A Comfort System Base on ZigBee Wireless Monitoring and Control in Smart Home

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Abstract

A system of wireless access monitoring and control for a smart home is presented in this paper. The transmit interface of this system include ZigBee-ZigBee modules, ZigBee modules-PC and PC-PDA. Where PDA plays a portable indoor remote controller with intelligent, we can monitor the information of indoor environment and control in real time if necessary. In order to obtain a reasonable solution between thermal comfort and saving energy in smart home, a CMAC based PMV evaluate scheme is proposed and implemented in this paper. Besides, the lighting control also is determined by ZigBee based wireless sensor to obtain a well illumination space. Experiment results shown that the proposed system based on ZigBee transmit and CMAC PMV thermal comfort scheme is feasible to implement in real time application for smart home.

Keywords: ZigBee、PDA 、CMAC、PMV、Smart Home.

1. Introduction

The comfortable environment is the ideal life state which the people have pursued. The level of thermal comfort is not easy to direct measured by the mathematical methods, because the human sensation of thermal comfort is vague and pectoral according to personal preferences. In general, the level of thermal comfort depends on both of environmental-dependent variables and personal-dependent variables. The environmental-dependent variables which contain air temperature, relative humidity, relative air velocity and mean radiant temperature, and the personal-dependent variables contain activity level and clothing. It is an interesting topic to find a reasonable solution between all variables of above for many studies in the last decade. P.O. Fanger [1] proposed PMV thermal comfort index was popular applied as ISO 7730 which is one of the most famous study of thermal comfort. Based on the PMV index, Emerson Donaisky [2] proposed developed predictive algorithms to analysis and control thermal comfort of building depend on the temperature and humidity. Some studies developed for thermal comfort by various strategies focus on the special case for various environments, such as the school classrooms or the offices. It not only promotes the thermal comfort but also reduces the energy consumption will be reached [3, 4].

However the value of PMV requires complex and interactive processing which make it impossible to implement in real-time applications. In this paper, by utilizing a novel framework of PMV, an efficiently and fast thermal comfort index algorithm is presented on the basis of CMAC and named it as the CMAC PMV [5]. The cerebellar model articulation controller (CMAC) is a nonlinear adaptive system proposed by Albus [6]. It is an associative memory network based on local approximation and be regarded as a look up table method. Moreover, its algorithm with built-in simple computation, fast learning and good local generalization properties, the CMAC is well suited for modeling the complex systems such as thermal comfort index and the capability of approximate nonlinear function will be applied to learn PMV index in this paper.

Along with the advancement of technology and economic growth, the quality of life for humans is driven and also promotes people to pursue the fashion of smart home-based life mode. Various functions based on smart home are proposed to satisfy different demand of people’s daily lives. For example, the lamps will be turn on or the curtains will be drawn when it was dark, the air-conditioning system will switch on to make sure the thermal comfort depend on indoor temperature changes, and multimedia devices and household appliances are set up by voice control in the room and so on. Above all of intelligent operators could be controlled by wireless transmit technique and combined into an intelligent remote controller such as PDA, PC and cell phone equipments, so the people will enjoy the facility life from the technology of smart home. There have been many studies integrated all in one remote control to control various household equipment by used of proposed URC [7, 8] to make people live easier and happier. However the URC must design various control codes for different kinds of electrical equipment which have different frequency of infrared ray. Recently, ZigBee [9] technological has widely applied in industry, building, hospital and home automation as the wireless sensor network and also used to control various electrical devices in place of URC. However this paper focuses on the intelligent switch of electrical appliances in smart home. We not only proposed an intelligent switch technique based on the wireless sensor but also develop an intelligent thermal comfort remote sensor. The purpose of this intelligent thermal comfort remote sensor is to obtain the reasonable resolution between comforts with energy saving, and also promote the convenience of people's daily lives.

2. Predicted Mean Value Index

PMV has been widely applied in the thermal field even though numerous studies for thermal comfort have been achieved for decades. The thermal sensation model based on PMV formula can be applied to calculate the thermal comfort index of the PMV value as follows International Standards Organization (ISO) [10].

The thermal comfort index can be simplified to six major factors which include two parts, the human body and the environment. The human body contains activity level and clothing insulation, and the environment contains the air temperature, relative humidity, air velocity and radiant temperature.

$$PMV = (0.303\, e^{-0.036\, M} + 0.028)\, L \tag{1}$$

And L is denotes the human thermal load which is computed as

$$\begin{aligned} L = {} & (M - W) - 3.05 \times 10^{-3} \times [5733 - 6.99(M - W) - P_a] \\ & - 0.42 \times [(M - W) - 58.15] - 1.7 \times 10^{-5} M(5876 - P_a) \\ & - 0.0014 M(34 - t_a) - 3.96 \times 10^{-8} \times f_{cl} \times [(t_{cl} + 273)^4 \\ & - (\bar{t}_r + 273)^4] - f_{cl} h_c \times (t_{cl} - t_a) \end{aligned} \tag{2}$$

Then, substitute into the equation (1) and obtain the equation (3)

$$\begin{aligned} PMV = {} & (0.303 e^{-0.036M} + 0.028) \times \{(M - W) - 3.05 \times 10^{-3} \\ & \times [5733 - 6.99(M - W) - P_a] - 0.42 \times [(M - W) - 58.15] \\ & - 1.7 \times 10^{-5} M(5876 - P_a) - 0.0014 M(34 - t_a) - 3.96 \times 10^{-8} \\ & \times f_{cl} \times [(t_{cl} + 273)^4 - (\bar{t}_r + 273)^4] - f_{cl} h_c \times (t_{cl} - t_a)\} \end{aligned} \tag{3}$$

And t_{cl}, h_c and f_{cl} are determined respectively by the equations listed as follows.

$$\begin{aligned} t_{cl} = {} & 35.7 - 0.028(M - W) - I_{cl}\{3.96 \times 10^{-8} \times f_{cl} \\ & \times [(t_{cl} + 273)^4 - (\bar{t}_r + 273)^4] + f_{cl} h_c \times (t_{cl} - t_a)\} \end{aligned} \tag{4}$$

$$h_c = \begin{cases} 2.38(t_{cl} \quad t_a)^{0.25} & for \quad 2.38(t_{cl} \quad t_a)^{0.25} > 12.1\sqrt{v_{ar}} \\ 12.1\sqrt{v_{ar}} & for \quad 2.38(t_{cl} \quad t_a)^{0.25} < 12.1\sqrt{v_{ar}} \end{cases} \tag{5}$$

$$f_{cl} = \begin{cases} 1.00 + 1.290 I_{cl} & for \quad I_{cl} \le 0.078 m^2 \cdot °C/W \\ 1.05 + 0.645 I_{cl} & for \quad I_{cl} > 0.078 m^2 \cdot °C/W \end{cases} \tag{6}$$

where

M = Metabolic rate W/m^2 or (met)

W = External work W/m^2 usually is 0

Pa = Partial vapour presser (Pa)

$\bar{t}_r$ = Mean radiant temperature $(°C)$

V_{ar} = Relative air velocity (m/s)

I_{cl} = Thermal resistance of clothing $(m^2 °C/w)$

t_a = Air temperature $(°C)$

h_c = Convective heat transfer coefficient $(w/m^2 °C)$

f_{cl} = Ratio of clothed body surface area to nude body surface area

From equation (2) the PMV can be calculated for different combinations of metabolic rate (activity level), clothing, air temperature, mean radiant temperature, relative air velocity and relative humidity. The equation for and may be solved by iteration. Furthermore, 7-point thermal sensation scale is used to measure the thermal comfort level as: +3(hot), +2(warm), +1(slightly warm), 0(neutral), -1(slightly cold), -2(cool) and -3(cold). Figure 1 shows the relationship between the corresponding parameters with thermal comfort index. To provide a comfortable room environment, ISO recommends maintaining the PMV at 0 with tolerance of ± 0.5.

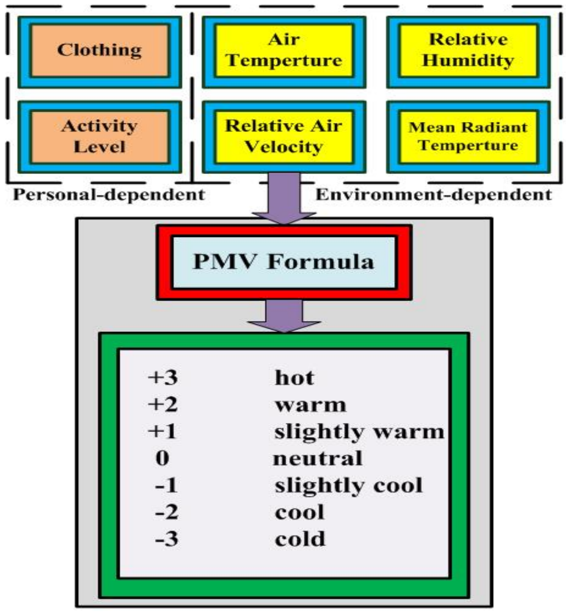

Figure 1. PMV and thermal comfort index

3. Cerebellar Model Articulation Controller, CMAC

In this section we will present a brief review of CMAC and architecture of CMAC is shown in Figure 2. It consists of two mappings and one output computation for determining the value of a complex function. The two mappings are denoted by Δ and Ω respectively, and the input space is denoted S, A^* represents an association memory, W is a weight memory and Y is the output of result. For each input signal X, first compute its discretization value x and encoding the corresponded codes. Then the first mapping Δ will excite the code to a location in the association memory A^*. Each location of A^* corresponds to a receptive field. The second mapping Ω relates each location of A^* to a particular adjustable value in the weight memory W. Then sum the weights from these addresses to determine the output and the output computation can be given by

$$y = \sum_{j=1}^{k} W_j \tag{8}$$

Where W_j is the weight stored in weight memory location j, and $j = 1,2...,K$. K is the active number of the memory

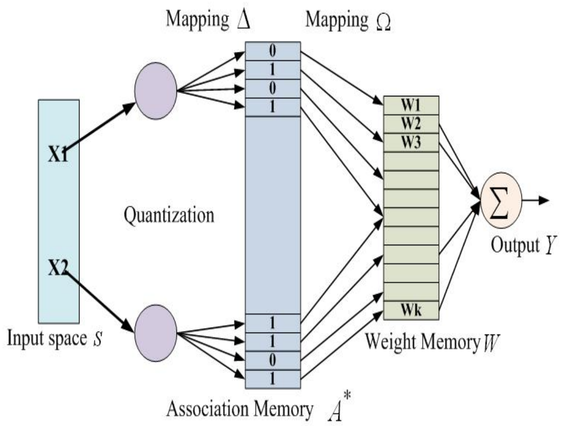

Figure 2. CMAC architecture

The mapping from input to output of CMAC is determined by weights stored in weight memory W. The learning algorithm for CMAC will be described as follows. Consider the output Y of CMAC for the input X, the desired output is y_d, and the output error between y_d and y is ε_i. Give an input $\overline{x}$ and the training signal $\overline{y_d}$, then the weights $\overline{W}_j$ associated with the input are updated according to

$$\widehat{W}_j = \overline{W}_j + \mu \frac{\varepsilon_i}{K} \tag{9}$$

Where $\widehat{W}_j$ is the updated weighting value and μ is a learning rate that governs a learning speed i.e. the rate of weight convergence and defined between 0 and 1. It can be intuitively understood from the overlapping associating cells which nearby inputs excite, providing some degree of correlation. In other words, nearby inputs can activate one or more of the same weights and lead to similar outputs. This correlation provides a very useful property of the CMAC, and called local generalization. The degree of local generalization can be modified by changing the size of K. The larger K gives larger receptive fields and wider local generalization region. For this reason, K is called generalization parameter.

4. CMAC PMV

From what were shown in Chapter 2, we know that PMV calculation formula is complex and iterative. Therefore, this research uses CMAC neural network to replace the complicated computing process. It is the CMAC PMV based on CMAC neural network. Input parameters of CMAC PMV are six main factors such as activity level, clothing, air temperature, relative humidity, relative air velocity and mean radiant temperature. Six main factors are quantified, coded, given active memory address and outputted with a summed up weighting value through CMAC neutral network, and then the adjusted weighting values are compared with the ideal output values until the learning process is completed. When parameters are inputted and processed by CMAC, we can get an output after summing up the active weighting memories, and it is the result of PMV value learned by CMAC. Figure 3 shows the calculation model of CMAC PMV.

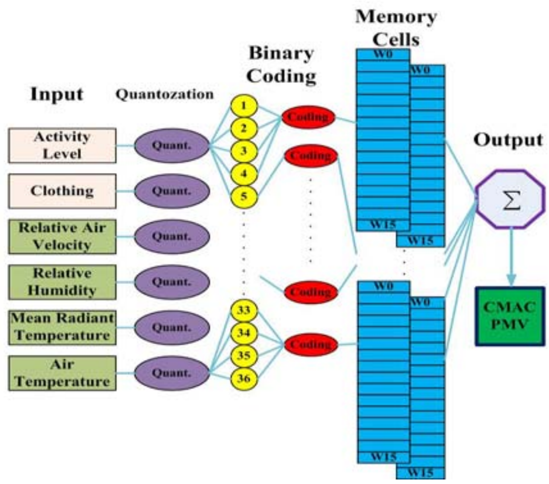

Figure 3. CMAC neural network diagram of PMV

Input parameters of learning samples are mostly analog signals. Therefore, CMAC neural network has to process quantization for input parameters first before it continues the following work. Input parameters are between the minimum value and the maximum value of a known range $[X_{\min}, X_{\max}]$. In the range, we divide the quantization level q_x with equal intervals. The higher the quantization level is, the better the resolution of input parameters is. On the contrary, it also must occupy more memory space. To divide the input values with quantization levels to divide levels from 0 to $(q_x - 1)$ according to the minimum and maximum value. The quantization values smaller than $X_{\min}$ are set to 0, quantization values bigger than $X_{\max}$ are adjusted to $(q_x - 1)$, and other values are shown with quantization levels. As shown in Figure 4 below, the quantization level $(q_x - 1)$ is set to be 64, and then the corresponsive quantization levels according to the signal size are between 0 and 63.

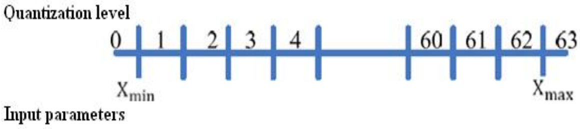

Figure 4. Indicators of quantization level

The mechanism for this mapping is illustrated in Figure 5. For instance, given the coding of input vector is001101011111011100010110110010010100 and partitioned it into nine groups, and each group contains four bits, and then rearranges the order from the least signification bit to the most signification bit in sequence. It can obtain nine active associated addresses in the association memory, A1=3, A2=5, A3=15, A4=7, A5=1, A6=6, A7=12, A8=9, A9=4 respectively.

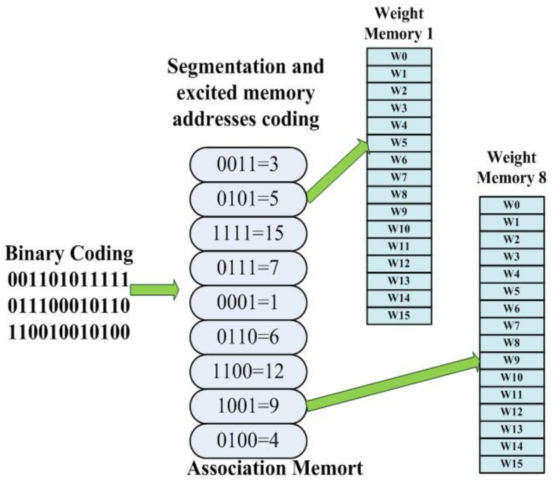

Figure 5. The mechanism for this mapping of associated addresses in the memory

Next, we consider the active addresses map the associated weighting values in the weighting memory, and the all of the active weighting values are summed up to yield the output of CMAC PMV, that is

$$y = \sum_{j=1}^{k} W_j^{a_j} \tag{10}$$

Where K is the active number of the memory, a_j is the active address of the memory, and W_j is the weighting value. The weighting values are updated based on gradient desired descent method so that the mapping reaches to a desired training signal. Thus, a learning process is adopted to modify the weights through an updating function using the difference between the set of desired parameters and that generated by the CMAC for each training pattern. The updating function is as follows:

$$\widehat{W}_j = \overline{W}_j + \mu \frac{\varepsilon_i}{K} \tag{11}$$

Where j is the stage of the training process, $\overline{W}_j$ and $\widehat{W}_j$ denote the weighting value before and after the j th stage of updating respectively, μ is a learning rate and the output error between desired training signal and output signal is ε_i, i is the number of learning data.

The learning process will terminate when the difference between the sets of parameters generated by the network and the desired sets of parameters for the sampled patterns are within a certain tolerance. One of the supervisor learning for different patterns for CMAC in this paper and the least square error method as the learning performance is used and defined as

$$E = \sum_{j=1}^{D} (y_j - 1)^2 \tag{12}$$

Where D is the pattern data numbers, y_j is denoted the sum of the weighting values of the j th step, and we can defined a positive number of ε as tolerance $(\varepsilon > 0)$ and the learning will be terminate as $E > \varepsilon$.

The procedure of proposed CMAC PMV is described in following steps:

Step1) Setting up the CMAC model. Discretized and quantized the input variables into n associated levels and making a relative levels number from 0 to $2^n - 1$.

Step2) Given the coding of input vector level by means of binary coding.

Step3) Partitioned into nine groups and each group contains four bits, and then rearranges the order from the least signification bit to the most signification bit in sequence.

Step4) Modified the weighting values in the weighting memory according to active addresses of memory.

Step5) Given the training patterns so that start the learning algorithm of CMAC.

Step6) Discretized these 6 input parameters, and finished the procedure of encoding, activing memory, summing up the all of the active weighting values and determined the output value of CMAC PMV.

Step7) Confirming the CMAC PMV whether the thermal comfort level lies between the +0.5 with the -0.5 or not.

Step8) Until the value of PMV is obtained and lie in the range of comfort, the procedure will return the step 5 and change the setting of indoor temperature for comfort achieved

5. ZigBee

Technology of wireless transmission is an important part of smart home control, and it is ZigBee used in this paper to access the transmission of values from sensors and control the power switches of home appliances.

ZigBee is the standard specified in the Wireless Personal Area Network (WPAN) by U.S.A. IEEE 802.15.4. IEEE 802.15.4 defines the physical layer and medium access control layer, and ZigBee defines the internet layer and application layer, etc. Each ZigBee network can has as many as 255 nodes at the same time. It may reach most 65000 networks nodes as install with a coordinator. It has many functions such as low transmission rate, lower power consumption, low price, high safety, capable of using a big amount of nodes to expand the network (such as star shape, net shape and tree shape) so that it has a wide range of applications such as the automation of industries and buildings, personal medical care, smart home control, etc. Working frequency is arranged between 2.4 GHz and 868/915MHz with a working distance around 10 meters. There are three types of devices in the ZigBee wireless network as follows:

1. ZigBee coordinator, ZC. There is only one ZC device in one ZigBee Network as the network control center.
2. ZigBee Router, ZR: it is in charge of tasks such as Routing, Forwarding and Address Allocation.
3. ZigBee End Device, ZED: it is in charge of functions such as sending back data and environmental detection.

This paper uses FT-6251 high power ZigBee basic development package which uses pre-installed humidity and temperature sensor to detect the value of humidity and temperature as shown in Figure 6.

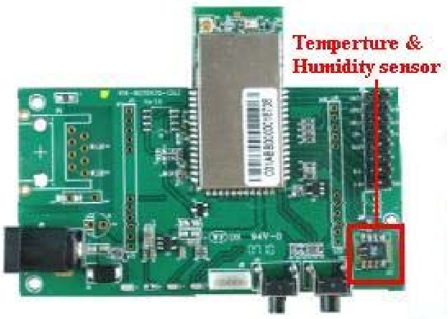

Figure 6. ZigBee Basic development package (FT-6251)

It is FT-6250 high power ZigBee basic development package uses in this study to detect the luminance. It is to connect the light sensor to ADC1 and DAC1 pins as shown in Figure 7 as follows.

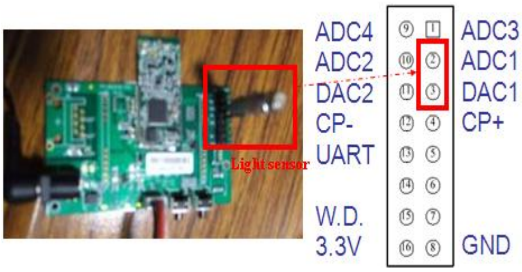

Figure 7. ZigBee Basic development package (FT-6250)

6. Research method

Firstly, we transmit the data from the humidity and temperature sensor, light sensor and wind velocity sensor to another ZigBee module and then transmit the data from the terminal ZigBee module to PC through RS232. Visual Studio 2008 software is used as the development environment interface, and then the information is shown real-time on PDA through Bluetooth as the monitoring system. Figure 8 shows the system framework.

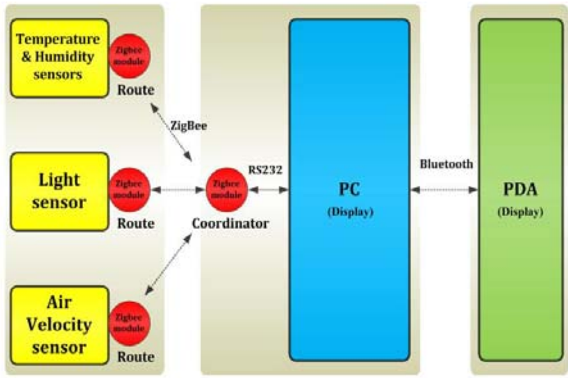

Figure 8. System framework drawing

The received temperature, humidity and wind velocity data detected along with activity level and clothing are brought into PMV formula as input parameters, and the system will analyze whether the environment under the moment is comfortable or not and then identify whether to turn the power of home appliances on/off based on the result.

Finally, we combine CMAC and PMV to adjust and compare with the ideal output values after CMAC quantizes, codes, gives the active memory address and output of summed up weighting values until the learning process is finished. After the parameters are inputted and processed by CMAC, it can get an output after summing up the active weighting memories, which is the result of CMAC neural network to learn PMV value.

6.1 Software framework and development procedure

We use Visual Studio 2008 software as the development environment interface. The development procedure is described in the following four steps.

1. Construct a transmission interface on the personal computer to receive RS232 and set up its communication port and Baud rate.
2. Establish an information interface to receive temperature, humidity, radiant temperature and wind velocity.

3. Put each parameter into the written CMAC PMV formula and show the interface of comfort level and each home appliance (step 1~3 as shown in Figure 9).
4. Using the PDA interface developed by the Smart Device project of Visual Studio 2008 as shown in Figure 10, and transmits the data received by the PC through bluetooth and display the real time result on the PDA.

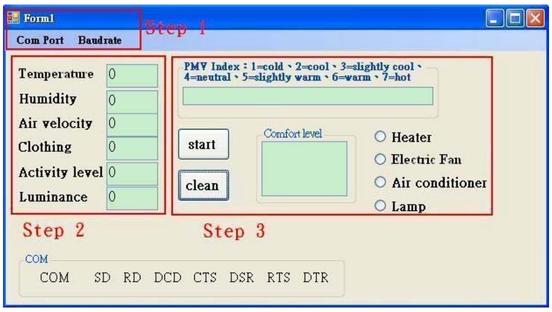

Figure 9. PC interface

Figure10. Development drawing of PDA interface

7. Research Results

In this paper, we install several sensors indoors to show the received data of humidity & temperature, luminance and wind velocity on PC and successfully display the comfort level at the moment after CMAC PMV calculation. Moreover, we simulate three environmental statuses and compare the comfort level at that moment and decide whether to turn on home appliances.

1. People work in the office and the season is spring. According to the comfort level, we set up the active level and clothing as 1.2met and 0.7 clo accordingly. As shown in Figure 11, the comfort level shows “comfortable” which means there is no need to turn on any home appliance and the radiant temperature has reached the standard value and no need to turn on lights or the lights are already on.

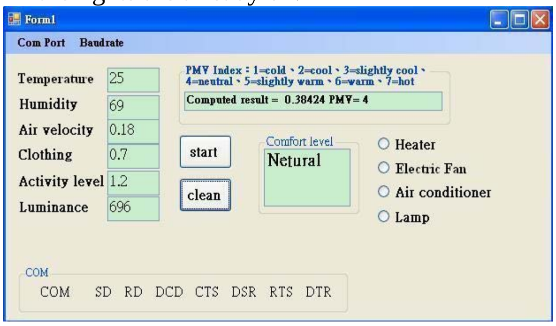

Figure 11. Illustration of the first simulation

2. People are sleeping indoors, and the reason is winter. According to the comfort index, we set up active level and clothing to 0.7met and 0.9col accordingly. As shown in Figure 12, when the comfort result is cold, it will identify automatically and turn on the heater.

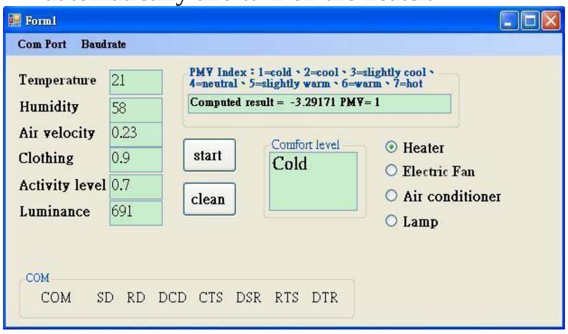

Figure 12. Illustration of the second simulation

3. People are walking indoors and the reason is summer. According to the comfort index, we set up active level and clothing to 1.7met and 0.5clo accordingly. As shown in Figure 13, the comfort status is “warm” and it identifies automatically to turn on the air conditioner.

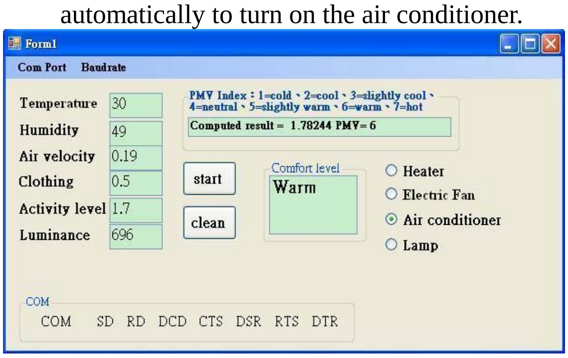

Figure 13. Illustration of the third simulation

As for the identification of turning on lights, according to CNS luminance standards, the radiant temperature for general office space is 500~750Lux. If it’s space for delicate operation, it rises to 750~1000Lux. Therefore, the identification to turn on the electric lights is based on whether the mean luminance is under 500Lux or not as shown in Figure 14.

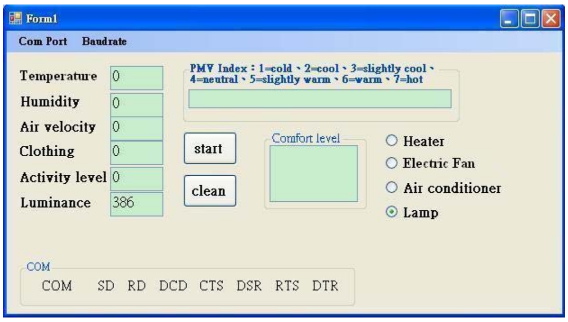

Figure 14. When the luminance is under 500Lux, it will identify and turn on the lights

The results above show that in this research, it can display the comfort level at the moment based different environmental parameters, and identify automatically whether it needs to turn on any home appliance. At the end, it transmits the various data from PC to PDA through bluetooth transmission for monitoring and display as shown in Figure 15. It successfully displays a various data to achieve the effect of controlling the indoor environment parameters anytime and anywhere.

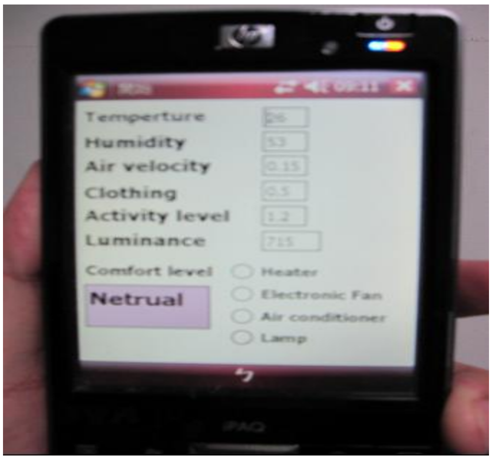

Figure 15. Successfully displays a various data on PDA

8. Conclusions

A wireless sensor system in smart home has been constructed in this paper. This system includes ZigBee to ZigBee, Zigbee to PC and PC to PDA transmit interfaces. In order to obtain an ideal environment which not only comfortable but also saving energy, we proposed a CMAC PMV algorithm to detect thermal comfort level and easily implemented in this system. In addition, we easily monitor and control the indoor environment parameters by use of PDA through Bluetooth transmit, and the PDA is successfully developed as an intelligent portable device in this paper.

References

[1] P. O. Fanger, “Thermal Comfort,” Analysis and application in Environment Engineering, New York, McGraw Hill,1972.

[2] Emerson Donaisky, Gustavo H. C. Oliveira, Roberto Z. Freire and Nathan Mendes, “PMV-Based Predictive Algorithms for controlling Thermal Comfort in Building Plants,” IEEE 22nd International Symposium Intelligent Control, pp.182 - 187 ,October. 2007.

[3] E. Rutman, C. Inard, A. Bailly and F. Allard, “A global approach of indoor environment in an air-conditioned office room,” Building and Environment, vol. 40, pp. 29-37, January 2005.

[4] E. L. Kruger and P. H. T. Zannin, “Acoustic thermal and luminous comfort in classrooms,” Building and Environment, vol. 39, pp. 1055-1063, September. 2004.

[5] N. S. Pai, H. Y. Hou, “Thermal Comfort Index Based on CMAC Neural Network,” Proceedings of the Third Intelligent Living Technology Conference, 2008.

[6] J. S. Albus, “A new approach to manipulator control: the cerebeller Model articulation controller (CMAC),” Trans. ASME J. Dynam. Syst. Meas. And Contr, vol. 97, pp. 220-227, 1975.

[7] J. R. Chang Chien and C. C. Tai, “The information home appliance control system - a Bluetooth universal type remote controller,” Proceedings of IEEE International Conference on Networking, Sensing and Control 2004, vol. 1, pp. 399-400, 21-23. March 2004.

[8] Akira Saito, Masteru Minami, Yoshihiro Kawahara, Hiroyuki Morikawa, and Tomonori Aoyama, “Smart Baton System: a universal remote control system in ubiquitous computing environment,” Proceedings of IEEE International Conference on Consumer Electronics (ICCE) 2003, pp .308-309, 17-19. June. 2003.

[9] J. Y. Jung and J. W. Lee, “ZigBee device access control and reliable data transmission in ZigBee based health monitoring system,” in Proceedings- 10th International Conference on Advanced Communication Technology, ICACT 2008, Phoenix Park, South Korea, February 17-20 2008, pp. 795-797.

[10] International Standards Organization (ISO), Geneva, ISO7730, “Moderate Thermal Environments-Determination of the PMV and PPD indices and specification of the conditions for thermal comfort,” 1994.