Comfort of Air Conditioning Using Sensor Networks with Game Theory*

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ABSTRACT

Air condition systems control the factors such as temperature and humidity to make people feel comfortable. But there are still many dynamics such as human entering in the environment deployed with the air condition systems. Although many control strategies are proposed to deal with dynamic environments. Most of the currently air condition systems try control the dynamics with the information provided by simple thermometers. With a sensor network, the information of the target environment can be fully collected instantly. Such information can be used by air condition systems to adjust the control scheme to provide a comfortable environment. However, there are always finite devices in an air condition system, and need to be well arranged to service the whole environment. The paper proposes an Intelligence Appliance with Air Condition System which adopts game theory for the arrangement of the resources of an air condition system based on the information collected by wireless sensor networks. A control system is implemented to verify the proposed system.

1: INTRODUCTION

Feeling comfortable for human bodies can be viewed as the fulfillment of a series of control factors, such as temperature, humidity and wind speed. But the definition of comfortable is different among different people. Comfort models are proposed to estimate the air condition. Predicted Mean Vote (PMV) and Predicted Percent. Dissatisfied (PPD) are two of the most often used models. Table 1 is the PMV mapping table. And PPD is defined as:

Table 1. PMV mapping

Item	Scale(PMV)	Range	Thermal Sensation
PMV	+3	+2.5< PMV≦+3.5	Hot
	+2	+1.5< PMV≦+2.5	Warm
	+1	+0.5< PMV≦+1.5	Slightly warm
	0	-0.5< PMV≦+0.5	Neutral
	-1	-1.5< PMV≦-0.5	Slightly cool
	-2	-2.5< PMV≦-1.5	Cool
	-3	-3.5< PMV≦-2.5	Cold

$$PPD = 100 - 95 * e^{\{-(0.03353 PMV^4 + 0.2179 PMV^2)\}} \quad (1)$$

According to the PMV and the two node model, the ANSI-51 defined the Effective Temperature:

$$^*ET = t_0 + W * i_m * LR * \left(P_a - 0.5 * P_{^*ET,s}\right) \quad (2)$$

where $t0$ is the operative temperature, W is the skin wettedness, i_m is the moisture permeability index and LR is the Lewis Ratio. These models provides standard for the design of air condition systems. But there are still many other factors affect the comfort in an air condition system. The most important one is the sensing density and precision of the environment thermal or humidity information. Wireless sensor networks [1] can help to collect instant information densely. But the heat source of the environment can be changing all the time such as human entrance or leave. Decision making according the information collected instantly by the wireless sensor network is than the new challenge for the air condition system design. In the paper, game theory is adopted to help the decision making of arrangement of the resource of the air condition system.

The rest of the paper is organized as follows: Section 2 describes the architecture of the proposed Intelligence Appliance with Air Condition System (IA2CS) and Section 3 details the implementation of the system. Experiment results are shown in the Section 4 and finally the conclusions are given in Section 5

2: Intelligence Appliance with Air Condition Systems (IA2CS)

Fig. 1 shows the model of the proposed Intelligence Appliance with Air Condition Systems (IA2CS).

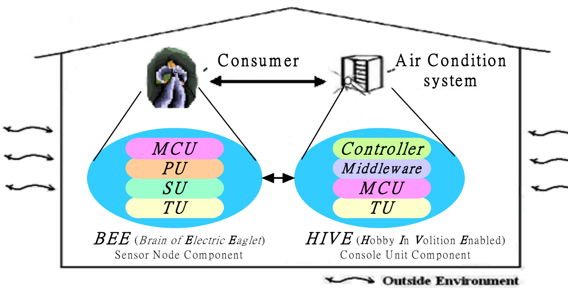

Fig. 1 Model of the IA2CS

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1. Customer/Buyer: Human in the environment with the air condition systems. They also play the roles of the buyer in the game.
2. Air conditioner/Seller: Air condition output producer, also the seller of the game. They are the resources to be arranged.
3. Sensor node: The sensing device of the control factors, such as temperature, humidity and the air quality. It plays the role of collecting data and is so called Brain of Electricity Eaglet (BEE).
4. Console unit (CU): Composed of controller, middleware and transceiver. It makes decisions according the data collected by BEE and is called Hobby In Volition Enable (HIVE).
5. Outside environment: The environment is not isolated and there will be energy transformation between the environment and the outside environment.

Signaling of the IA2CS model is shown in Fig. 2.

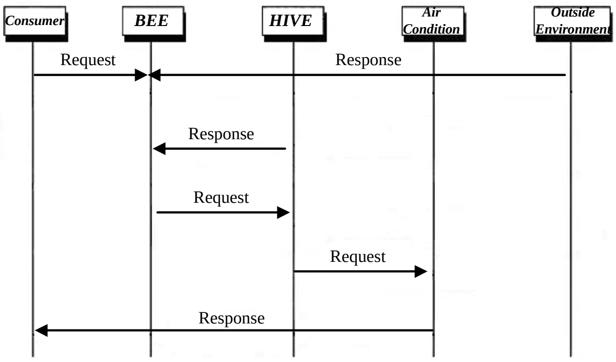


Fig. 2 The signaling of the IA2CS model

Three important factor of air condition systems are comfortable, power saving and locality. In the paper, four models of the game theory are adopted. They are the NCG, AA, HLG and the HPG models, respectively. There are some restriction for the four models, and should be modified to apply to the proposed system. First we list the restriction below.

1. NCG model focuses on the strategy that reaches the results but not finding the estimation of stable results.
2. AA decreases fixed quantity each time, and finish the transaction after the buyer makes the decision. There are some approaches that improve the model [2] [3].
3. HLG in the linear mode has not equilibrium among three or more competitors [4].
4. In linear mode, devices are in different location in the HLG mode, but where the location is on a circle, every node has the distance from the center of the circle. There are no CSC differences among the buyers [5], as in Fig. 3.
5. HPG model should map the comfort level previously.

By modifying the models, circular location is adopted, and all devices interact with NCG model. AA model is used as operating range and comfort level degree to help the system achieve best results. Finally, there are two BEE access models proposed in the system, Random Access BEE Model (RABEEM) and the Location Access BEE Model (LABEEM). In the

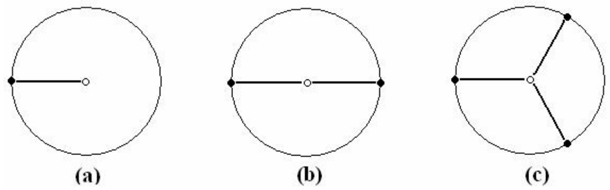


Fig. 3 Circular location (a) same side (b) 180° (c) 120°

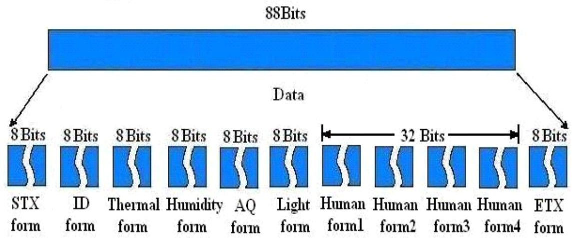


Fig. 4 The packet format of the BEE module

proposed IA2CS system, the data communication interface is RS-232. And the packet format of the proposed system is customized for the beacon of different devices. The customized packet format is shown in Fig. 4.

The algorithm of the proposed IA2CS system is

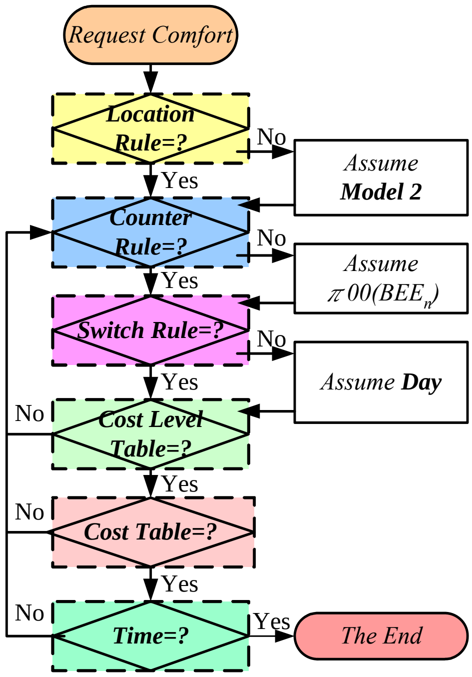
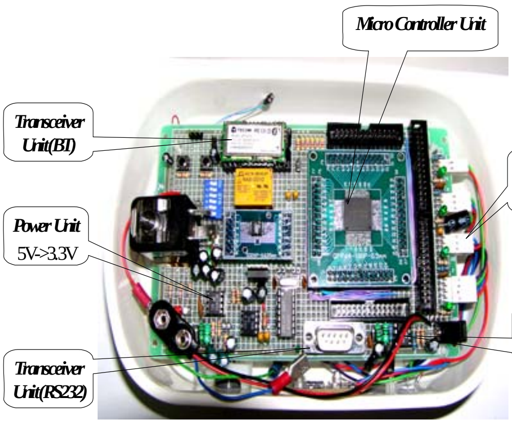


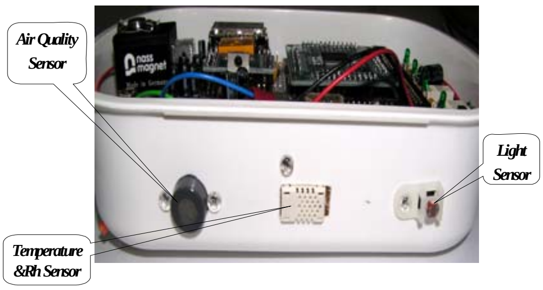
Fig. 5 The procedure of the algorithm

described as follows.

1. After system initiated, the BEE module will select the Location Rule (*LR*). There are three models for the Location Rule: Model 1 is NORMAL model; Model 2 is the RABEEM and Model 3 is the LABEEM. The Location Rule defines the parameters of the three models. The parameter includes time needed ($\boldsymbol{BEE}_{nT}$), comfort level ($\boldsymbol{BEE}_{\gamma n}$) and costs ($\boldsymbol{BEE}_n^R$).
2. The BEE module collects the data and the HIVE module outputs the rules for the data.



(a)



(b)

(c)

Fig. 6 The implementation of the BEE module

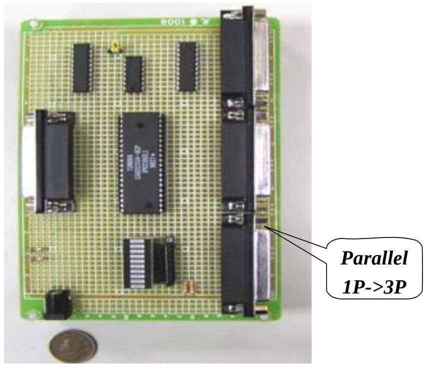
3. Check the data enter the comfort level range and fulfill the Counter Rule (*CR*).
4. Compare the factors with the Comfort Level Table (*CLT*). If all the factors meet the requirement. The decision is done and returns.

The detail procedure is shown in Fig. 5

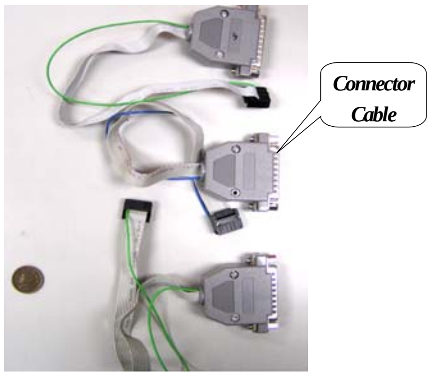
3: Implementation of the IA2CS

There are two main modules of the IA2CS, the BEE module and the HIVE module. The BEE module composes of the following components:

1. Power unit: For the different DC voltage requirement, a regulator is used.
2. Transceiver unit: A Bluetooth module is used for the data transmission in the BEE.
3. Micro controller unit: a 16 bit, 20MHz M16C/62 chip is used as the micro controller.
4. Sensor unit: sensors that can sense temperature, humidity, light, air quality and human trigger.



(a)



(b)

(c)

Fig. 7 The implementation of the HIVE module

Fig. 6 shows the implementation of the BEE module. The details of the HIVE module are described below:

1. Circuits between he host and the 8255 chip help to control the output to the parallel ports according to different requirement of the system. The host use the circuits to program the 8255 chip and thus control the parallel ports connect to the chip to output control messages of the system requirements.
2. Circuits between 8255 chip and the parallel ports transmit the message from 8255 chip to parallel ports.
3. Circuits between HIVE control port and the 74HC4066 chip.
4. Circuits of the controller design to controller the remote controller of the air condition machine.

Fig. 7 shows the implementation of the HIVE module. LEDs are added in the system for the status display and debug. Table 2 shows the development tools of the IA2CS system.

Table 2 The development tools

Item	Contest(Vendor)	Remark(user)
ORCAD v9	Draw circuit	Initial plan(HIVE)
M30620-CPE	Emulator(Renesas)	Test coding function(BEE)
NC30UE	Ansi C	Programming(BEE)
PD30ne	Monitor test results	View various parameter(BEE)
Visio 2002	Draw related figures	Paper figure(HIVE)

4: EXPERIMENTS

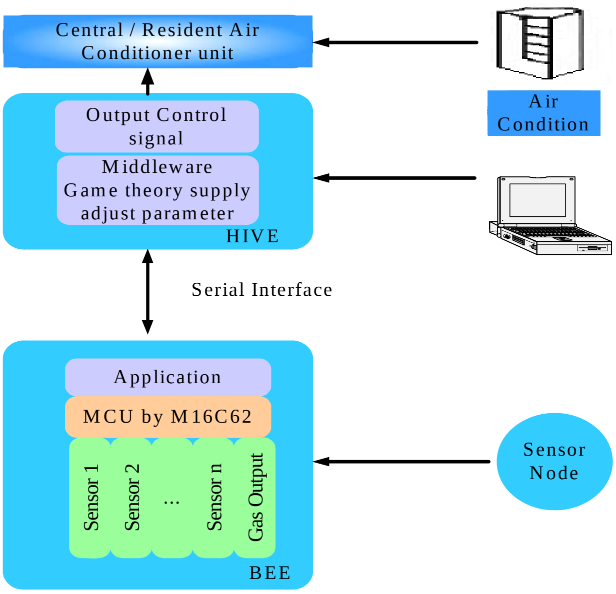


Fig. 8 Architecture of the experiments

Fig. 9 The location of the BEE module

The architecture of the experiments is shown in Fig. 8. 5 BEEs are deployed in the environment throughout the all experiments, and the locations of the BEE modules are shown as in Fig. 9. There are 3 air condition machines deployed in the environment and the location of the air condition machines is shown in Fig. 10. Models used for the experiments are NORMAL, RABEEM and LABEEM.

Experiment 1: High comfort level test.

The experiment tests the capability of providing comfortable environment of three models. In the experiment, the temperature is set to be the summer air condition factor with a 2°C to 4°C tolerance. Three models are experimented in different time at the same day. Time interval of individual test is 2 hours. For each model, the result is observed after half an hour operating. The result shows that the NORMAL model has the best performance; the RABEEM has the second best performance than the LABEEM. That is because the number of the air condition machines is not enough to cool down the whole environment. For such situation, the proposed models need time to decide to do nothing, as the NORMAL model does at the beginning. And thus achieve the same comfort level a little bit latter than the NORMAL model.

Experiment 2: Medium comfort level test.

In the experiment, the temperature is set to be the summer air condition factor with a 4°C to 6°C tolerance. T hree models are experimented in different time at the same day. Time interval of individual test is 2 hours. For each model, the result is observed after half an hour operating. The result shows that the LABEEM outperforms than other two models.

5: CONCLUSIONS

In the paper, the Intelligence Appliance with Air Condition System (IA2CS) is proposed to arrange the resources in an air condition system to achieve the comfortable factors, such as temperature and humidity as required in the whole environment. A wireless sensor network is adopted as bees to collect the information of factors to help to make decisions for the resources arrangement. Three models based on the game theory are proposed to arrange the resources of the air condition systems. The system is implemented and experiments are done to verify the proposed arrangement algorithms. Control factors are temperature and humidity. The experiments show that the system can effectively provide a comfortable air condition environment when there are enough resources or air condition machines.

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