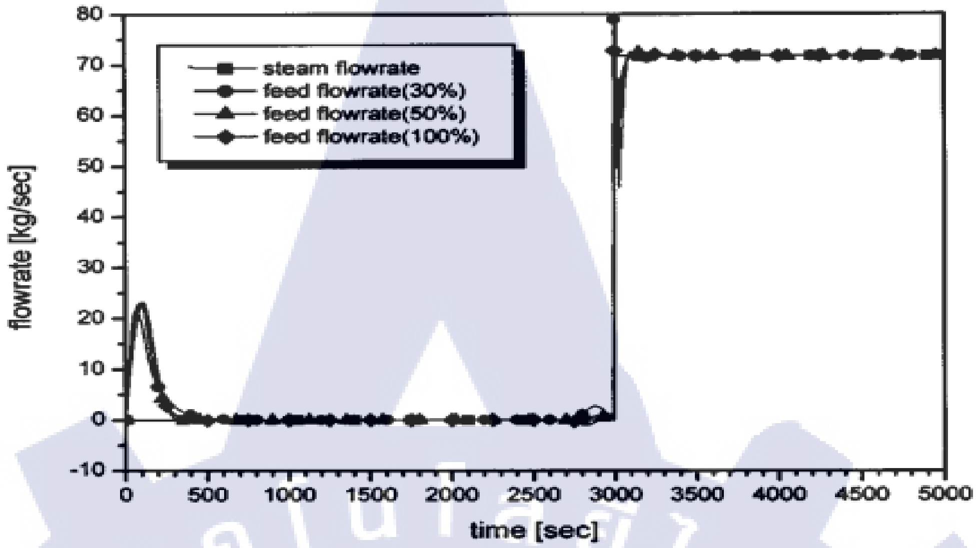



**Figure 2.12** Performance of model predictive control

Figure 2.12 Show the result of performance control of water feed flow rate to nuclear steam generator that propose model predictive control to auto tuning PID. The system was success to stable feed flow rate from 30- 100 percent. In order to steam load profile changing.

Sung-Su Kim; and Seul Jung (2006) [2] has proposed the creation of an artificial neural network controller, which can mimic the functionality of the PID controller. Such a design creates during normal operating conditions as a reference. For teaching neural networks. After that, the technology has developed, F. PGA. to test and control the motion of the pendulum. The control is very good and has a few errors


**Figure 2.13** Control box diagrams purposed by  Sung-Su Kim

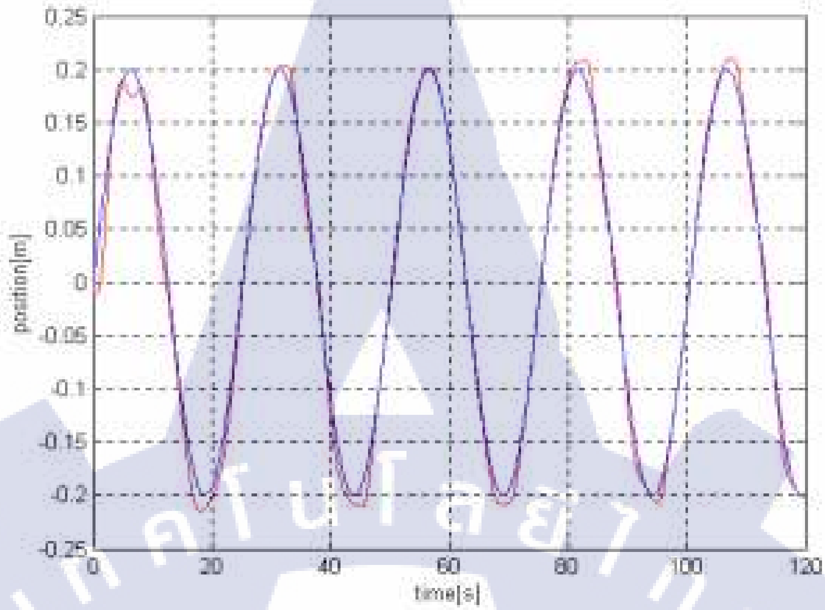



**Figure 2.14** Position tracking of the cart of a sinusoidal trajectory tracking task

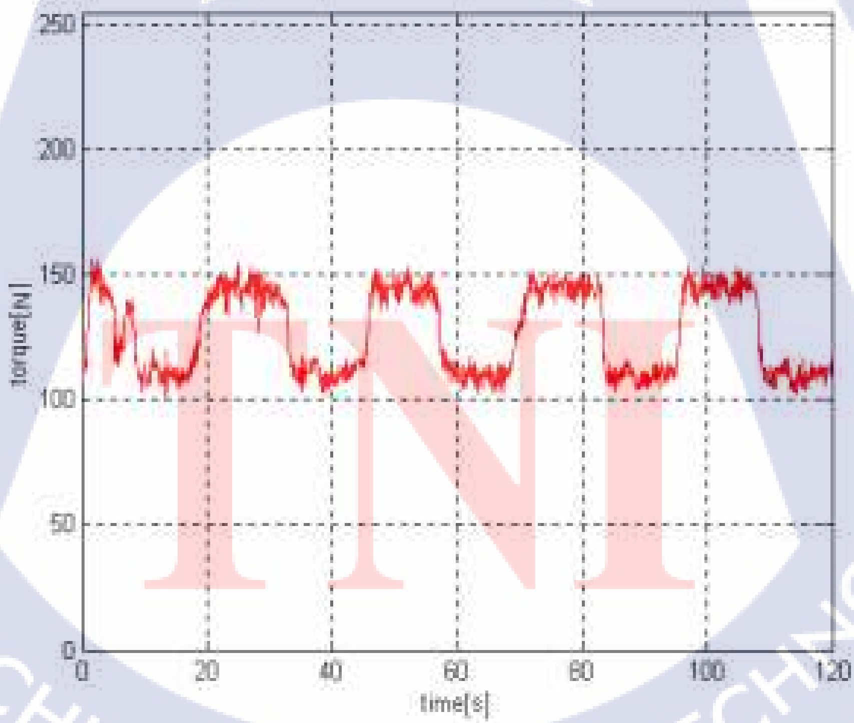



**Figure 2.15** Control torque of the cart of a sinusoidal trajectory tracking task

Figure 2.14 and 2.15 Show the results of performance control of balance position tracking of pendulum inverted by maintain the angle error by minimize overshoot and torque control was much smoothly.

Jin Woo Moon; Sung Kwon Jung; and Jong- Jin Kim (2009) [3] proposed the use of neural networks to generate strategic control systems to predict the heat inside the building. Neural networks can be simulated with MATLAB Simulink Promotion Department of the simulation showed that three vehicles to reduce energy consumption as well.

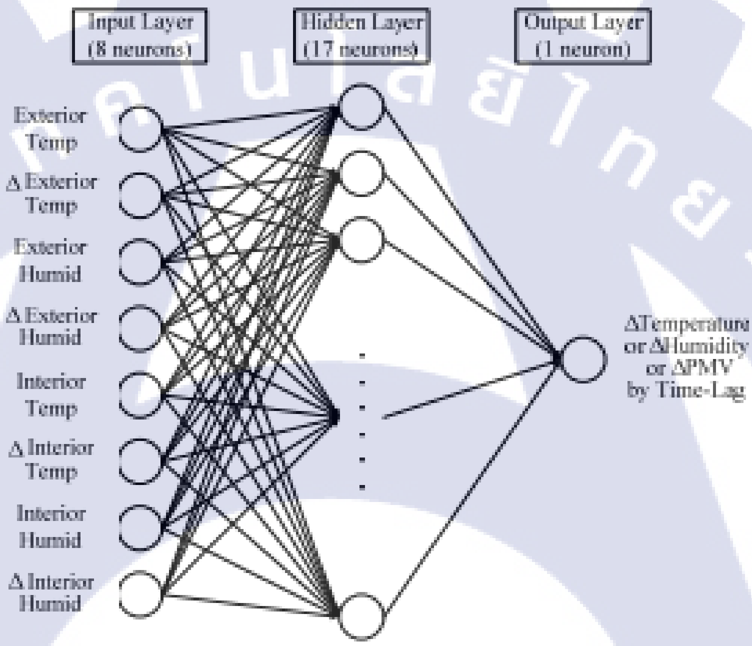



**Figure 2.16** Structure of ANN models

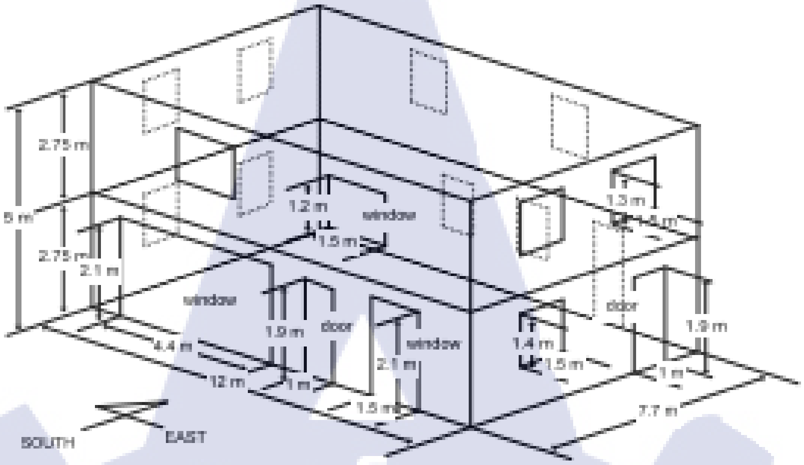



**Figure 2.17** View of a target building

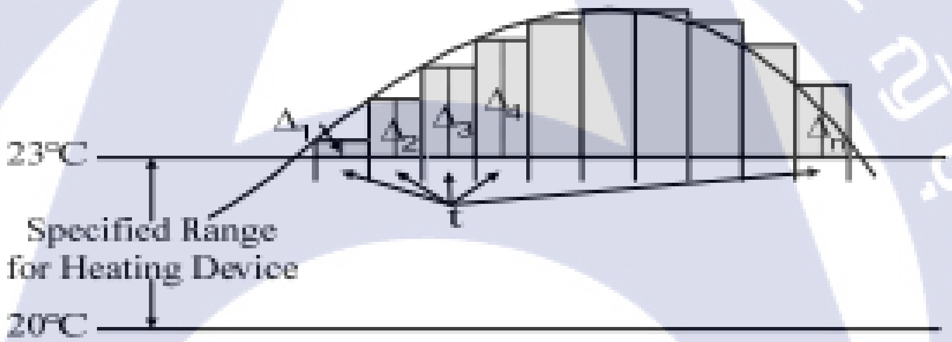



**Figure 2.18** Magnitude of overshoot of air temperature

Figure 2.18 Show the magnitude of a control system overshoots or undershoots can be measured by a combination of two factors: the duration time (t) and the degree (Δ) of overshoots or undershoots. The multification of these two factors (Δ × t) will indicate the magnitude of over- or under-shoots as in Equation 3. Figure 6 exemplifies it for overshoot of air temperature using the shadowed area. The magnitude of shoots out of specified range by each control logic was compared for air temperature, humidity, and PMV. Units were °C×minutes, %×minutes, and PMV×minutes, respectively.

Xuepeng Liu; Dongmei zhao;and Jianxin Wu (2009) [4] have presented research. "Frequency-variable air conditioner controller using neural network" in 2009, which technique is presented. Variable frequency air conditioning control using neural networks . The neural network is presented over three floors with the top floor has two inputs, hidden layer and output layer one for the class. Function tests showed Can be controlled online with good performance And a current of 6.7 amps

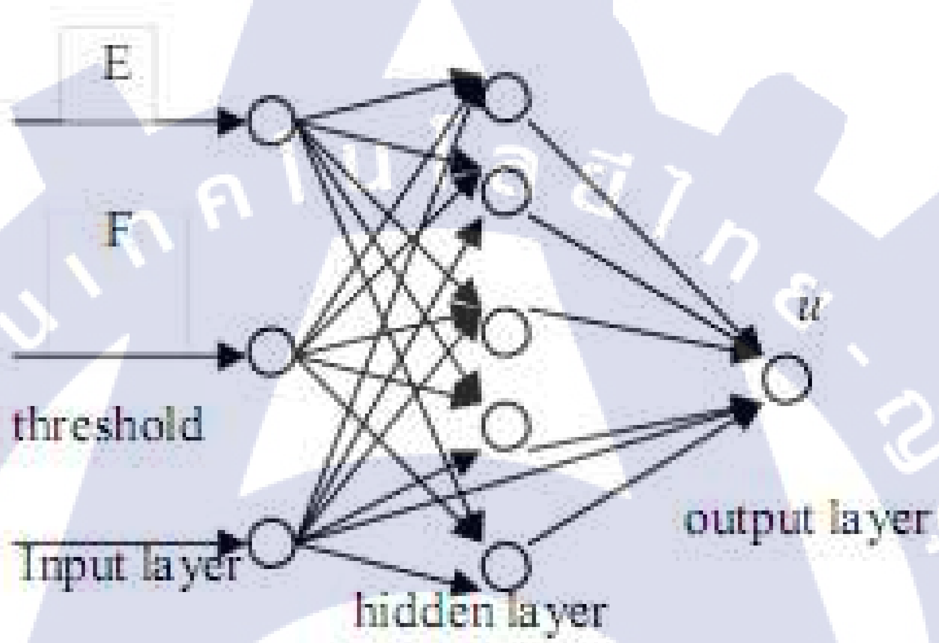



**Figure 2.19** Structure of ANN models  purposed by Xuepeng Liu (2009)

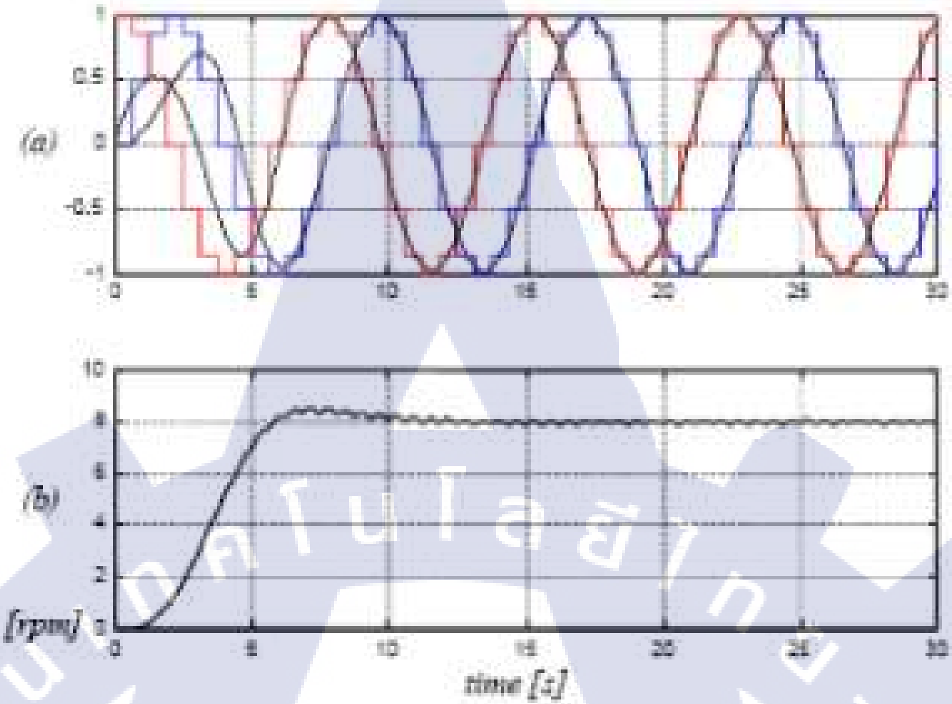



**Figure 2.20** Performance control of neural work controller

Figure 2.18 Show performance control of neural network controller with mathematical model is illustrated. The fuzzy model is deducted from weighted factor. For fuzzy model, a neural network for frequency variable air conditioner is presented based on cost function. The experimented and simulation and demonstrated that the controller has good performance.

Woo-yong Han; Jin-wook Han; and Chang-goo Lee (1999) [5] porposed to develop a fast tracker for time-varying nonlinear systems which previous knowledge (i. e., dynamic equations) about the plant were not known. In order to carry out this research goal, this paper suggests a novel error self-recurrent neural networks, and develops a fast on-line learning algorithm by using the recursive least squares method. The new neural networks are considerably faster than the backpropagation algorithm and have advantages of being less affected by poor initial weights and learning rate. Nonlinear adaptive PID controller based on these neural networks has been derived and tested for the fast tracking problem in a robot manipulator.

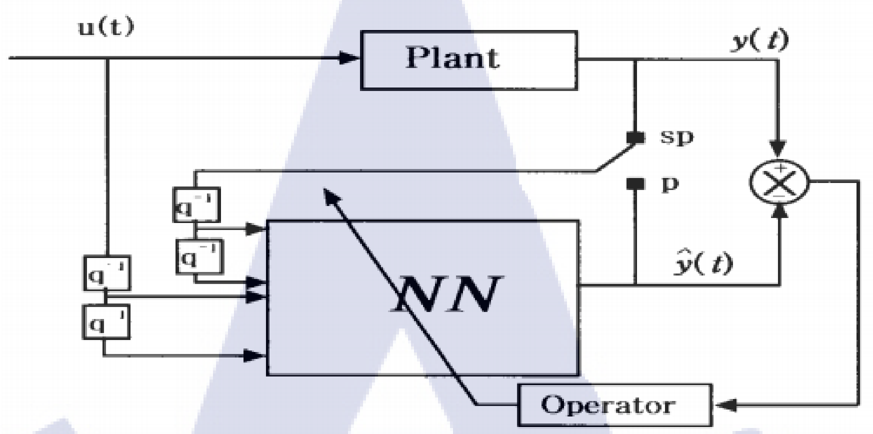



**Figure 2.21** Identification methods for dynamic systems

Figure 2.21 show computer simulation of the system identification has been done for the performance analysis of the new learning algorithm and the error self-recurrent neural networks. As shown in Figure 2.19 the time delayed plant output and the control input are connected to the input layer for the dynamic system identification using multilayer feed forward neural networks.

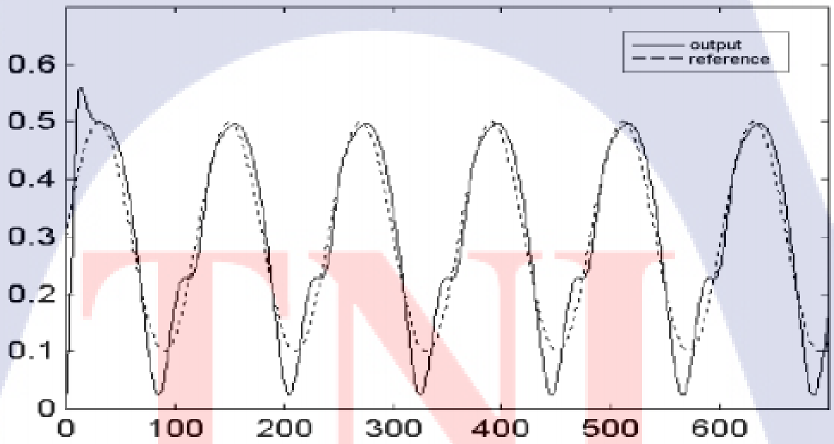



**Figure 2.22** Control response by ER neural networks based PID controller

Figure 2.20 show the performance of PID controller by using the error recurrent neural networks, and also got a good result in the case of robot manipulator experiment. Future research is to prove ER neural model convergence and the controller design based on the multilayer ER neural network model.

Leila Fallah Araghi; M. Habibnejad Korayem; Amin Nikoobin; and Farbod Setoudeh (2008) [6] purposed new method for the control of two link- robotic manipulator systems using Neural Network has been presented, The first method is based on Proportional-Derivative controller, The second method is based on Proportional-Integral-Derivative controller, the third method is based on artificial Neural Network by PD controller, and the forth method is based on artificial Neural Network by PID controller for control of two link- robot.

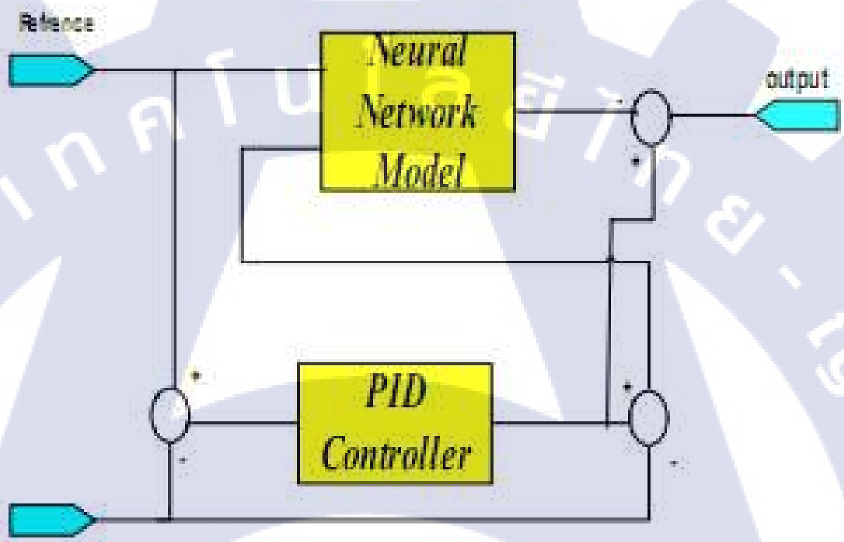



**Figure 2.23** The structure of the Neural Network controller

Figure 2.23 show the neural network model predicts the plant response over a specified time horizon. The Neural Network controller based on PD controller has been used for control of two link- robotic manipulator systems. The block diagram of a Neural Network controllers based on PD controllers.

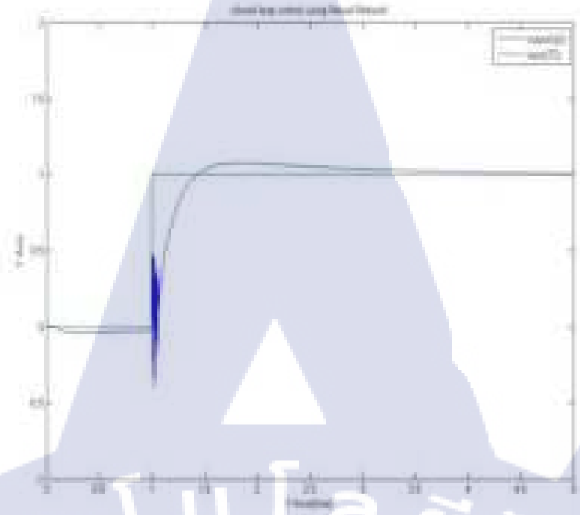


**Figure 2.24** The output of two link- robotic manipulator systems using Neural Network controller based on PID controller

Figure 2.24 show the control of Two link- robotic manipulator systems, The first method is based on Proportional-Derivative controller, The second method is based on Proportional-Integral-Derivative controller, and the thirth method used artificial Neural Network by PD controller, and the forth method used artificial Neural Network by PID controller for control of Two link- robotic manipulator systems.

Petr Dolezel; Ivan Taufer; and Jan Mares (2012) [7] purpose automatic tuning or continuous adaptation – and continuous adaptation of PID controller via neural model of controlled system (which is considered to be significantly nonlinear) is the aim of this contribution. Artificial Neural Networks have traditionally enjoyed considerable attention in process control applications, especially for their universal approximation abilities. In next sections, there is to be explained how to use artificial neural networks with piecewise-linear activation functions in hidden layer in controller design. To be more specific, there is described technique of controlled plant linearization using nonlinear neural model. Obtained linearized model is in a shape of linear difference equation and it can be used for PID controller parameters tuning.

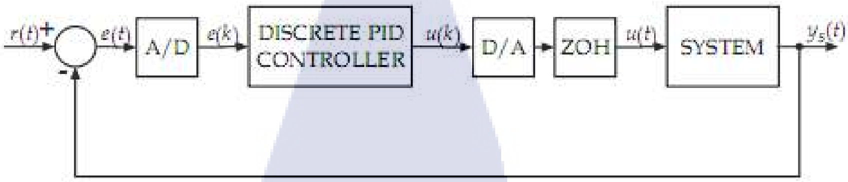



**Figure 2.25** Feedback control loop with discrete PID controller

Discrete PID controller computes output signal only at discrete time instants k·T (where T is sapling interval and k is an integer). Thus, conventional control loop has to be upgraded with zero order hold (ZOH), analogue-digital converter (A/D) and digital-analogue converter (D/A) – see Fig. 3 (k·T is replaced by k for formal simplification).

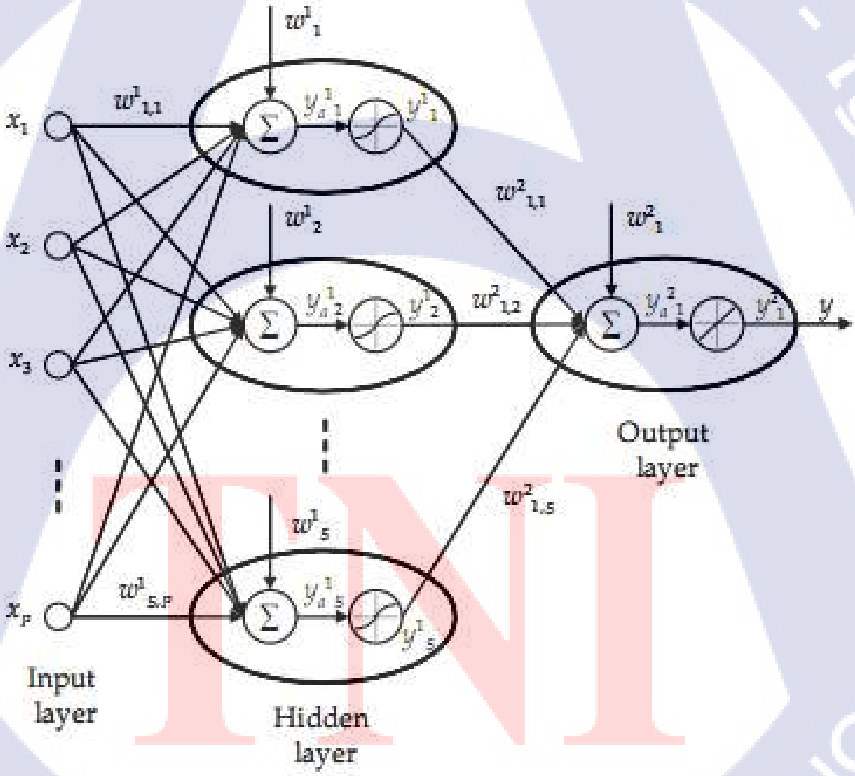



**Figure 2.26** Structure of ANN models purposed by Petr Dolezel (2012)

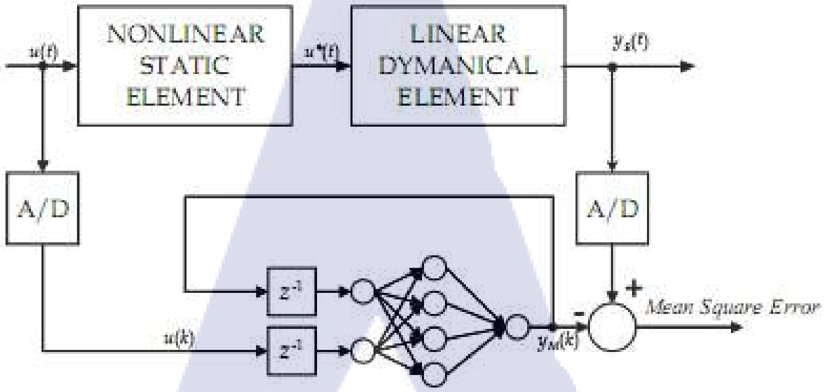



**Figure 2.27** Structure of ANN and box diagram

There is introduced the technique above, which performs continuous adaptation of PID controller via neural model of controlled system. Neural model is used for controlled system continuous linearization and that linearized model is used for discrete PID controller tuning using pole assignment. The technique is suitable for highly nonlinear systems control, while it brings no advantages to control of the systems which are close to linear ones.

V.Shanmuga Sundaram; and T.Jayabarathi (2011) [8] purposed the Artificial Neural Network ( ANN) is applied to self tune the parameters of Proportional-Integral-Derivative(PID) controller. The single, Two Area non-reheat system has been considered for simulation of the proposed self- tuning ANN based PID controller. The simulation works developed by MATLAB- SIMULINK Environment. The simulink results are obtained by qualitatively and quantitatively .The qualitative comparison is used for the Integral Square Error (ISE), Integral Absolute Error (IAE) and Integral Time Absolute Error (ITAE) is minimized in single and multi area power system. Therefore the Comparison of responses with conventional integral controller(PI) & PID controller show that the neural-network controller (ANN-PID) has quite satisfactory generalization capability, feasibility and reliability, as well as accuracy in both single and multi area power system.

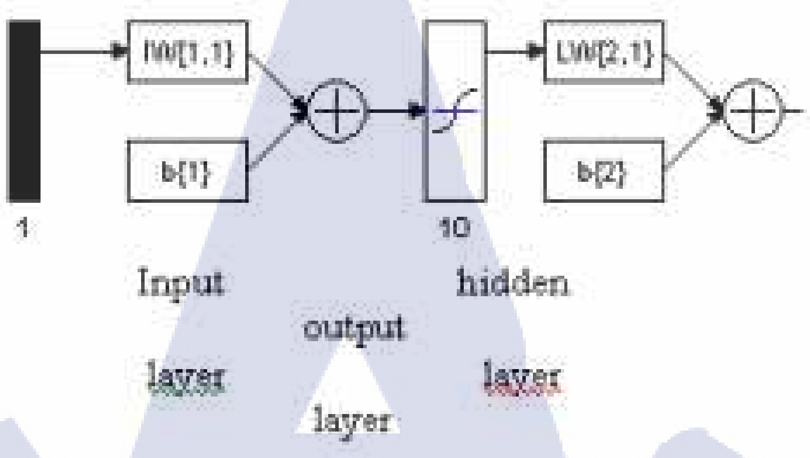



**Figure 2.28** Neural network for the design of ANN based PID controller

In the neural network developed figure 2.28 TANSIG is employed as transfer function in the hidden layer and PURELIN in the output layer. Then the obtained weights and biases are chosen as the initial weights and biases.

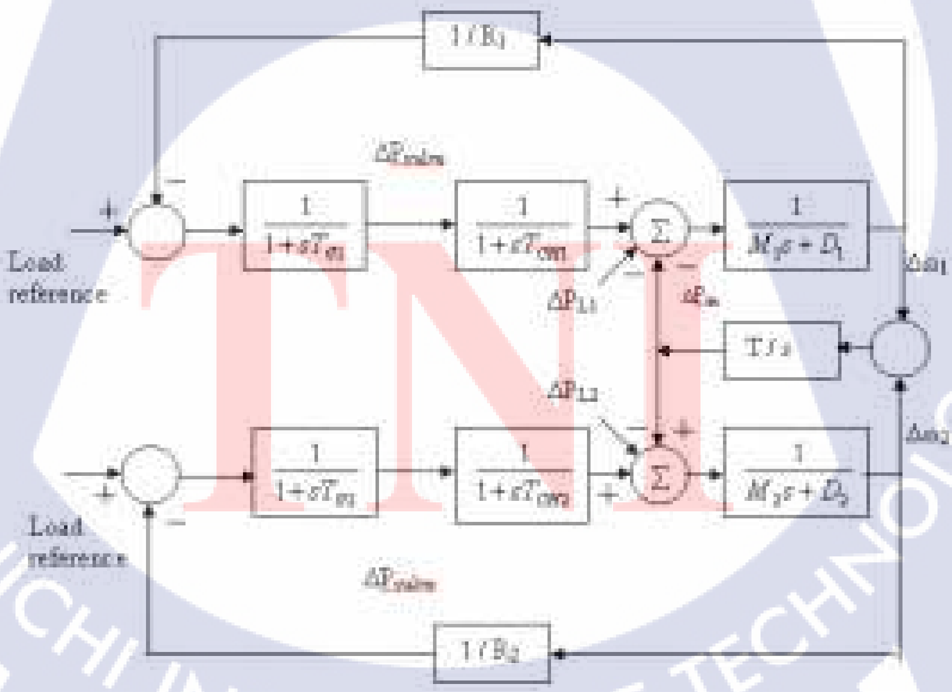



**Figure 2.29** Block diagram of inter connected areas Tie-Line Control

A complete block diagram representation of isolated power system comprising turbine, generator, governor and load is obtained by combining the block diagram of individual components. The block diagram with feedback loop is as shown in figure 2.29

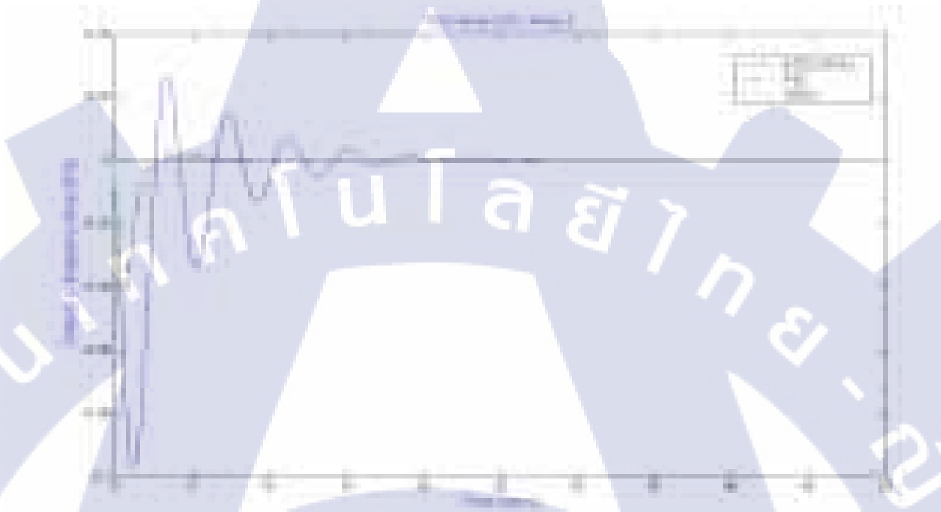


**Figure 2.30** Simulation of Two area system in Area 2

From the simulation results obtained for load disturbances for ANN controller, PID controller, Conventional integral controller we can conclude that ANN controller is faster than the other, Peak undershoot is reduced, Settling time is reduced. The superiority of ANN controller is established in the cases of two area systems. From the Qualitative and Quantitative comparison of the results we can conclude that the ANN controller yields better results. ANN controller gives minimum IAE/ISE/ITAE compared to the conventional integral and PID controllers.

Neerparaj Rai; and Bijay Rai (2013) [9] purposed the design and build of a DC motor speed control using PID and neural network. The design process reference model for teaching neural networks which is structured over backward. A story or two story and one output layer. Motor speed is controlled by the width of his themes France. Interoperability of control PID and neural network can provide better control for. Test runs on simulated MATLAB / Simulink R2009b and experimentation with microcontrollers actually created.

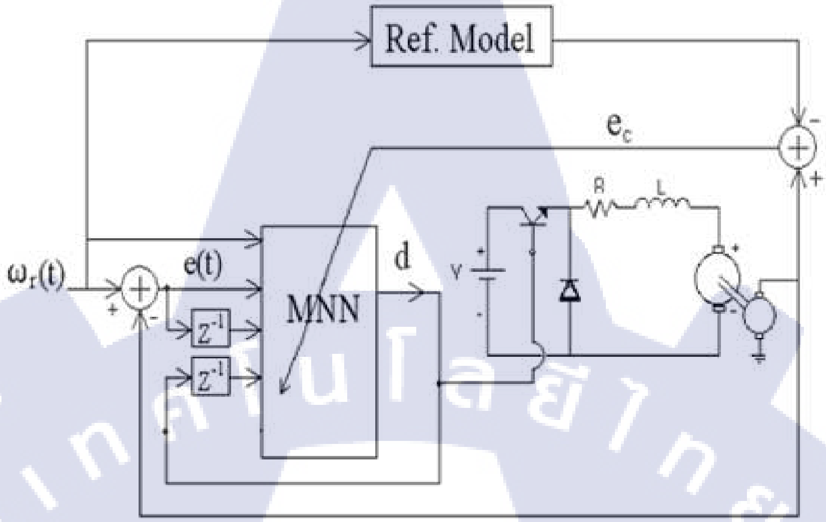



**Figure 2.31** Architecture reverse the spread of neural networks

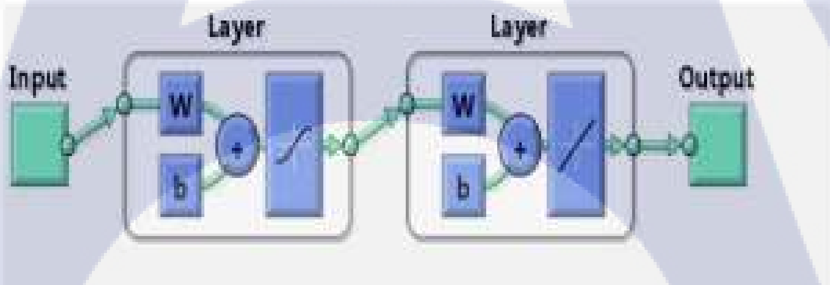



**Figure 2.32** Architecture of the proposed ANN controller in MATLAB Simulink.

Figure 2.32 show the network is trained for 500 second applying a 0.2 Hz square wave to the reference model. The load was 10gm-cm during training. The architecture of the proposed ANN controller in MATLAB Simulink

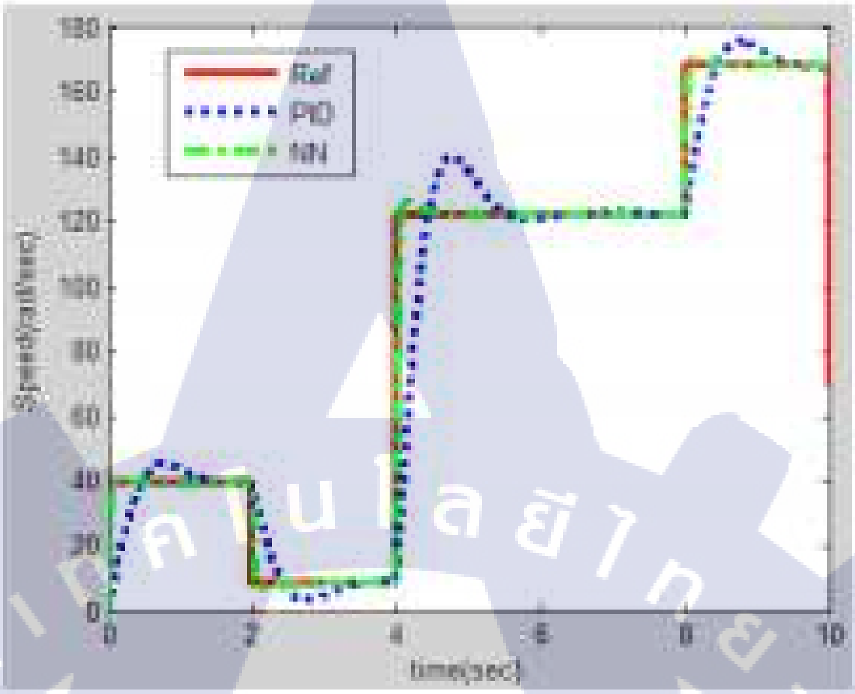



**Figure 2.33** Regulation of DC Motor speed with ANN and PID.

Figure 2.33 shows the regulation of speed at different levels for both conventional PID control method and ANN control. Maximum overshoot is more in case of PID control which is 16.7% compared to 5.8% in case of ANN control. Motor takes a longer settling time of 1.3 sec for PID control whereas the motor takes only 0.2 sec with ANN control. To implement the neural controller in Arduino, 278 training samples were obtained out of which 10% each was used for validation and testing and rest 80% for training.

# Chapter 3
# Research Methodology

## 3.1 Introduction

This chapter presents the research methodology for implementation process of this research. The research establishes procedures and processes as follows.

## 3.2 Overall Research Processes

3.2.1 Reviewing related research papers and studies

The first for research is the study and review of past research of IEEE explorer, and Science Direct databases is relevant to ensure that the research that is being done is not a repeat. And the research that is done, then the work is outstanding and has been using technology to achieve innovation. And can be made into actual production. Detailed study of the literature of the past. The objective will be to cover the entire system, including experimental design, data collection, analysis and interpretation of results, including the possibility of further development in the future.

3.2.2 Designed to install a temperature sensor. Controls and Adjustable To provide the measurement parameters. And collect data for analysis Designing, installing the right equipment is essential, as the following devices.

3.2.2.1 Installation location Temperature must be measured at the point representing the average temperature of the area. The main idea is Conductivity measurements of each point are averaged across the room and sent to the controller to operate.

3.2.2.2 PID temperature controller must be installed in the proper location and input correct parameters to control the movement.

3.2.2.3 The speed adjustment selecting the appropriate power to prevent overload while the motor and setting parameters.

3.2.2.4 The installation of measuring devices for use in energy storage for energy analysis.

.

3.2.3 Designed to customize the PID control with the neural network.

The system design, customization PID control is done using neural networks. It started to be designed.The neural network learning from receiving the signal and decided to leave in order to adjust the gain of the PID controller. Which is designed to make the two systems work together efficiently then it is the end of it. Designing neural network such a feed forward neural cells, regardless of the layers. Input layer, called the input. Reply layer that produces the network output layer called the other layers to help with the process, called the hidden layer and the error value able to except.

3.2.4 Provide tools and equipment for research.

Tools and equipment used in research can be classified into the following types. Measurement equipment used to store data. Equipment used to control the tool used to simulate the movement and storage.

3.2.4.1 Temperature and humidity sensor model DHT11 to measured room temperature and send signal analog to wireless transceiver.

3.2.4.2 Temperature wireless transceiver model nRF24L01 to receive analog signal from sensor and then processed to micro controller.

3.2.4.3 Micro controller model Arduino Uno R3 to received analog signal from transceiver and processed output analog signal to inverter.

3.2.4.4 Vary speed drive (VSD) model VF-nC3 to received analog signal from micro controller and processed output signal to adjusted speed of AC motor.

3.2.4.5 Induction motor (AC motor) model SK-220VAC to transmit power to drive compressor.

3.2.4.6 MATLAB Simulink is a tool used in the simulation process instead of working or instead actually to perform comparison and data analysis.

## 3.3 Data collecting and summarization

The data collecting of the research done by measuring and recording the temperature data was recorded by controller. The results of the speed control by VSD device for measuring. The energy that is used for measuring and recording by power meter. Graphs and parameters of the simulation are stored and collected MALLAB Simulink.

## 3.4 Data Analysis Methods

3.4.1 To perform grouping of data such as the default of data have been excluded from the trial. For example the position of the thermometer. The temperature before the experiment

3.4.2 To prepare a data table that is a primary or a primary translation tables or variables to be adjusted according to error prevention, for example to configure speed each point. To find the savings after manipulating.

3.4.3 Upon completion of the trial. The adoption of simulation by actual experiment by MATLB analysis. The prudent to consider of sources, units of measure must be the same unit. Also the environment to make the analysis is accurate and reliable.

## 3.5 Conclusions

This chapter has presented the research methodology for the development of a multi sensor temperature control system through a neural network base self-tuning PID controller. Including the overall research processes, data collecting and summarization, research tools, data analysis methods and research procedures.

# Chapter 4

# Research Results

## 4.1 Introduction

This chapter presents the research results for a An Intelligent Wireless Mulit-Sensor Temperature Control System using a Self-Tuning PID Contoller with Neural Networks

4.1.1 Multi temperature sensors design system

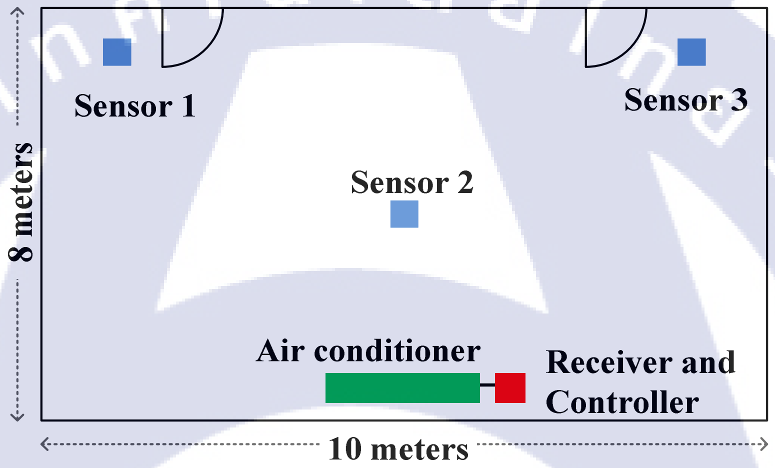



**Figure 4.1** The design of equipment installation.

The design system are consists of multi point of temperature sensor that located on average area of room control. This design were accuracy for temperature detecting when compare with the traditional that used only one temperature sensor by setting at return air before entrance to evaporator unit. Figure 4.2 Show the overall wireless multi-sensor industrial temperature control system. The principle of measurement method was start from temperature of each sensor will send measure signal to receiver then send to weighing box for calculated an average final temperature control signal. Then send control signal to PID controller.

4.1.2 The overall architecture

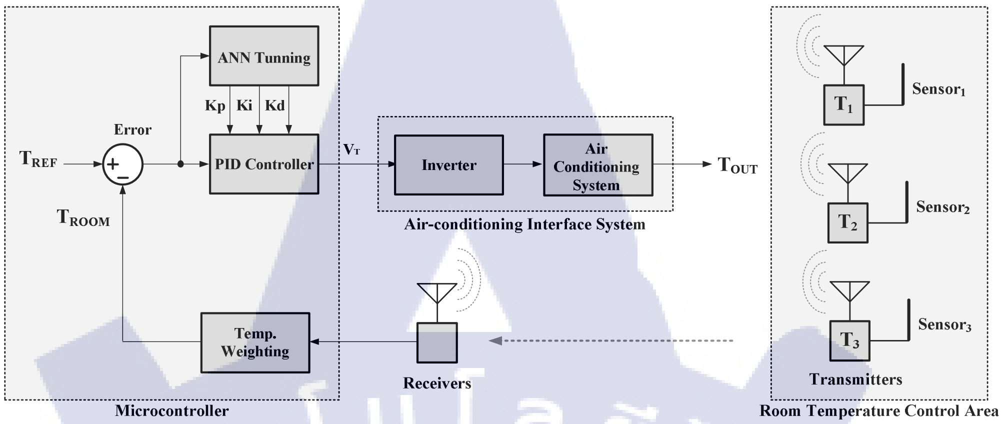



**Figure 4.2** The overall wireless multi-sensor industrial temperature control system.

The overall architecture of the proposed wireless multi-sensor industrial temperature control system is depicted in Fig.1. It can be seen in Fig.1 that the system consists of three major sections. First, the PID controller and the ANN tuning system with weighting algorithm are implemented by a microcontroller. The PID controller accepts the errors between the primary set temperature $T_{ref}$ and the actual temperature $T_{room}$. The error is also used for tuning the three gains $K_p$, $K_i$, and $K_d$ of the PID controller through the ANN tuning system. It can also be seen that the Temperature weighting algorithm is also included for averaging the actual temperature sensors to a single value.

Second, the air conditioning system consists of the inverter which accepts the voltage value in the range of 0V to 5V that sets the maximum and minimum speed of the motor and hence the output temperature Tout. Last, the three wireless temperature sensors are implemented for the three locations in the room, including the front of the air conditioner and the two locations in the back of the room. The multi-sensor systems have been implemented in order to average the temperature at different locations in the room. The wireless transmission system is equipped for transmitting data without any difficulties in wiring the temperature sensors. It can be concluded that the proposed system is newly designs not only for the multi-sensor system but also the intelligent controller using artificial neural networks tuning for the PID controller.

4.1.3 Wireless Temperature Sensor Designs

The wireless systems have been designed using the microcontroller-based system. For the temperature sensor, the model DHT11, which is a temperature and humidity sensor, has been employed. This DHT11 sensor is cost-effective and provides a calibrated digital signal output with 8-bit microcontroller. The measuring temperature range is between $0^{O}C$ to $50\ ^{O}C$ with the power supply of 3.5V to 5V. The transmitter and receiver are implemented

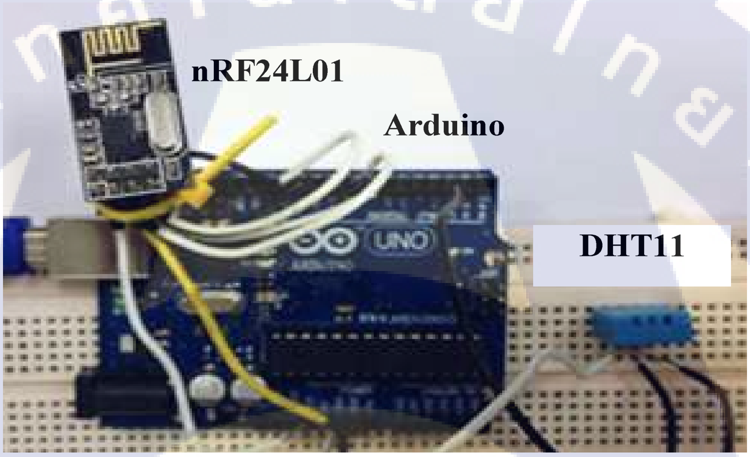



Figure 4.3 The temperature sensor and transmitter.

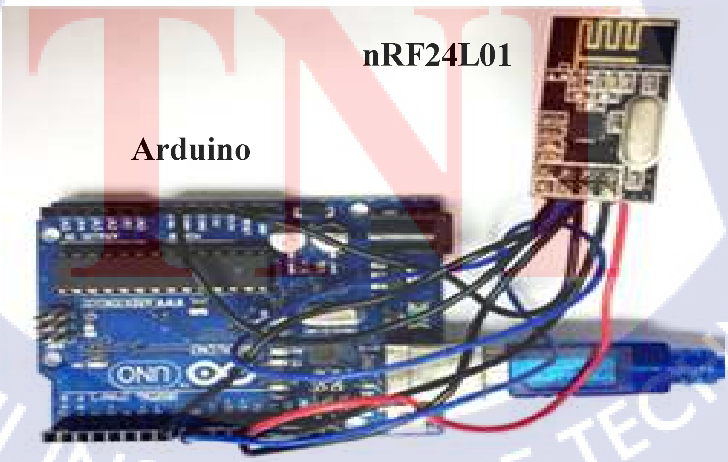



Figure 4.4 The PID micro controller and transceiver

The model nRF24L01. This transceiver model is a cost-effective data transmitter and receiver in a single chip operating at 2.4GHz ISM band and the data rate is relatively high up to 2Mbps. Fig.4.3 shows the design and implementation of the wireless temperature sensor and transceiver system. In Fig.4.4 show the temperature sensors sense the room temperature and send the data to the microcontroller as an interface unit to the transceiver prior

**Table 4.1** Comparison of temperature control signal

| **Sending Method** | **Sensing Position-1** | **Sensing Position-2** | **Sensing Position-3** | **Final Temperature** |
|---|---|---|---|---|
| Traditional | - | - | 25.0 ° C | **25.0 ° C** |
| New propose | 27.5 ° C | 28.0 ° C | 25.0 ° C | **26.83 ° C** |

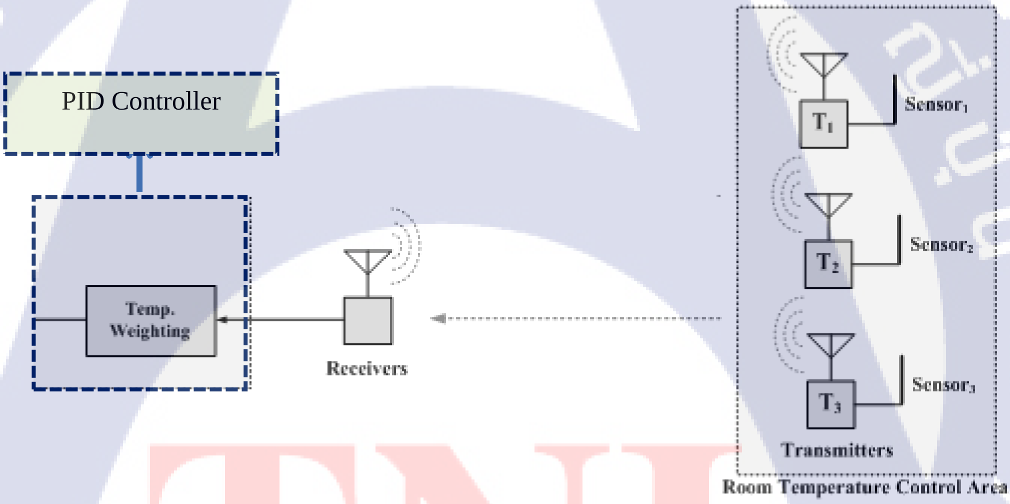



**Figure 4.5** Remote multi-temperature sensor design system

From table 4.1 Show comparison temperature control signal between single temperature sensor and multi temperature sensors. The final signal control from multi temperature sensors was given real value. Because of the temperature control signal is the real signal as average from many position of temperature. The PID controller able to processing to control room temperature reaches to target of control point.

The figure 4.3 and 4.4 show the comparison of controlling response between on-off controller and micro controller. When we consider the on-off control respond it cannot achieve to target control that it is characteristic of on off controller. For the micro controller response is same as PID controller. So the responses of control are easy to achieve to target by PID turning.

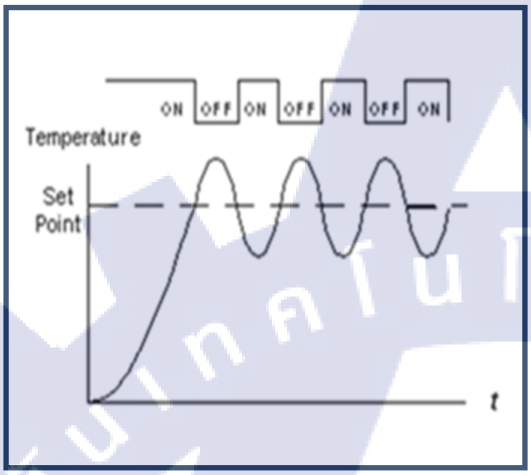



**Figure 4.6** Show On-Off control respond

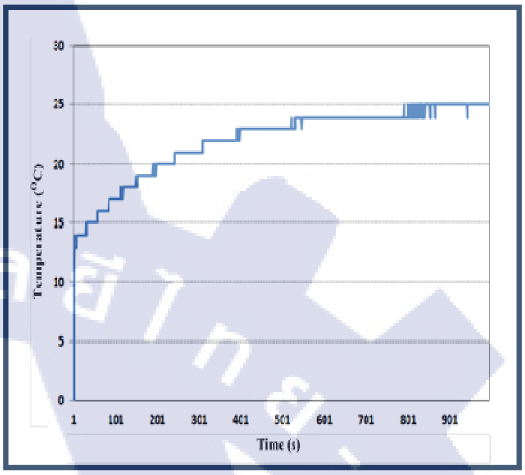



**Figure 4.7** Show micro control respond

4.1.4 PID and Self-Tuning control design system

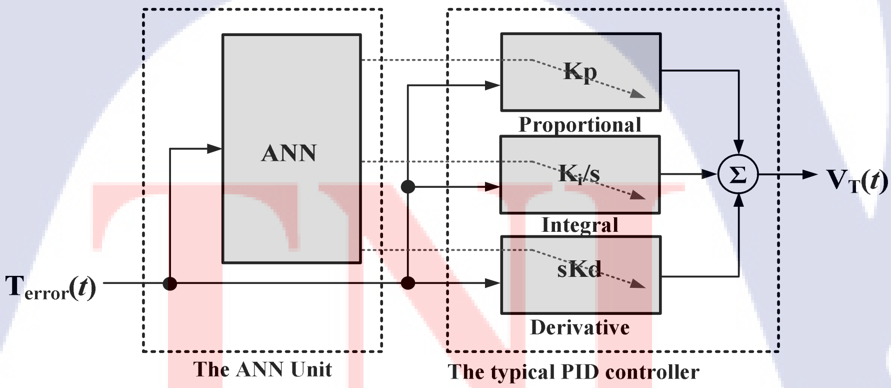



**Figure 4.8** The PID controller with Self-tuning of PID gains using neural network

Figure 4.8 shows the PID controller with self-tuning of PID gains using neural network. The typical form of the PID controller is given by

$$V_T(t) = k_p T_{err}(t) + k_p \int_0^t T_{err}(t) d\tau + k_d \frac{dT_{err}(t)}{d\tau} \qquad (1)$$

The output $V_T(t)$ is the control voltage output in the range of 0V - 5V which is used to drive the motor speed that ultimately sets the air temperature through the compressor. The error temperature $T_{err}(t) = T_{ref}(t) - T_{room}(t)$ is the error temperature obtained from the difference between the preset temperature and the weighted temperature of three sensors. The values of this $T_{err}(t)$ changes corresponding to the change in room temperature.

With reference to Fig.4.3 and (1), there are three sub-blocks. The proportional controls the loop gain in order to make the system less sensitive to load disturbances, the integral of error is used to eliminate the steady-state errors, and the derivative of errors is used to improve closed loop stability. In addition, the PID gains $K_p$, $K_i$, $K_d$ are set in order to meet prescribed performance criteria in terms of rise and settling times, overshoot and steady-state error. In this work the values of these gains are primarily set to $K_p$= 624.57, $K_i$= 1355.56, and $K_d$= 50.13. These values are obtained from the optimized procedure using MATLAB Simulink. The gains are automatically tuned by ANN through a summation of values from the ANN.

4.1.5 Artificial Network Designs

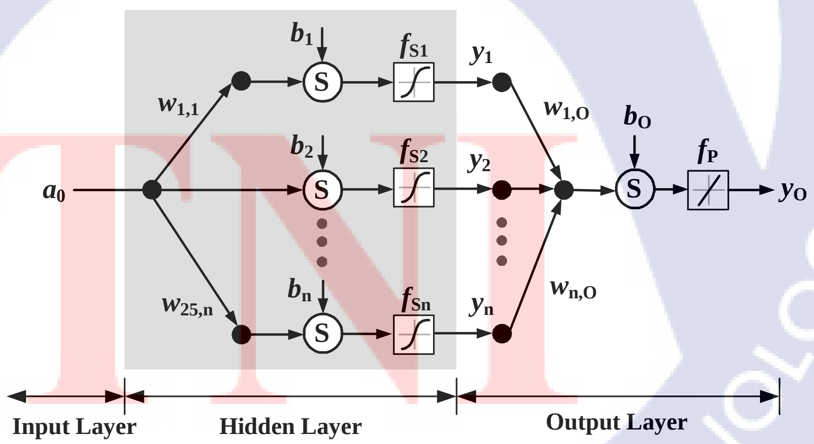



**Figure 4.9** The designed and optimized back propagation neural network.

Figure 4.9 shows the structure of designed and optimized back propagation neural network as a controller for the boost converter. This ANN is initially trained for a required certain output value. The realized ANN topology is a kind of back propagation multi-layer perceptron, which is a class of supervised learning neural networks, and is suitable for applications in, for instance, data classification and approximation. It is seen in Fig.4 that the ANN comprises three layers, i.e. input, hidden, and output layers. The input layer is an error temperature Terr(t).

The hidden layer then processes the input digital signals through weighting, biasing, and mapping operations. This work realizes a Hyperbolic Tangent Sigmoid (tansig) activation function in the hidden layer described as

$$y_n = \text{tansig}(\textstyle\sum_{i=1}^{n} a_b w_{b,n} + b_n) \tag{2}$$

Where $a_b$ represents the input value. $w_{b,n}$ is a weight for each input bit at $n^{th}$-node and $b$=25. $b_n$ is a bias for $n^{th}$-node. In fact, the values of n can be obtained from the trial-and-error process till optimization is found. Last, the output layer processes the outputs from the hidden layer using pure line (pureln) activation function as follows

$$y_O = \text{pureln}(\textstyle\sum_{i=1}^{n} y_n w_{n,O} + b_o) \tag{3}$$

Where $y_n$ represents the output from the hidden layer at nth-node. $w_{n,O}$ is a weight for each hidden layer output from nth-node. $b_o$ is a bias of the output layer. It can be considered that the performance of the ANN depends upon the number nodes in the hidden layer. This work also optimizes such number nodes in order to find the appropriate node numbers in terms of operating speed and complexity where $y_n$ represents the output from the hidden layer at nth-node. $w_{n,O}$ is a weight for each hidden layer output from nth-node. $b_O$ is a bias of the output layer. It can be considered that the performance of the ANN depends upon the number nodes in the hidden layer. This work also optimizes such number nodes in order to find the appropriate node numbers in terms of operating speed and complexity.

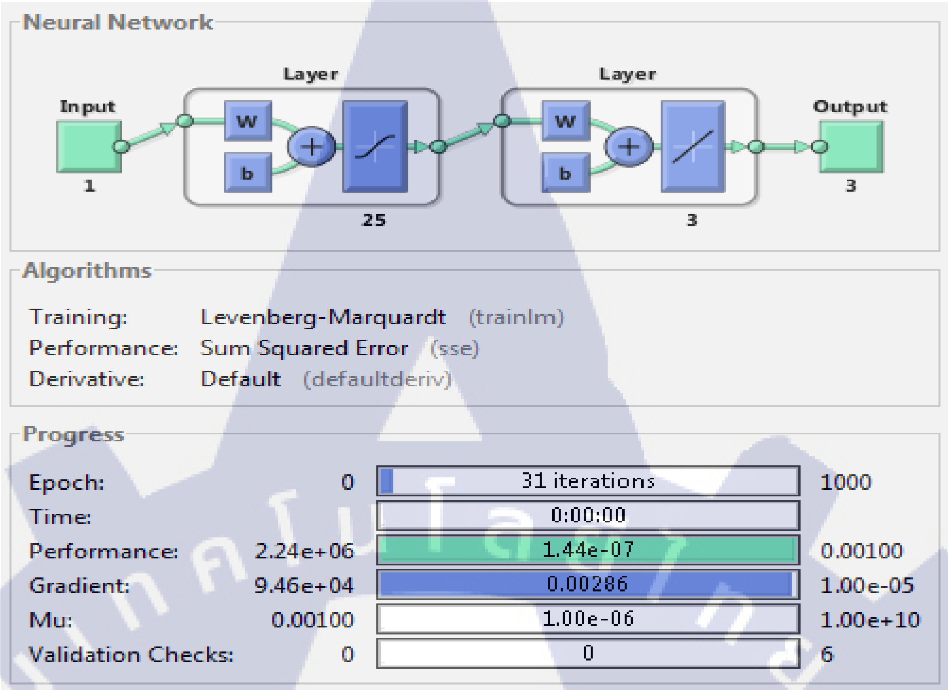
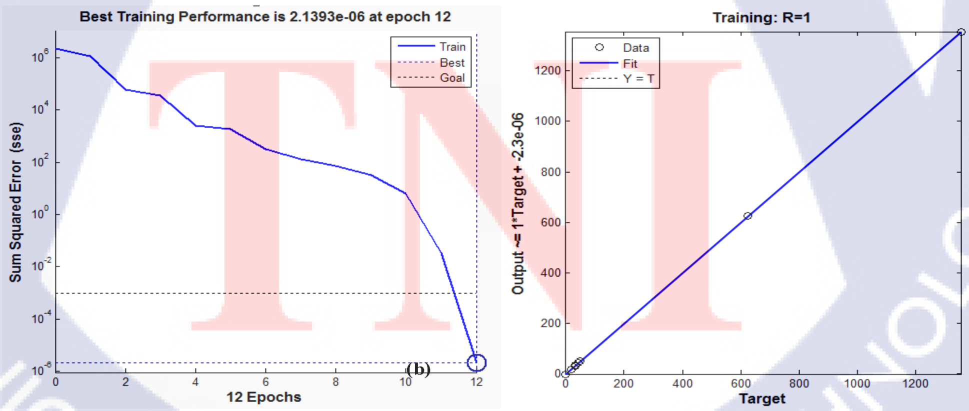



**Figure 4.10** Structure of the trained neural network.

Figure 4.10 shows the structure of the trained neural network. It can be seen that the optimized structure has 25 hidden layers and 3 outputs layers for the PID gains $K_p$, $K_i$, $K_d$.




(a) (b)

**Figure 4.11** (a) the best training performance at 31 epochs and (b) the neural network training regression

Figure 4.11 shows results of Levenberg-Marquardt (LM) training method and the performance was set to $10{\times}10^{-3}$ and it achieves at the iterations of 31 epochs.

```
%%%%%%%%%  Matrix INPUT  %%%%%%%%%%

num=1:3;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


%%%%%%%%%  Matrix TARGET  %%%%%%%%%%
t=ones(1,3);

t(1,1)=11;
t(1,2)=12;
t(1,3)=13;

t(2,1)=21;
t(2,2)=22;
t(2,3)=23;

t(3,1)=31;
t(3,2)=32;
t(3,3)=33;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


%%%%%%%%%  Model Neural Network  %%%%%%%%%%

net=newff(minmax(num),[10,3],{'tansig','purelin'},
'trainlm','learngdm','sse');
net.init(net);
net.trainParam.goal=1e-10;
net.trainParam.min_grad=1e-5;
[net,tr]=train(net,num,t);
a = sim(net,num);
disp('a');
gensim(net)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

**Figure 4.12** Program of trained neural network

## 4.2 Experimental Results

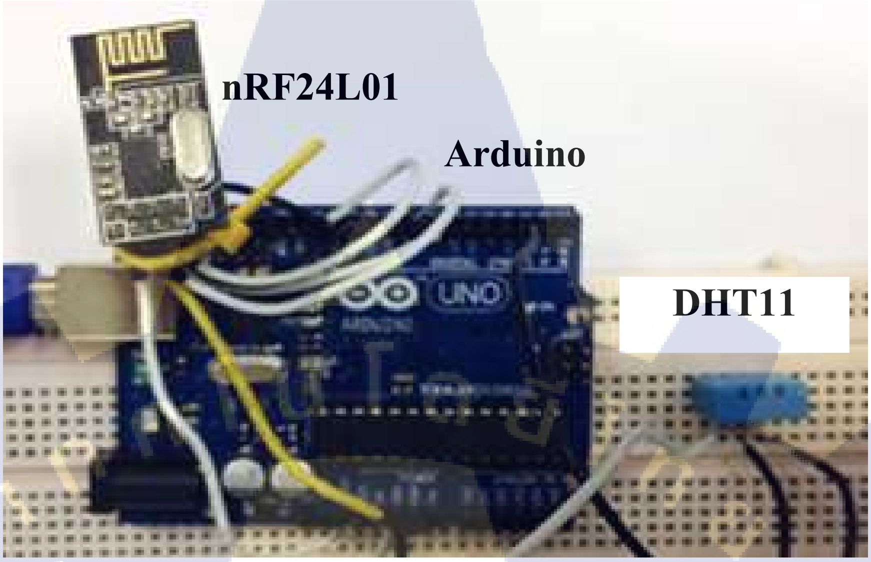



**Figure 4.13** The picture of PID micro controller hardware


**Figure 4.14** The picture of hardware and the inverter model VF-nC3 which control Speed of motor 0.75 kw.

The experiments have been performed through the use of AC motor controlled by the VF-nC3 that controls speed of motor as shown in Figure 4.14. The sensors were placed at three locations in a closed area of 8m×10m. The room temperature was early set at a very low temperature of 12$^{o}$C in order to investigate the tremendous changes in temperature and the effectiveness of the proposed system implementation. The temperatures were monitored through the average or weighted temperature obtained from the microcontroller.

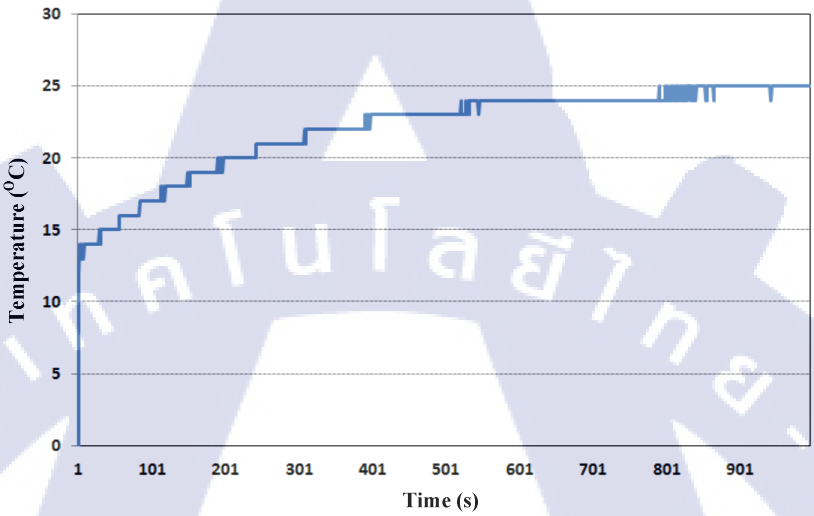



**Figure 4.15** The measured results of the temperature from the microcontroller Showing a stable temperature of 25$^{o}$C

Figure 4.15 shows the measured results of the temperature from the microcontroller showing a stable temperature of 25 $^{o}$C. The system could quickly reset to the set value within approximately 15 minutes. The system keeps operate at stable temperature of 25 $^{o}$C throughout the operating day.

**Table 4.2** Relation input signal control, motor speed,motor current and room temperature

| Input Signal (0-5 V.) | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Motor Speed (RPM) | 0 | 290 | 580 | 870 | 1160 | 1450 |
| Motor Current (A) | 0 | 0.50 | 0.8 | 1.0 | 1.2 | 1.28 |
| Room Temperature (°C) | Ambient | <25 | <25 | 25 | >25 | >25 |

## 4.3 Conclusion

This thesis has presented the practical implementations of the intelligent temperature control systems. The system employs the multi-sensor temperature sensing system with wireless data transmission. The control system is a PID controller with self-tuning feature through the artificial neural network. The experimental results show a fast and stable setting of any specifically set temperatures. The proposed temperature control system can be applied to a stable temperature for industrial plant, energy saving, and long life time of air conditioner. The future works include the enhancement of ANN-PID controller and the tests under different environment conditions.

# Chapter 5
# Conclusion and Suggestion

## 5.1 Conclusion

The control system of air conditioner is very important. The main factor of control system is temperature controller. The good control system design are direct effect to performance of air conditioner operation such as able save energy from electric consumption, decrease of maintenance cost and increase life time of air conditioner. The traditional of control system at the present to many of design control system such as on-off control system, fuzzy control system, and PID control system. Also some special equipment were applies as inverter to control and adjusting speed of fan motor and compressor motor to increase the performance system. The scope of this thesis is to design system of multi sensors temperature detection with PID controller and design the PID auto tuning by neural network. The literature reviews have involved nine related publications including Man Gyun Na (2001) “Auto-Tuned PID Controller Using a Model Predictive Control Method for the Steam Generator Water Level”., IEEE 2001 pp. 1664 – 1671. [1] Sung-Su Kim; and Seul Jung (2006) “Hardware Implementation of a Neural Network Controller an MCU and an FPGA Nonlinear System” International Journal of Control, Automation, and Systems, vol. 4, no. 5, pp. 567-574, October 2006[2] Jin Woo Moon;Sung Kwon Jung; and Jong- Jin Kim (2009) “Application of ANN (artificial-neural-network) in residential thermal control”, Eleventh International IBPSA Conference 2009 pp. 64-71 [3] Xuepeng Liu; Dongmei zhao;and Jianxin Wu (2009) “Frequency Variable Air Conditioner Controller Using Neural Network” Science and technique project. NO 20083A211 2009 [4] Woo-yong Han; Jin-wook Han; and Chang-goo Lee (1999) “Development of a Self-tuning PID Controller based on Neural Network for Nonlinear Systems”, Proceedings of the 7th Mediterranean Conference on Control and Automation 1999, pp. 979 – 988 [5] Leila Fallah Araghi; M. Habibnejad Korayem; Amin Nikoobin; and Farbod Setoudeh (2008) “Neural Network Controller Based on PID Controller for Two links- Robotic Manipulator Control”, Proceedings of the World Congress on Engineering and Computer Science 2008.[6] Petr Dolezel;

Ivan Taufer; and Jan Mares (2012) "An artificial neural network approach of load frequency control in a multi area interconnected power system" Introduction to PID Controller Frontier Areas 2012, pp. 193-202 [7] V.Shanmuga Sundaram; and T.Jayabarathi (2011) "Application of ANN (Artificial Neural Network) in Residential Thermal Control" Shanmuga Sundaram et al./ Elixir Elec. Engg. 38,2011, pp.4394-4397 [8] Neerparaj Rai; and Bijay Rai (2013) "Neural Network based Closed loop Speed Control of DC Motor using Arduino Uno" International Journal of Engineering Trends and Technology 2013, pp. 137 – 140 [9]

All proposed techniques are applicable for control system that concern with PID micro controller and artificial neural network. The simulations have been performed in MATLAB and hardware micro controller, hardware control panel with inverter. The results are described in terms of response time and accuracy of temperature control from PID microcontroller and self-tuning by artificial neural network as show in figure 4.15 The Figure 5.1 show hardware prototype that consists of micro PID controller and temperature sensing unit and hardware for speed control of motor compressor.

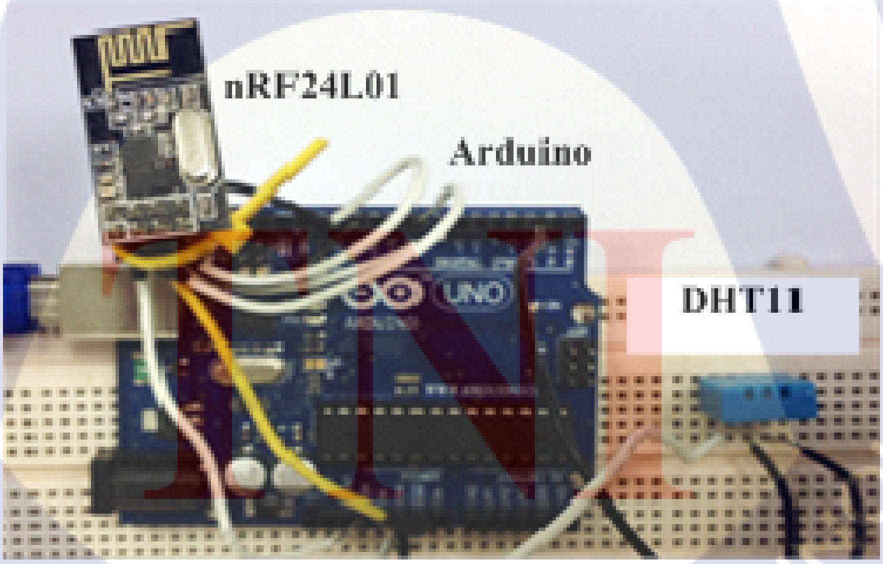



**Figure 5.1** Prototype picture of micro controller

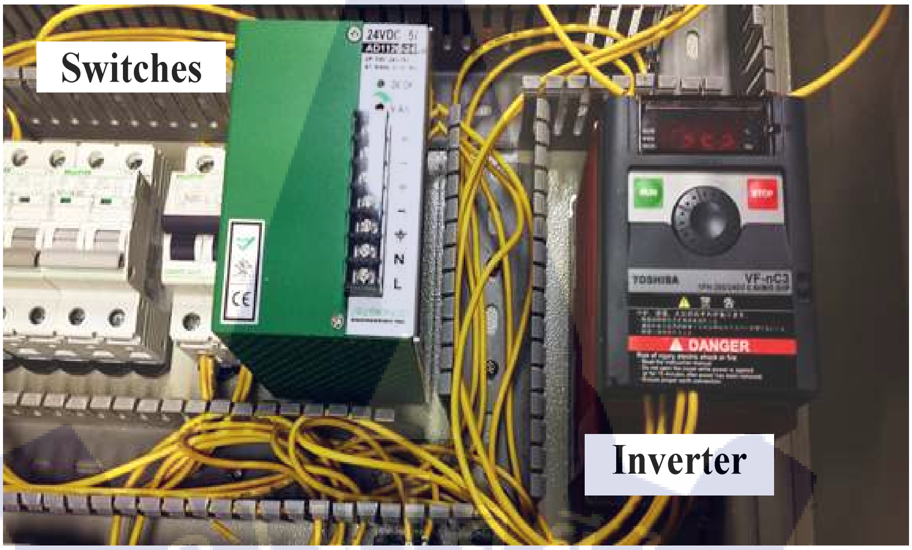



**Figure 5.2** Prototype picture of speed control

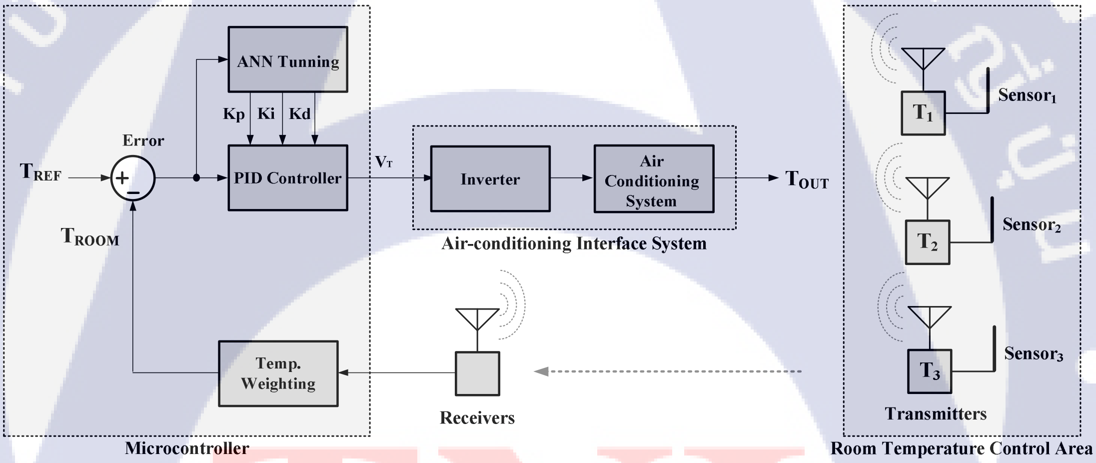



**Figure 5.3** Shown overall system configuration

## 5.2 Suggestion

From the research result in chapter 4 till have many uncompleted and limitation such as difficulty to find out area for testing with real area as design. For future researching the other researcher able to developing hardware prototype to be hardware complete set and utilization for industrial controller.

# References

# References

[1] Man Gyun Na. (2001). Auto –Tuned PID Controller Using a Model Prediction Control Method for The Steam Generator Water Level. **IEEE Transactions on Nuclear Science**. 48 (5) : 1,664 – 1,671.

[2] Sung-Su Kim; and Seul Jung. (2006). Hardware Implementation of a Neural Network Controller MCU and FPGA Nonlinear System. **International Journal of Control, Automation, and Systems.** 4 (5) : 567-574.

[3 Jin Woo Moon; Sung Kwon Jung; and Jong- Jin Kim. (2009). Application of ANN (Artificial Neural Network) in Residential Thermal Control. **Eleventh International IBPSA Conference.** Scotland : Glasgow**.**

[4] Xuepeng Liu; Dongmei Zhao; and Jianxin Wu. (2009). Frequency Variable Air Conditioner Using Neural Network. **IEEE Science and Technique Project.** NO. 20083A211.

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[6] Leila Fallah Araghi; M. Habibnejad Korayem; Amin Nikoobin; and Farbod Setoudeh. (2008). Neural Network Controller Based on PID Controller for Two Links- Robotic Manipulator Control. **Proceedings of the World Congress on Engineering and Computer Science.** USA: WCECS.

[7] Petr Doležel; Ivan Taufer; and Jan Mares. (2012). **Discrete PID Controller Tuning Using Piecewise-Linear Neural Network.** Czech Republic : University of Pardubice & Institute of Chemical Technology Prague.

[8] V.Shanmuga Sundaram; and T.Jayabarathi. (2011). Application of ANN (Artificial Neural Network) in Residential Thermal Control. **Elixir Elec. Engg.** 38 (2011) : 4,394- 4,397.

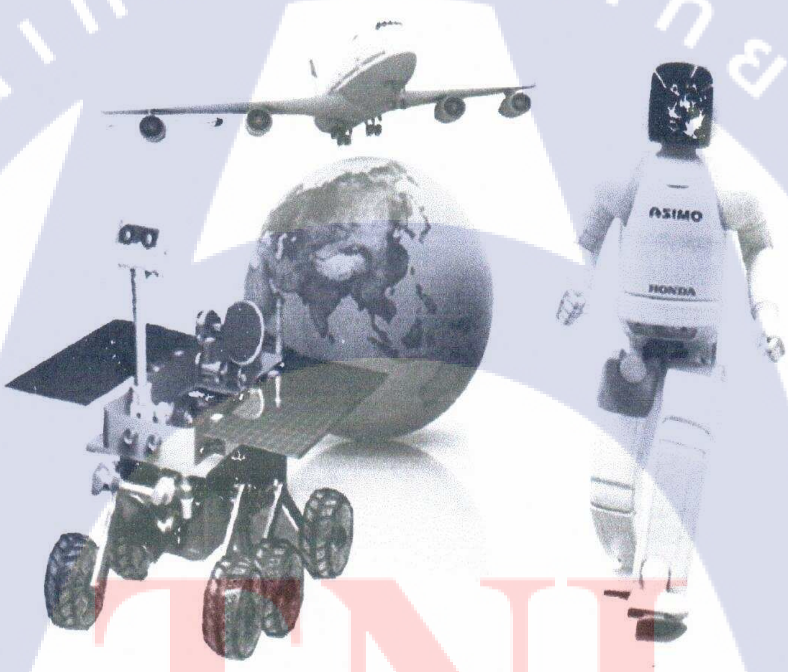
[9] Neerparaj Rai; and Bijay Rai. (2013). Neural Network based Closed Loop Speed Control of DC Motor Using Arduino Uno. **International Journal of Engineering Trends and Technology.** 4 (2) : 137 – 140.

# Appendix

**2013 2rd International Conference on Mechatronic Sciences, Electric Engineering and Computer (MEC 2013)**

**December, 14-16, 2013, Shenyang, China.**

# Conference program guide

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UQTR Faculty of Engineering, Canada
Heilongjiang Computer Federation, China

# Table of Contents

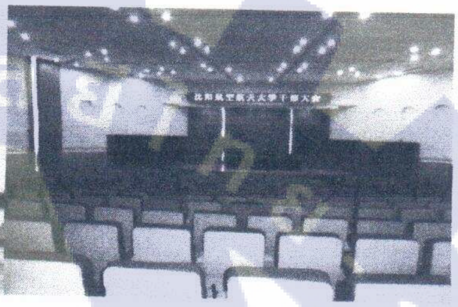
# Venue

**Opening: Shenyang Aerospace University Library**

**Keynote: Shenyang Aerospace University Library**

开幕式\主题报告：沈阳航空航天大学图书馆

**International Conference Hall**



**Oral Session：Shenyang Aerospace University Administration Building**

分会会场：沈阳航空航天大学行政楼（会议室）

**Administration Building  The Meeting Room**

# Part I Keynote Speeches

## Keynote Speech1:

**Title: Technology and Application of Additive Manufacturing**

**Speaker: Wang Wei**

**Professor and the Party Secretary**
**Shenyang Aerospace University Committee (SAU),China**
**doctor and doctoral supervisor and the expert entitled to Government Special Allowance.**

**Abstract:**

The report will be developed in the following four aspects:

(1) The background and principle of additive manufacturing technology.

(2) Typical nonmetal additive manufacturing technology, such as SLA, SLS, FDM, LOM and their principle, equipment structure and typicalapplication.

(3) Manufacturing equipment, technological characteristics and typical application of additive manufacturing technology of metal, especially titanium alloy.

(4) The researching result of SAU laser manufacturing team, including titanium alloy additive manufacturing equipment, process control software, scanning method of infrared subarea and titanium alloy laser additive manufacturing and remanufacturing process assisted in area of the outfield, and the application cases in aviation and medical fields so on.

**Biography:**

Professor Wang is the academic leader of the Liaoning Collegial Innovative Team entitled "Special and Precision Machining Technique of Aviation Parts" and the academic leader of two national characteristic specialties: Machine Design & Manufacturing and Automation.

He has assumed the responsibility of over 30 national and provincial-level scientific projects funded by Natural Science Foundation of China(NSFC), National Science and Technology Major Project(NSTMP), National Defense Pre-Research Foundation of China, Aeronautical Science Fund, Liaoning province science Fund, enterprises entrust project, and so on. The representative projects include the compounding mechanism and microstructure evolution of laser deposition repair titanium alloy assisted by ultra sound (NSFC), the laser repair equipment research of titanium alloy structure used to support the main force (NSTMP), etc. He advanced the technology of laser rapid prototyping manufacturing used to process titanium alloy gradient functional materials. In this way, both functional materials design and advanced laser manufacturing technology are well integrated together. Therefore a sort of new processing method for both difficult-to-machine materials and high melting point materials is developed. Professor Wang has received many awards, including one Second Prize of National Defense Science and Technology Progress, two First Prize of Liaoning province teaching achievements, three prizes of Mechanical Industry Science and Technology Progress. He tutored 2 doctors and 18 masters and published over 70 papers, in which 30 more papers have been included by SCI, EI and ISTP. He has edited in chief one collegial textbook entitled "NC machining process and programming", co-edited one book entitled "manual of machinery manufacturing" and has obtained 7 invention and utility model patents and 2 software copyright registrations.

# Part II Schedule

**December 14** (Saturday)
10:00—19:00

Registration, Shenyang North University City Hotel of Shenyang Engineering College

**December 15** (Saturday)

8:00—11:30

Registration, The meeting hall on the first floor of the Administrative Building, Shenyang Aerospace University *Note*: Providing Shuttle bus between the meeting place and the Hotel.

| Time | Activity | Location |
|---|---|---|
| ***Morning*** | Shenyang Aerospace University Administrative Building | |
| 08: 30-11: 30 | Session I: Control theory and Application | Room 222 |
| | Session II : Sensor and Instrument Technology | |
| | Session III: Robotics | |
| | Session IV : Pattern Recognition and Signal Processing | Room 304 |
| | Session V: Computer Science and Technology | |
| | Session VI: Aerospace Science and Technology | Room 328 |
| | Session VII: Mechatronics and Electrical Engineering | |
| 10: 00-10: 20 | Tea Break | |
| 12: 00-13: 00 | Buffet Lunch | Shenyang North University City Hotel Restaurant Floor 2 |
| ***Afternoon*** | | International Report Hall Shenyang Aerospace University Library Floor 2 |
| 13:30 -17:30 | **Opening Ceremony** | |
| | Keynote Speech 1 | |
| | Keynote Speech 2 | |
| | Tea Break& Photo | |
| | Keynote Speech 3 | |
| | Keynote Speech 4 | |
| 18:00-19:00 | Welcome Banquet | Shenyang North University City Hotel Restaurant Floor 2 |

**December 16** (Monday)

| Time | Activity | Location |
|---|---|---|
| ***Morning*** | | |
| 08: 30-11: 30 | Students' Forum | Shenyang Aerospace University Administrative Building Room 328 |
| 10: 00-10: 20 | Tea Break | |
| 12: 00-13: 00 | Buffet Lunch | Shenyang North University City Hotel Restaurant Floor 2 |
| ***Afternoon*** | | |
| 13:30 -14:30 | Visit History Museum of Shenyang Aerospace University , General Aviation Laboratory | |
| 15:00-16:00 | Awards Ceremony & Photo | |
| 16:00-17:00 | Farewell Banquet | Shenyang North University City Hotel Restaurant Floor 2 |

# Part III Oral Sessions

| Oral Session I , II , III | | |
|---|---|---|
| Conference Room | | Administrative Building 222 |
| Chair | | Pro. Xu Guangyan |
| **S I Control theory and Application** | | |
| **ID** | **Speaker** | **Title** |
| 69 | *Gu Wenbin* | A novel hormone-based implicit coordination approach for manufacturing control system |
| 612 | *Xu Hongke,Chen Huiru* | The design of Microcontroller-based traffic signal controller |
| 1276 | *Chen Lei,Zhu Tianlin* | Packet Delay Estimation With Minimum FIFO Block Based On Asymmetric PTP Network |
| 1346 | *Han Huilian, Liu Xiujuan* | Elastic Disturbance Modeling and Analysis for Hypersonic Vehicle |
| 1571 | *Hongzhe Jin, Yi Zheng* | Hybrid Position-Attitude Control of DF-UAV Based on Generalized Flight Dynamics |
| 1780 | *Zhao Bing,Cao Jianzhong* | Study on NNPID-based Adaptive Control for Electro-Optical Gyro Stabilized Platform |
| 966 | *Hui Qin, Qingqing Li* | A hybrid cultural algorithm based on clonal selection principle for optimal generation scheduling of cascaded hydropower stations |
| 1880 | *Somsak thaicharoen , Wimol San-Um* | An Intelligent Wireless Mulit-Sensor Temperature Control System using a Self-Tuning PID Contoller with Neural Networks |
| **S II Sensor and Instrument Technology** | | |
| 782 | *Lv Jian,Que Longcheng* | CMOS Readout Integrated Circuit for Uncooled Microbolometers without Substrate Temperature Stabilization |
| 1253 | *Si Junhong, Wang Sujian* | The correction method of air velocity transducer in underground mine roadway |
| 1375 | *Li Xiuhong,Cheng Xiao* | Design and Implementation of an Audio-visual Integrated Wireless Sensor Remote Monitoring Network on Wetland |
| 1407 | *Wang Ye，Bai Xiangyu* | Research of Fall Detection and Alarm Applications for the Elderly |
| 1565 | *Liu Yusheng,Su Wanxin* | Application of Area CMOS Image Processing for 2-D Optoelectronic Autocollimator |
| 1653 | *Ye Lizao,Li Hu* | Study on Urban Green Landscape Pattern Based on High Resolution Remote Sensing Image |
| 1879 | *Wimol San-Um , Chiramathe Nami* | Robust Weak Periodic Signal Detection Based On Optimized Duffing Chaotic Oscillator |
| **S III Robotics** | | |
| 341 | *Luo Zhongbao,Yang Zhidong* | Design of a novel support device and its application in two-axis centrifuge shaker |

# Part IV Student Form

| Student Form | | |
|---|---|---|
| Conference Room | | Administrative Building 328 |
| Chair | | Pro. Yibo LI |
| ID | Speaker | Title |
| 1780 | *Zhao Bing* | Study on NNPID-based Adaptive Control for Electro-Optical Gyro Stabilized Platform |
| 1219 | *Jiun-Ting Jiang* | The Basic Method for Using QPN to Model Routing Protocol under RWP Mobility in DTNs |
| 1571 | *Yi Zheng* | Hybrid Position-Attitude Control of DF-UAV Based on Generalized Flight Dynamics |
| 560 | *Hai Pan* | PDF Controller Applications In Ocean Engineering Of Constant Tension Winch |
| 1409 | *Chun Wang* | A Stackelberg Game and Improved Logit Model Based Traffic Guidance Model |
| 1403 | *Bao Qihui* | Path Selection Algorithm based on Grey Incidence Decision |
| 1830 | *Ling Jiafei* | Two-Staged Cloud Computing Service Supply Chain Coordination with Service Interruptions |
| 1460 | *Ding Guozhen* | Study of Working-handover Threshold of SBIRS-GEO Satellite' s Scanning/Staring Detector |
| 1426 | *Zhao Zhichun* | The spectrogram associated with the linear canonical transform |
| 1743 | *Wu Yang* | A Quantitative SNR Analysis of LFM signals in the Linear Canonical Transform Domain with Gaussian Windows |
| 1388 | *Wang Jian* | A New Method in Acquisition to Detect GNSS Spoofing Signal |
| 1855 | *Gu Qiming* | Design and Implementation of GPS Reflections Software Receiver |
| 1869 | *Zhifeng Gao* | Adaptive Parameter Estimation in MIMO Radar |
| 1072 | *Yangyang Wang* | Recognizing Human Actions Based on Gist Descriptor and Word Phrase |
| 1439 | *Yang Liu* | Target Tracking Using Two-stage Sparse Coding |
| 1880 | *Somsak thaicharoen , Wimol San-Um* | An Intelligent Wireless Mulit-Sensor Temperature Control System using a Self-Tuning PID Contoller with Neural Networks |
| 1879 | *Wimol San-Um , Chiramathe Nami* | Robust Weak Periodic Signal Detection Based On Optimized Duffing Chaotic Oscillator |

# Part IV Hotel Information

## Shenyang North University City Hotel
## 沈阳北大学城宾馆

Address: No.18, Puchang Road, shenbei new district, Shenyang, China

Telephone: 024-31974222

| Type | Public Price | Reduced price |
|---|---|---|
| Standard Double | 228 元/间（含双早）<br>228 RMB (breakfast included) | 190 元/间（含双早）<br>190 RMB (breakfast included) |
| King Bed Room | 280 元/间（含双早）<br>280RMB (breakfast included) | 240 元/间（含双早）<br>240 RMB (breakfast included) |

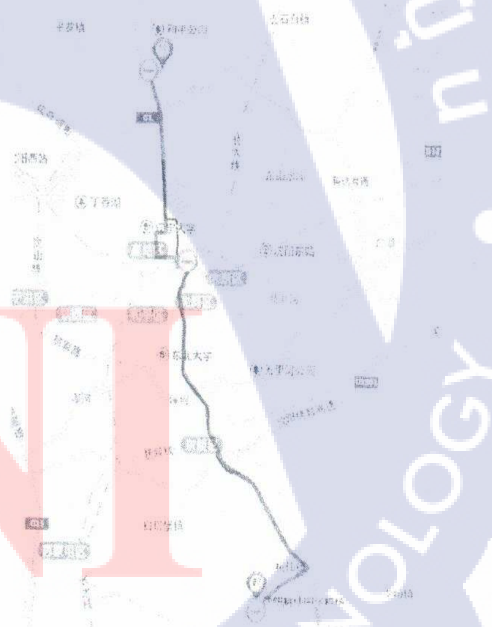
## Shenyang Xiangyu Hotel
## 沈阳祥宇宾馆

Address: No.1, Daoyi South Street, shenbei new district, Shenyang, China

Telephone: 024-89796555 89737508

| Type | Public Price | Reduced price |
|---|---|---|
| Standard Double | 258 元/间（含双早）<br>258 RMB (breakfast included) | 178 元/间（含双早）<br>178 RMB (breakfast included) |
| King Bed Room | 298 元/间（含双早）<br>298 RMB (breakfast included) | 258 元/间（含双早）<br>258 RMB (breakfast included) |

The organizer doesn't provide accommodation, and we suggest you make an early reservation. Please relate the MEC 2013 conference when booking.



**Routes to Shenyang North University City Hotel**

**How**

Route 1: From Shenyang Tao Xian International Airport （ 90~110￥ by taxi)

距机场：42.2 公里（出租车 90~110 元人民币）

Route 2: From Railway Station, by Subway line 2 ,Bus 178（14.32 km）

距火车站：14.32 公里（乘地铁 2——三台子下车换乘公交 178——沈北巴士下车）

（15.8km to downtown）距离市中心：15.8 公里

MEC 2013

# *Session Best Student Paper Award*

**(For Second)**

***presented to***

Somsak thaicharoen, Wimol San-Um

***for the paper***

An Intelligent Wireless Mulit-Sensor Temperature Control System using a Self-Tuning PID Controller with Neural Networks

in recognition of outstanding work on

2013 International Conference on Mechatronic Sciences,Electric Engineering and Computer

December 20-22,2013,Shenyang Aerospace University,Shenyang,China

2013 MEC Executive Committee

**General Chairs**

Prof. Dazhi Wang, Northeastern University

**Program Chairs**

Prof. Yibo Li, Shenyang Aerospace University

# An Intelligent Wireless Mulit-Sensor Temperature Control System using a Self-Tuning PID Contoller with Neural Networks

**Somsak thaicharoen and Wimol San-Um**
Intelligent Electronic Systems Research Laboratory (IES)
Faculty of Engineering, Thai-Nichi Institute of Technology (TNI)
Patthanakarn, Suanlaung, Bangkok, Thailand, 10250. Fax :( +662)-763-2700, Tel :( +662)-763-2600
E-mail addresses: kie2511@gmail.com, wimol@tni.ac.th

***Abstract*—this paper presents an intelligent temperature control system that provides a fully automatic air conditioner operation for a stable room temperature. The proposed technique employs the multi-sensor temperature sensing system with wireless data transmission in order to obtain accurate temperature measurement over a wide area. The control system is a PID controller with self-tuning feature using an artificial neural network. The wireless control system is designed using temperature sensor model DHT11, Arduino microcontroller and the transceiver model nRF24L01. The controller provides a control signal to VSD model VF-nC3 to control speed of motor compressor. The experimental results show a fast and stable setting of any specifically set temperatures. The proposed temperature control system offers a stable temperature for industrial plant, energy saving, and long life time of air conditioner.**

***Keywords-air conditioning; temperature control; neural network; wireless data transmission; intelligent technique.***

## I. Introduction

Air conditioning system typically controls the temperature in a closed area at a constant value and the temperature deviation should not exceed 2 °C as for generally acceptable temperature criteria in industrial plants. The typically and commercially available on-off temperature control system operates by sensing temperature and sending the control signals to stop the the compressor when the temperature is higher than the preset value. Consequently, the temperature is not stable due to start-stop operation, resulting in the short life-time of compressor motor. In addition, such a system also consumes much energy for starting the motor repeatedly.

As a potential alternative to the on-off control system for air conditioner, the use of a Proportional-Integral-Derivative (PID) controller still remains as a common control algorithm in industry. The PID controller offers versatility, high reliability and ease of operation [1]. Nonetheless, the performance of PID controller degrades during operational time owing to process non-linearity or process time varying parameters, and consequently retuning process is ultimately required [2]. Moreover, Retuning such a PID controller is mostly performed through a trial-and-error procedure which is a time consuming process and only skillful operators could effectively adjust to suitable operational conditions. As a results, there has been extensive research attempts to find the effective tuning procedures for PID controllers.

The trend of system control techniques has recently focused on artificial intelligent and fuzzy logic techniques. Nonetheless, the fuzzy logic control may not stable in some circumstances, and difficult for hardware implementations [3-4]. Therefore, an artificial Neural Network (ANN) has become a promising solution for nonlinear system controls with capability of learning the problems, predicting the next solution, and providing low response time with high precision. In terms of system identification and control applications, the feed forward multilayer neural networks are the most widespread architecture using a back propagation training algorithm.

In the field of temperature control systems, there have also been attempts to apply ANN for controlling temperatures. N. Rai and B. Rai [5] presented the PID gain controls using approximation through ANN. S. Kim and S. Jung [6] proposed the use of ANN that imitates the operation of PID controller. A. Al-Ghasem and N.Ussaleh [7] employed the ANN model to predict and control the temperature and energy consumption in buildings. In particular, X. Liu [8] proposes the frequency control of air conditioner through the use of ANN. Specific PID controllers for morotor control also found in [9-10]. Despite the fact that ANN has been applied to motor controls with high precision operations, it has been found that all previous works employed only a single temperature sensor which may not be suitable for a large room.

This paper therefore presents an intelligent and automatic temperature control system for a stable room temperature. Multi-sensor temperature sensing system with wireless data transmission is designed in order to achieve accurate temperature measurement over a wide area. The control system is a PID controller with self-tuning feature using an artificial neural network. The wireless control system is designed through cost-effective temperature sensor, transceiver and Arduino microcontroller. The controller provides a control signal to VSD to control speed of motor compressor. The experimental results using a modified air conditioner of 24,000 BTU reveal a fast and stable setting of any specifically set temperatures.

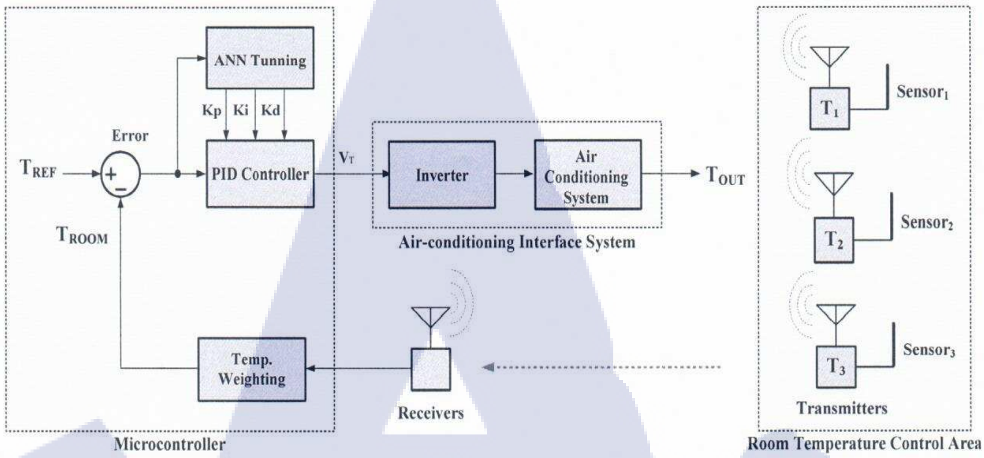



Figure 1. The overall wireless multui-sensor industrial temperature control system.

## II. PROPOSED WIRELESS MULIT-SENSOR INDUSTRIAL TEMPERATURE CONTROL SYSTEM

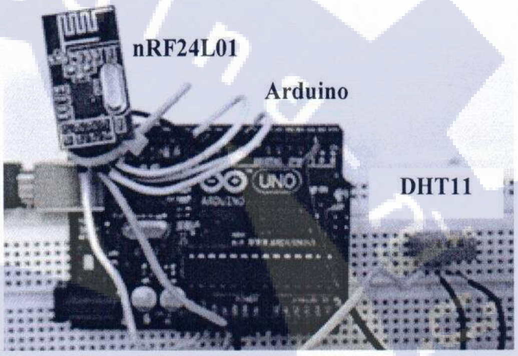
### *A. Overall Architecture*

The overall architecture of the proposed wireless multi-sensor industrial temperature control system is depicted in Fig.1. It can be seen in Fig.1 that the system consists of three major sections. First, the PID controller and the ANN tuning system with weighting algorithm are implemented by a microcontroller. The PID controller accepts the errors between the primary set temperature $T_{ref}$ and the actual temperature $T_{room}$. The error is also used for tuning the three gains $K_p$, $K_i$, and $K_d$ of the PID controller through the ANN tuning system. It can also be seen that the Temperature weighting algorithm is also included for averaging the actual temperature sensors to a single value.

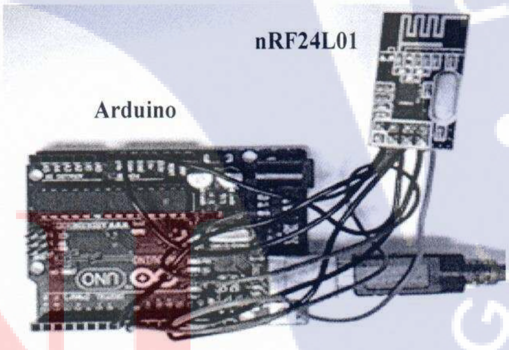
Second, the air conditioning system consists of the inverter which accepts the voltage value in the range of oV to 5V that sets the maximum and minimum speed of the motor and hence the output temperature $T_{out}$. Last, the three wireless temperature sensors are implemented for the three locations in the room, including the front of the air conditioner and the two locations in the back of the room. The multi-sensor systems have been implemented in order to average the temperature at different locations in the room. The wireless transmission system is equipped for transmitting data without any difficulties in wiring the temperature sensors. It can be concluded that the proposed system is newly designs not only for the multi-sensor system but also the intelligent controller using artificial neural networks tuning for the PID controller.

### *B. Wireless Temperature Sensor Designs*

The wireless systems have been designed using the microcontroller-based system. For the temperature sensor, the model DHT11, which is a temperature and humidity sensor, has been employed. This DHT11 sensor is cost-effective and provides a calibrated digital signal output with 8-bit microcontroller. The measuring temperature range is between $0^{O}C$ to $50\ ^{O}C$ with the power supply of 3.5V to 5V. The transmitter and receiver are implemented




(a) The temperature sensor and the transmitter.




(b) The receiver and the controller.

Figure 2. The design and implementation of the wireless temperature sensor and transciever system.

by the model nRF24L01. This transceiver model is a cost-effective data transmitter and receiver in a single chip operating at 2.4GHz ISM band and the data rate is relatively high up to 2Mbps. Fig. 2 shows the design and implementation of the wireless temperature sensor and transceiver system. In Fig.2 (a), the temperature sensors sense the room temperature and send the data to the microcontroller as an interface unit to the transceiver prior

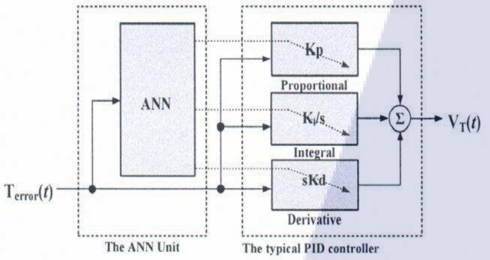



Figure 3. The PID controller with self-tunning of PID gains using nueral network.

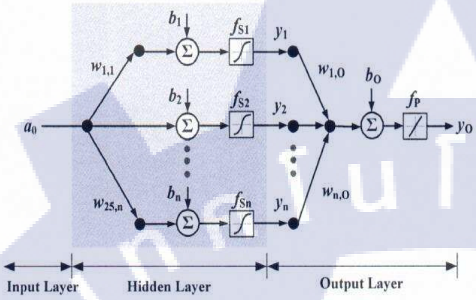



Figure 4. The designed and optimized back propagation neural network.

to the wireless data transmission to the base station. In Fig.2 (b), the receiver receives the data from all sensors and weights for the average temperature. In addition, this controller also implements the PID controller and the ANN tuning units. The primary set values for the room temperature is 25°C.

### C. PID Controller Designs

Figure 3 shows the PID controller with self-tuning of PID gains using neural network. The typical form of the PID controller is given by

$$V_T(t) = k_p T_{err}(t) + k_p \int_0^t T_{err}(t)d\tau + k_d \frac{dT_{err}(t)}{d\tau} \quad (1)$$

The output $V_T(t)$ is the control voltage output in the range of 0V-5V which is used to drive the motor speed that ultimately sets the air temperature through the compressor. The error temperature $T_{err}(t) = T_{ref}(t) - T_{room}(t)$ is the error temperature obtained from the difference between the preset temperature and the weighted temperature of three sensors. The values of this $T_{err}(t)$ changes corresponding to the change in room temperature.

With reference to Fig.3 and Eq. (1), there are three sub-blocks. The proportional controls the loop gain in order to make the system less sensitive to load disturbances, the integral of error is used to eliminate the steady-state errors, and the derivative of errors is used to improve closed loop stability. In addition, the PID gains Kp, Ki, Kd are set in order to meet prescribed performance criteria in terms of rise and settling times, overshoot and steady-state error. In this work the values of these gains are primarily set to Kp =624.57, Ki=1355.56, and Kd=50.13. These values are obtained from the optimized procedure using MATLAB

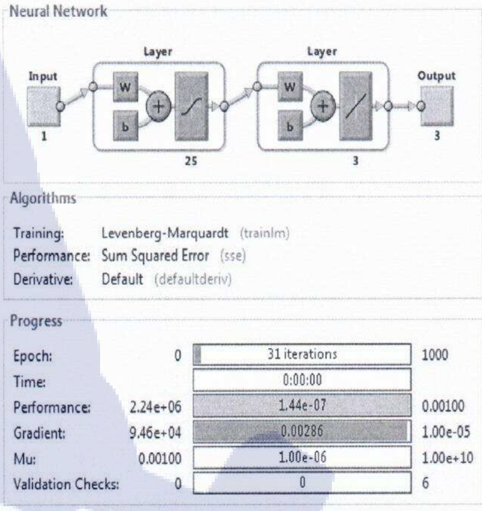



Figure 5. The structure of the trained neural network.

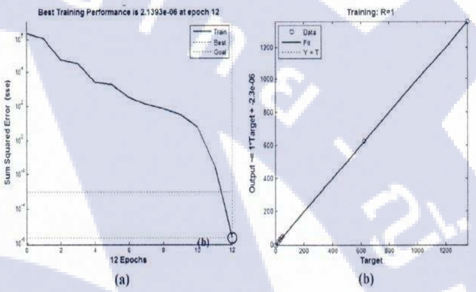



Figure 6. (a) the best training performance at 31 epoch and (b) the neural network training regression.

Simulink. The gains are automatically tuned by ANN through a summation of values from the ANN.

### D. Artificial Network Designs

Fig.4 shows the structure of designed and optimized back propagation neural network as a controller for the boost converter. This ANN is initially trained for a required certain output value. The realized ANN topology is kind of back propagation multi-layer perceptron, which is a class of supervised learning neural networks, and is suitable for applications in, for instance, data classification and approximation. It is seen in Fig.4 that the ANN comprises three layers, i.e. input, hidden, and output layers. The input layer is an error temperature $T_{err}(t)$. The hidden layer then processes the input digital signals through weighting, biasing, and mapping operations. This work realizes a Hyperbolic Tangent Sigmoid (tansig) activation function in the hidden layer described as

$$y_n = \text{tansig}\left(\sum_{i=1}^{n} a_b w_{b,n} + b_n\right) \quad (2)$$

where $a_o$ represents the input value. $w_{b,n}$ is a weight for each input bit at $n^{th}$-node and $b$=25. $b_n$ is a bias for $n^{th}$-node. In fact, the values of n can be obtained from the trial-and-error process till optimization is found. Last, the output layer processes the outputs from the hidden layer using pure line (pureln) activation function as follows

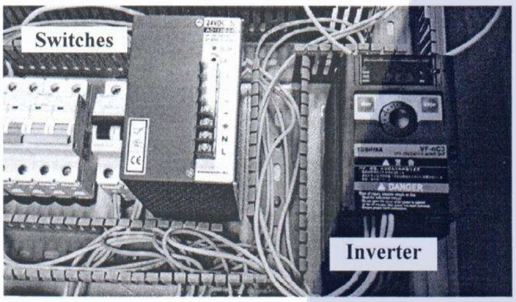



Figure 7. The photograph of the inverter model VF-nC3 that controls speed of motor compressor of the modified 24,000-BTU air conditioner.

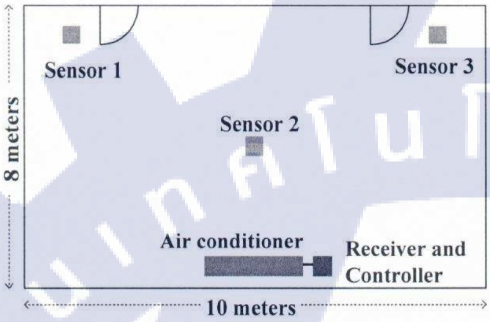



Figure 8. The locations of the temperature sensors in a closed area.

$$y_O = \mathrm{pureln}\left(\sum_{i=1}^{n} y_n w_{n,O} + b_O\right) \qquad (3)$$

where $y_n$ represents the output from the hidden layer at $n^{th}$-node. $w_{n,O}$ is a weight for each hidden layer output from $n^{th}$-node. $b_O$ is a bias of the output layer. It can be considered that the performance of the ANN depends upon the number nodes in the hidden layer. This work also optimizes such number nodes in order to find the appropriate node numbers in terms of operating speed and complexity. Fig. 5 shows the structure of the trained neural network. It can be seen from Fig. 5 that the optimized structure has 25 hidden layers and 3 output layers for the PID gains Kp, Ki, Kd. As shown in Fig.6, The training method is Levenberg-Marquardt (LM) and the performance was set to $10\times10^{-3}$ and it achieves at the iterations of 31 epochs.

## III. Experimental Resuls

The experiments have been performed through the use of the modified air conditioner of a 24,000 BTU controlled by the VF-nC3 that controls speed of motor compressor as shown in Fig.7. The sensors were placed at three locations in a closed area of 8m×10m. The room temperature was early set at a very low temperature of 12$^{O}$C in order to investigate the tremendous changes in temperature and the effectiveness of the proposed system implementation. The temperatures were monitored through the average or weighted temperature obtained from the microcontroller. Fig. 9 shows the measured results of the temperature from the microcontroller showing a stable temperature of 25$^{O}$C. The system could quickly reset to the set value within approximately 15

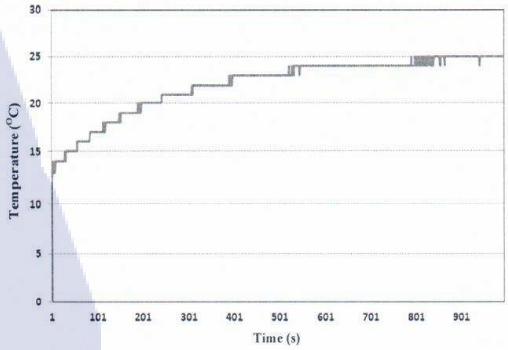



Figure 9. The measured results of the temperature from the microcontroller showing a stable temperature of 25$^{O}$C.

minutes. The system keeps operate at stable temperature of 25$^{O}$C throughout the operating day.

## IV. Conclusion

This paper has presented the practical implementation of the intelligent temperature control system. The system employs the multi-sensor temperature sensing system with wireless data transmission. The control system is a PID controller with self-tuning feature through the artificial neural network. The experimental results show a fast and stable setting of any specifically set temperatures. The proposed temperature control system can be applied to a stable temperature for industrial plant, energy saving, and long life time of air conditioner. The future works include the enhancement of ANN-PID controller and the tests under different environment conditions.

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