

PID Control Aided Thermal Comfortable of the User's Temperature Tracing Movable Electrical Heating Radiator

Haolin Zou*, Zhongyong Wang*, Pao-An Lin**, Weilong Zhan*, Peixin Chen*,
Yuxin Li***, Yuyang Chen*, Zide She*, Juhui He*, [Bing-Yuh Lu*](mailto:franklinlu888@outlook.com)

*Faculty of Automation, Guangdong University of Petrochemical Technology, Maoming City, Guangdong, China

**Faculty of Physics, Guangdong University of Petrochemical Technology, Maoming City, Guangdong, China

***Faculty of Electronic information engineering, Guangdong University of Petrochemical Technology, Guangdong, China.

franklinlu888@outlook.com

Abstract— This study presents a movable electrical heating radiator with the function of user's temperature tracing and constant temperature control to enhance the thermal comfortable of the users. The system was modified by the previous studies in our laboratory. The control unit engaged Holtek HT66F2390 which is a newly designed microcontroller in China. The thermal sensing camera detected the user's temperature and transferred the data to microcontroller to move and follow the user up. The results display the reliable performance of system operations. The better distance between user and the traditional heat radiator is 150 to 250 cm. However, the distance might too long in a small space or room. Therefore, we reduce the distance to 50 cm and keep the thermal comfortable by PID control of output heating power of the radiator.

Keywords—heat radiator, user's temperature PID control, thermal comfortable, Holtek MCU.

I. INTRODUCTION

Lo et al. [1] announced a patent regarded to heating radiator with multiple sensing and control functions which included the voice controlled applications. Xu et al. [2] studied on the user's voice command input into the microphone and the voice was recognized by the Arduino UNO with voice recognition module to turn the power switches on or off. Li et al. [3] presented the wireless voice-controlled movable electrical heating radiator which based on the prototype Xu et al's study [2] and improved the functions of button or voice controlled the radiator by smartphone APP; heat radiation power control, moving control and timing control; and feedback artificial synthesis voice for instruction, temperature feedback, and ultrasonic sensing for anti-collision.

However, the comfortability of the user is one of the crucial necessities of the electrical applications. Therefore, the idea of

the user's temperature tracing system has been developed in this study. Originally, the thermal comfortable is defined by Fanger [4] and standardized by ISO 7730 [5]. Fanger hypothesized that user's thermal comfort was intuitively decided by one's skin temperature and their sweat secretion. The trade-off of the two factors narrowed the comfortability in a little range. Furthermore, ISO 7730 formulized the equations of comfortability. In comfortable conditions, the person almost does not sweat, the physical workload is low, the clothing is light, there is almost no heat radiation, and the air temperature is between 18 and 25 °C. Therefore, thermal comfortable is described by tow indexes. One is the prediction of the mean value of votes of a group of occupants on a seven-point thermal sensation scale (PMV), the other is the index that establishes a quantitative prediction of the percentage of thermally dissatisfied occupants (i.e., too warm or too cold), can be determined (PPD). Fanger [5] established a model of correlation between the subjective human perception, expressed through the vote of comfort on a scale ranging from -3 (very cold) to +3 (very hot), and the difference between the heat generated and the heat released by the human body. The ranges of PMV values from -0,2 to 0,2, -0,5 to 0,5 and -0,7 to 0,7 map to PPD values below 6, 10 and 15%, respectively. The distribution of PMV v.s. PPD displays the thermal comfortable in a form of quantitative analysis which was presented in this study to compare the thermal comfortable between with and without the function of user's temperature tracing.

This study aimed at the users' thermal comfortable and employed a Holtek HT66F2390 chip as the microcontroller to control the motors of the carrier of the heating radiator, send the user's temperature data to the ESP8266 communication module, and read the distance data to avoid the collision and so on. The electrical heating radiator device can reads the user's temperature data and transmits it to the server on the

Internet. The user can control the server via an app installed on a smartphone to calculate a comfortable temperature for the current environment based on PMV. The electrical heating radiator device obtains this temperature from the server and determines the output power of heating radiation to meet the user's comfort level through a proportional-integral-derivative (PID) control algorithm with pulse width modulation (PWM) technology [6-8].

II. METHODS

A. System structure

The system block diagram is presented in Fig. 1. The microcontroller Holtek HT66F2390 connected with ESP8266 to communicate with the server through the APP in smartphone to interactively transfer user input, and send the status of the system. In addition, the microcontroller connected with 2 sensors and 2 drivers. In the parts of sensors, the infrared temperature imaging sensor (AMG 8833) was employed to sense the temperature distribution of the user's body. Besides, the ultrasonic distance sensor (HC-HR 04) was used to avoid the collision of the object when the radiator was moving and protect the users when they were almost touching to the radiator. In the parts of drivers, the PWM module (YYAC-3) received the digital values, which were computed by the formulas of thermal comfortable, from microcontroller to modulate the output power of the electrical heating radiator to keep the user's temperature of the users constantly. In addition, the motor driver (L298N) also received the digital values from microcontroller to control the rotation speeds of the motors that were connected with the wheels. The power supply of the system was 220 V AC which was converted to DC power sources for the operations of the digital system in this radiator.

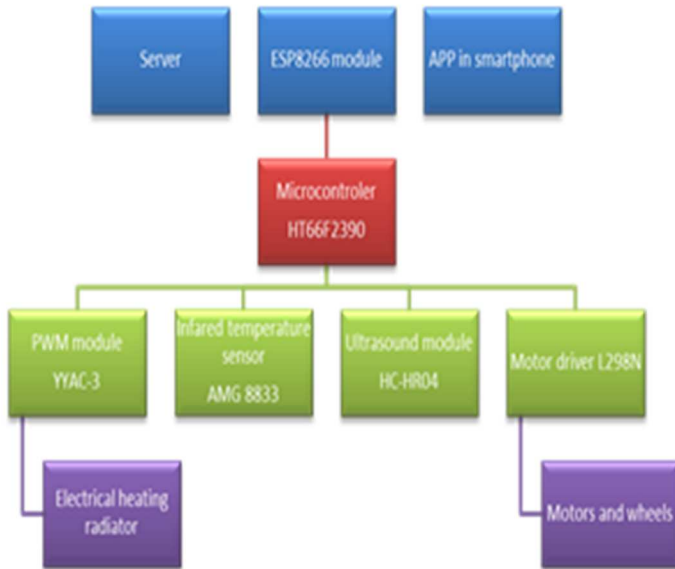


Figure 1. The system structure of the heating radiator

B. Computation of thermal comfortable

PMV can be computed by the following equations,

$$PMV = [0,303 \cdot e^{(-0,036 \cdot M)} + 0,028] \cdot \left\{ \begin{aligned} &(M - W) - 3,05 \cdot 10^{-3} \cdot [5733 - 6,99 \cdot (M - W) - p_a] \\ &- 0,42 \cdot [(M - W) - 58,15] \\ &- 1,7 \cdot 10^{-5} \cdot M \cdot (5867 - p_a) - 0,0014 \cdot M \cdot (34 - t_a) \\ &- 3,96 \cdot 10^{-8} \cdot f_{cl} \cdot [(t_{cl} + 273)^4 - (\bar{t}_r + 273)^4] \\ &- f_{cl} \cdot h_c \cdot (t_{cl} - t_a) \end{aligned} \right\} \quad (1)$$

$$t_{cl} = 35,7 - 0,028 \cdot (M - V) - I_{cl} \cdot \left\{ \begin{aligned} &3,96 \cdot 10^{-8} \cdot f_{cl} \cdot [(t_{cl} + 273)^4 - (\bar{t}_r + 273)^4] \\ &+ f_{cl} \cdot h_c \cdot (t_{cl} - t_a) \end{aligned} \right\} \quad (2)$$

$$h_c = \begin{cases} 2,38 \cdot |t_{cl} - t_a|^{0,25} & \text{for } 2,38 \cdot |t_{cl} - t_a|^{0,25} > 12,1 \cdot \sqrt{v_{ar}} \\ 12,1 \cdot \sqrt{v_{ar}} & \text{for } 2,38 \cdot |t_{cl} - t_a|^{0,25} < 12,1 \cdot \sqrt{v_{ar}} \end{cases} \quad (3)$$

$$f_{cl} = \begin{cases} 1,00 + 1,290 l_{cl} & \text{for } l_{cl} \leq 0,078 \text{ m}^2 \cdot \text{K/W} \\ 1,05 + 0,645 l_{cl} & \text{for } l_{cl} > 0,078 \text{ m}^2 \cdot \text{K/W} \end{cases} \quad (4)$$

where the different terms represent, respectively:

M is the metabolic rate, in Watt per square meter (W/m^2); W is the effective mechanical power, in Watt per square meter (W/m^2); I_{cl} is the clothing insulation, in square meters Kelvin per watt ($\text{m}^2 \text{K/W}$); f_{cl} is the clothing surface area factor; t_a is the air temperature, in degrees Celsius ($^{\circ}\text{C}$); $\bar{t}_r$ is the mean radiant temperature, in degrees Celsius ($^{\circ}\text{C}$); v_{ar} is the relative air velocity, in meters per second (m/s); p_a is the water vapor partial pressure, in Pascal (Pa); t_{cl} is the clothing surface temperature, in degrees Celsius ($^{\circ}\text{C}$).

The computation of PPD which is based on PMV is followed the equation:

$$PPD = 100 - 95 \cdot e^{-0,03353 \cdot PMV^4 - 0,2179 \cdot PMV^2} \quad (5)$$

In this study, the algorithm of computation of thermal comfortable is installed in the server. The thermal camera detected the temperature of the user i.e. t_r , and sent the data to the sever for computation the thermal comfortable to adjust the output heat power by PID controller.

C. PID controller

The functional block diagram of PID control is presented in Fig. 2. In this figure, sp is the set-point, e is the error, that is

$$e[n] = sp[n] - t_r[n] \quad (6)$$

u is the output of the PID controller. The PID control algorithm for the temperature control can be described by the following equation:

$$u[n] = K_p \cdot e[n] + K_i \cdot \sum_{k=0}^n e[k] + K_d \cdot (e[n] - e[n-1]) \quad (7)$$

where K_p , K_i , and K_d are the coefficients of proportional, integral, and differential controls, respectively [9].

D. Experiment

For the evaluation the thermal comfortable of the heating radiator, an experiment was designed for measuring the temperature of users to compute PMV and PPD indexes. The distances between the user and the heating radiator were from 50 to 250 cm with the step of 50 cm under the condition of the same output heating power. The moveable radiator stayed at every step for 120 seconds. The conditions were as follows, $t_a=12.5^\circ\text{C}$, $M=1$ met, $f_{cl}=1.1$ clo, and relative humidity=50%.

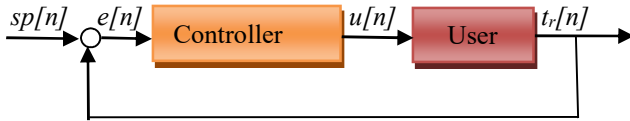


Figure 2. Functional block diagram of the PID controller in this system.

III. RESULTS

A. System

The implementation of the system was displayed in Fig. 3. From top to bottom, there are heating radiator, infrared camera, ultrasonic modules and carrier. The function of tracing is implemented by the interlocking sensing of infrared camera, and ultrasonic detectors. The power control of heat radiation which is modulated by PWM is achieved by PID control algorithm where $K_p=65$, $K_i=0$, and $K_d=55$. Therefore, user's temperature can be approached constantly.



Figure 3. The user's temperature tracing voice-controlled movable electrical heating radiator.

B. Thermal comfortable of traditional mode (without control)

The sequence of measured PMV index without output power control radiator (traditional radiator) was presented in

Fig. 4. The X axis is time in sec. and left Y axis is the value of PMV index. In addition, the right Y axis is the distance between heat radiator and the subject, i.e. d . Therefore, d was adjusted with the step of 50 cm from $d=50$ cm to $d=250$ cm in every 2 minutes. In the duration of 0 to 2 minutes, the heat radiator turned on, and the PMV index changed from -0.5 to +2.5 rapidly. Obviously, d is too small so that the user's temperature increased very speedy.

In the duration of 2 to 4 minutes, the value of PMV index reduced between +1 and +1.5 when $d=100$ cm. Consequently, it went to the next 2 minutes. the value of PMV index reduced between +0.5 and +1.0 when $d=150$ cm. In the duration of 6 to 8 minutes, the value of PMV index reduced between 0 and +0.5 when $d=200$ cm. Finally, in the duration of 8 to 10 minutes, the value of PMV index reduced between -0.5 and 0 when $d=250$ cm.

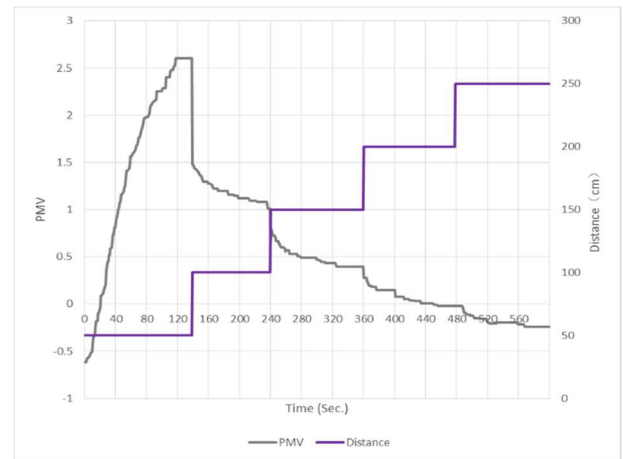


Figure 4. Measured PMV index (traditional mode)

The sequence of PPD index of this experiment was presented in Fig. 5. The X axis is time in sec., the left Y axis is the value of PPD index, and the right Y axis d . In the duration

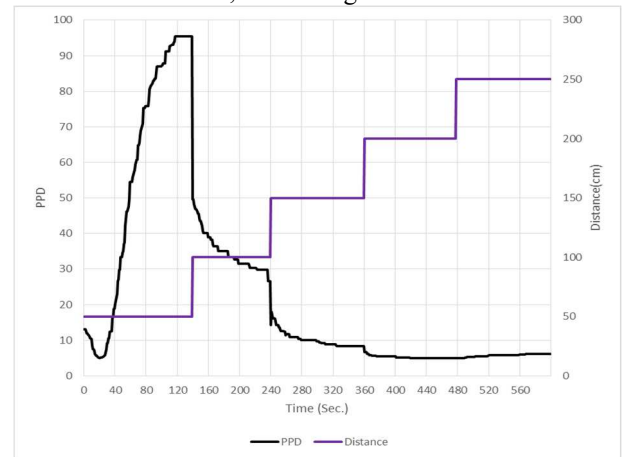


Figure 5. Measured PPD index (traditional mode)

of 0 to 2 minutes, the heat radiator turned on, and the PPD index changed from 5% to 95% rapidly. In the duration of 2 to 4 minutes, the value of PPD index was between 30% and 95% when $d=100$ cm. Consequently, it went to the next 2 minutes.

the value of PPD index reduced between 10% and 20% when $d=150$ cm. In the duration of 6 to 8 minutes, the value of PPD index reduced between 5% and 10% when $d=200$ cm. Finally, in the duration of 8 to 10 minutes, the value of PPD index was around 5% when $d=250$ cm.

C. Thermal comfortable of PID controlled mode

In this experiment, $d = 50$ cm. The PMV and PPD index in Figs. 4 and 5 indicated the values are around 2.5 and 95%, respectively. Therefore, the user feels little hot or hot. However, we activated the PID controller to adjust the output heat power of the radiator for constantly keeping the user's temperature. Consequently, the comparisons of PMV and PPD indexes between traditional mode (without feedback control) and PID control mode are presented in Figs. 6, and 7, respectively. In Fig. 6, PMV index are almost approaching to 0 after the 30th sec. In Fig. 7, PPD index are almost approaching to 5% after the 30th sec. It keeps in the state of "comfortable". Therefore, the design of PID controller works!

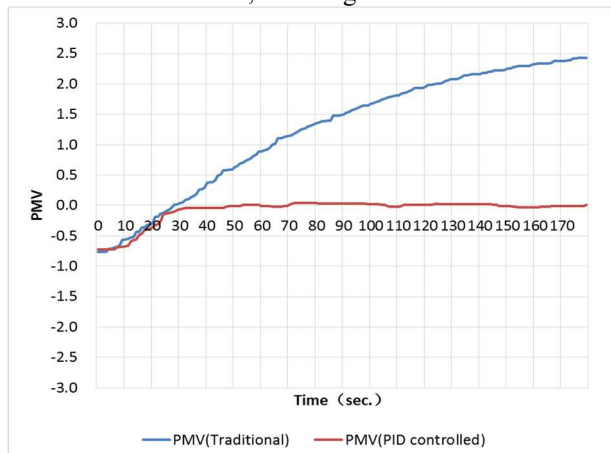


Figure 6. Comparison of PMV index between traditional mode (without feedback control) and PID control mode

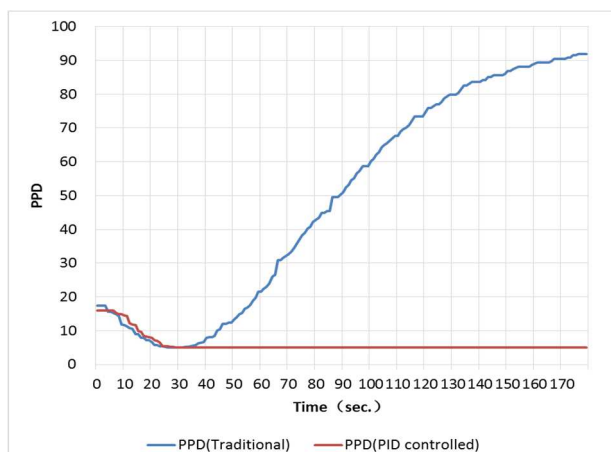


Figure 7. Comparison of PPD index between traditional mode (without feedback control) and PID control mode

IV. DISCUSSION

The scales of PMV index is from -3 to +3. The scales -3, -2, -1, 0, +1, +2, and +3 indicate "too cold", "cold", "little cold", "comfortable", "little hot", "hot", and "too hot", respectively.

The thermal comfortable can be categorized to Classes A, B, and C (Table 1).

TABLE 1. CATEGORIES OF THERMAL COMFORTABLE

Class	PMV	PPD (%)
A	-0.2~+0.2	6
B	-0.5~+0.5	10
C	-0.7~+0.7	15

The traditional mode of heating makes some one feel comfortable at $d=150$ to 250 cm. However, the distance might too long in a small space or room. It is notable that the PID control mode of heating can constantly keep the user's temperature when $d=50$. This mode can solve the distance limitation of the traditional mode for achieving the thermal comfortable.

V. CONCLUSION

This study examined PMV and PPD indexes of a user's temperature tracing voice-controlled movable electrical heating radiator of the different distances between user and radiator. The better distance between user and the traditional heat radiator is 150 to 250 cm. However, the distance might too long in a small space or room. Therefore, we reduce the distance to 50 cm and keep the thermal comfortable by PID control of output heating power of the radiator.

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Haolin Zou is a student with Faculty of Automation, Guangdong University of Petrochemical Technology, Guangdong, China. He is the winner of Silver award in the embedded system design competition of China in 2020 and Golden award in the embedded system design competition of Southern China in 2020, respectively. His interests of research fields are face detection, and embedded system.



Zhongyong Wang received his BS in electrical engineering from Shandong Agricultural University in 1996, MS in electrical engineering From Huaqiao University in 2003, and PhD in electrical engineering from Guangxi University in 2008. He is currently a Dean with Faculty of Automation, Guangdong University of Petrochemical Technology, Maoming City, Guangdong, China. He was an instructor, associate professor, and full professor with Department of Fujian Wuyi university, Wuyishan City, China during 2003 to 2014. His academic interests focus on circuit design, microcontroller applications, embedded system applications, electrical engineering and digital signal processing.



Pao-An Lin received his BS degree in physics from National Tsing Hua University and his MS and PhD degrees in physics from National Tsing Hua University in Taiwan in 1997, 1999, and 2006, respectively. He was an instructor at the Department of Physics, National Tsing Hua University, and served as a post-doctor in academia sinica, Taiwan during 2006-2012. He also joint department of physics in University of Illinois at Urbana-Champaign (UIUC) as a visitor scholar, 2009. He served as a Researcher in CMS, ITRI, Taiwan since 2014. He is currently an associate professor with Faculty and Department of Physics, Guangdong University of Petrochemical Technology, Guangdong, China. His academic interest is condensed matter physics, especially on superconductivity, multiferroics, and topological insulator.



Weilong Zhan is a student with Faculty of Automation, Guangdong University of Petrochemical Technology, Guangdong, China. He is the winner of Silver award in the embedded system design competition of China in 2020 and Golden award in the embedded system design competition of Southern China in 2020, respectively. His interests of research fields are IoT, and embedded system.



Peixin Chen is a student with Faculty of Automation, Guangdong University of Petrochemical Technology, Guangdong, China. He is the winner of Silver award in the embedded system design competition of China in 2020 and Golden award in the embedded system design competition of Southern China in 2020, respectively. His interests of research fields are applications of server, and embedded system.



Yuxin Li is currently a student with Faculty of Electronic information engineering, Guangdong University of Petrochemical Technology, Guangdong, China. He is the winner of Copper award in the embedded system design competition of Southern China in 2020. His interests of research fields are applications of microcontroller, and embedded system.



Yuyang Chen is a student with Faculty of Automation, Guangdong University of Petrochemical Technology, Guangdong, China. She is the member and winner of the student competition of innovation and creation proposal which is currently supported by Government of Guangdong Province, China. Her interests of research fields are applications of server, and embedded system.



Zide She is a student with Faculty of Automation, Guangdong University of Petrochemical Technology, Guangdong, China. He is the student leader and winner of the student competition of innovation and creation proposal which is currently supported by Government of Guangdong Province, China. His interests of research fields are applications of microcontroller, and embedded system.



Juhui He is a student with Faculty of Automation, Guangdong University of Petrochemical Technology, Guangdong, China. He is the member and winner of the student competition of innovation and creation proposal in Faculty of Automation, Guangdong University of Petrochemical Technology. His interests of research fields are IoT, and embedded system.



Bing-Yuh Lu received his BS in electrical engineering from National Central University in 1988, MS in electrical engineering from National Taiwan University in 1993, and PhD in electrical engineering from National Taiwan University in 2000. He is currently a professor with Faculty of Automation, Guangdong University of Petrochemical Technology, Maoming City, Guangdong, China. He was an instructor, associate professor, and full professor with Department of Electronic Engineering, Tunghan University, New Taipei City, Taiwan during 1993 to 2020, as well as an adjunct associate professor with the Department of Business Administration, National Taipei University of Business, Taipei, Taiwan during 2014 to 2016, and was the director of Department of Information Management, Catholic St. Mary's Medicine, Nursing, and Management College, YiLan County, Taiwan during the intervening years of 2011 to 2013. He is a member of IEEE. His academic interests focus on acoustics, educational applications of engineering, medical engineering and pulmonary signal processing.