

An Energy-saving Fuzzy Control Fan Array with Bluetooth Received Signal Strength Indicator Sensing

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In this study, we developed a group of multipoint user location sensing fans to achieve an energy-saving control system. In general, a fan has functions of cooling and exhausting, depending on the use scenario. The proposed system employs the wireless signal strength of a user's mobile device to control the fan speed by multipoint position sensing. The signal strength is suitable for use as a control parameter to allow the wind speed to be stabilized to achieve a comfortable environment, and the results of the calculation of the fan group energy efficiency control algorithm based on the multipoint location information established in this paper are compared with the actual measured values validated to achieve an energy-efficient fan control system.

1. Introduction

In this paper, we propose a smart control fan group with Bluetooth received signal strength indicator (RSSI) sensing. To establish group fan control, we have to solve two major issues. The RSSI of Bluetooth is unstable owing to the environment background noise and various electrical devices (e.g., smartphone, laptop, and Wi-Fi access point), so we used a Kalman filter to reduce interference. The system has a multiple-input multiple-output (MIMO) architecture as shown in Fig. 1. We used a fuzzy controller to reduce the complexity of the algorithm used to control the system.^(1–11) The micro-controller analysis and optimization of RSSI are applied to the fan speed control,^(12–16) and a fuzzy controller system, based on the value of the processed RSSI, is used, which is the basis for determining the distance between the user and the fan. In the group system, the speed of the fan closer to the user is calculated through the algorithm, and the fan speed is adjusted instantly. The other fans reduce the speed to save energy.^(17–21)

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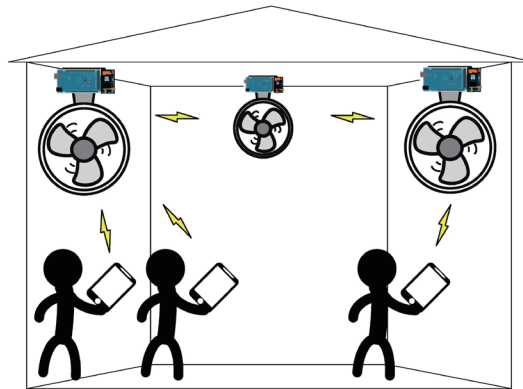


Fig. 1. (Color online) Energy-saving control system for fan group.

2. Hardware Equipment

In this study, we used the Nordic 52 DK development board shown in Fig. 2. This board includes the micro-controller CortexM4 and a built-in Bluetooth hardware core. Because of the high computing power, Bluetooth transmission supports many-to-many Bluetooth connectivity and the master–slave mode. Although its development is difficult, it has a high flexibility in Bluetooth communications. In this study, we used three Nordic 52 DK development boards and three ceiling fans (one is shown in Fig. 3) in the experiment. Our purpose is to make the system achieve the group energy-saving function.

2.1 Test environment

We performed measurements at the basic electric experiment classroom in Tamkang University's new engineering building. The positions of three Bluetooth devices were set at a maximum relative interval of about 360 cm, and we divided the measurement space into a rectangular array of 16 points. The distance between the front and back of the 16 points is about 160 cm, and the distance between the left and right of the 16 points is about 200 cm, as shown in Fig. 4.

2.2 Three-point Bluetooth channel measurement

The positions of the receiver and transmitter are shown in Fig. 5. In the experiment, we consider the smart phone of HTC Corporation (HTC) M9 as the transmitter. Then, we consider the three nRF52 DK Bluetooth development modules as receivers. These development modules are attached to the ceiling. In the experiment, 16 points in a classroom were distributed in a rectangular area. One minute of data was received at each test point. The distances between the test points and the three Bluetooth devices were measured in units of 40 cm per brick. To achieve better filtering results, we used 300 data points to adjust the Kalman filter.

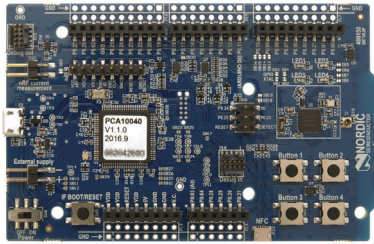


Fig. 2. (Color online) Nordic 52 DK development board.



Fig. 3. (Color online) DC fan.

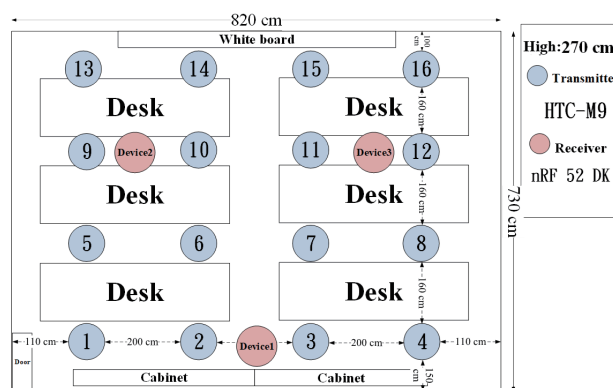


Fig. 4. (Color online) Test point positions.

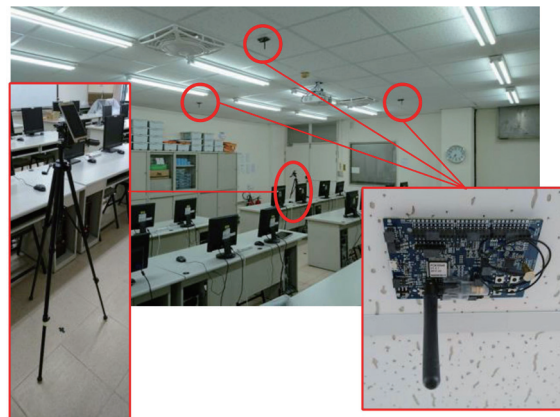


Fig. 5. (Color online) Receiver and transmitter real positions.

To reduce the antenna-field-type error problem, we used the development board provided by the antenna expansion interface to connect the 2.4 GHz omnidirectional antenna. In addition, to rule out the impact of human interference, we used a tripod to install the mobile phone as the transmitter in order to reduce the handset movement or standing position interference. We fixed the mobile phone from a ground height of 130 cm and included the vertical height in the distance estimate.

2.3 Kalman filter

In accordance with the above 16-point test positions, we performed a one-minute measurement at each point and drew the RSSI values measured between 16 test points and three receivers in MATLAB. The original RSSI value is measured between the 16 testing points and the three receivers. The original RSSI value is drawn into a waveform diagram after being filtered by Kalman filtering as shown in Fig. 6. The blue line is the raw data of the measurement, and the orange line is the result of the raw data processed using the Kalman filter.

2.4 Regression curve

Figure 7 shows the regression analysis curve of Bluetooth RSSI relative to the distance. We plotted the regression analysis curve of Bluetooth RSSI relative to the distance using the averaged RSSI values of different measurement points and corresponding to the straight line distance between the transmitter and the receiver. Because Bluetooth used three different frequency bands for transmission in the Bluetooth Advertising Protocol, different channel effects may be observed in the different frequency bands, and the actual channel conditions may change. We can see that there are many divergent situations, but owing to the close distance between the transmitter and the receiver, a higher sensitivity and a higher signal stability to the distance are observed.

3. Position Estimation

As shown in Fig. 8, the RSSI values were measured with the three Bluetooth modules. The RSSI values are converted to the distance using the regression analysis curve of the Bluetooth

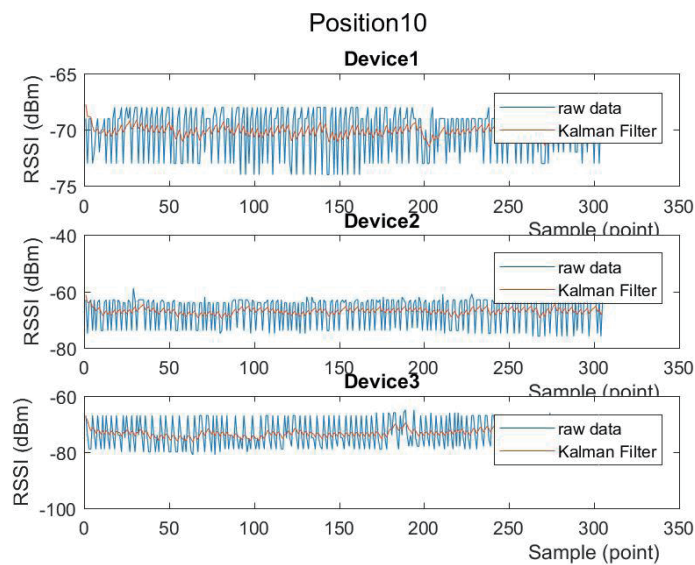


Fig. 6. (Color online) Position 10 and device RSSI.

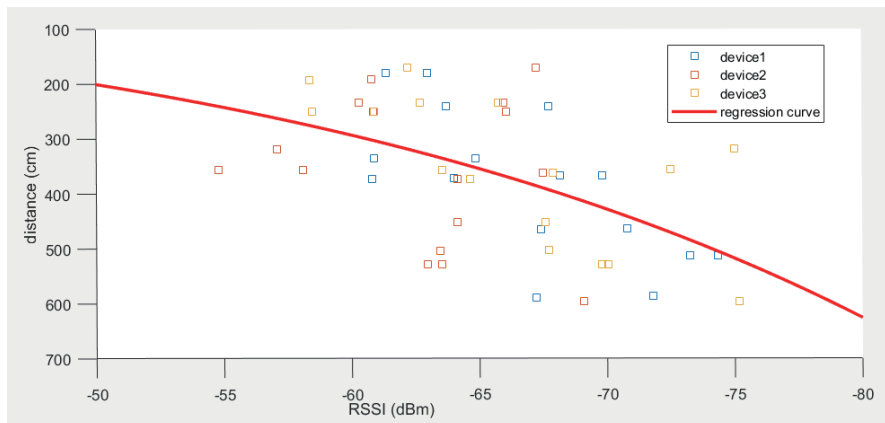


Fig. 7. (Color online) Regression analysis curve of Bluetooth RSSI relative to distance.

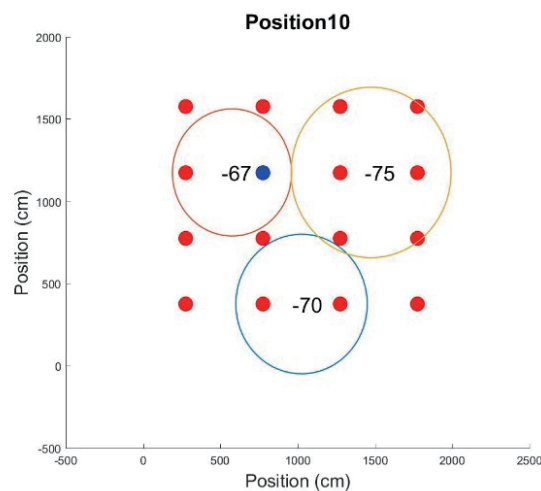


Fig. 8. (Color online) Position 10 indoor positioning diagram.

RSSI relative to the distance; then, we used this distance to draw the position estimation diagram around the center of the Bluetooth module. The radius of the circle is the distance estimated using the regression analysis curve. If the circle is large, it means that a weak signal is received and that the distance between the transmitter and the receiver is far. In contrast, a small circle means a strong signal. The figure shows the relationship between the three Bluetooth module distances and RSSI. It can also be seen that the closer Bluetooth module can provide more accurate location information, and through the two remaining Bluetooth modules, the direction of information is provided to determine the user's position to facilitate the actual operation of the fan's control in the future.

3.1 Verification of fan group energy-saving control system

In this study, the three fans were mounted on the ceiling 270 cm off the ground, the locations of which are shown in Fig. 9, and the actual situation test is shown in Fig. 10.



Fig. 9. (Color online) Fan installation location.



Fig. 10. (Color online) Actual situation test.

3.2 Fuzzy control rules

The system architecture of the fuzzy controller uses three fans as the receiver and three mobile phones as the transmitter, so that all the results actually received are a 3×3 matrix, if the standard design process of the fuzzy system must contain many rules (about three to the power of nine) to cover all possible situations. However, the relative relationship between the three fans and the three mobile phones has a certain degree of commutative property. The control can be simplified after analysis. As a result, the three fans collect the RSSI value detected by the same mobile phone for fuzzy control, as shown in Fig. 11.

The fuzzy control is used to convert the fuzzy concept of human perception into the numerical value of computer operation, and it has a good and practical control effect. Concerning the fuzzy control system, Fig. 12 shows the membership function of the input (the RSSI values received by the receiver) and Fig. 13 shows the output (fan speed). The RSSI value is classified into three situations, namely, long, middle, and near distances, and the fan speed into three situations, namely, low, medium, and high. Moreover, the expected distribution status is analyzed to design fuzzy control rules.

Figure 14 shows the output result of actually inputting the RSSI value into the fuzzy control system. In this result, we set the RSSI values of the same handset received by all the three fans to -75 dBm and input them into the system. We can conclude that for this handset, we have to output 59.8 rpm.

4. Fan Group Energy-saving Control System Results

Figures 15–17 show the test results obtained using three fans and three mobile phones. We use three mobile phones to move around the test area. Three Bluetooth modules control the speed of the three fans. The three fans (Devices 1, 2, and 3) will change the wind speed through the change in the RSSI value received. We can see that there are a few spikes in the process, mainly because the detected RSSI value of the mobile phone farthest from the fan continues to be weak for a period of time. Moreover, we defined a threshold of the RSSI value. When the

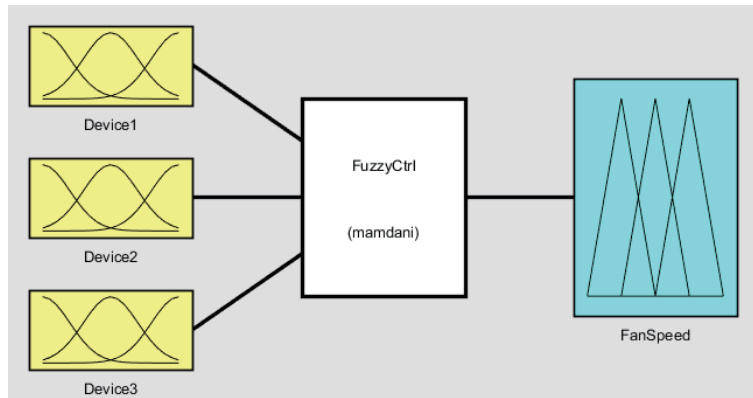


Fig. 11. (Color online) Fuzzy control architecture.

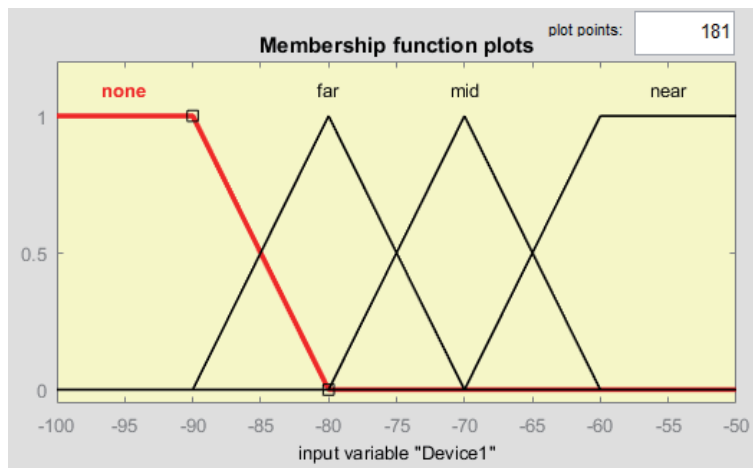


Fig. 12. (Color online) The Bluetooth device receives the membership function of the RSSI values.

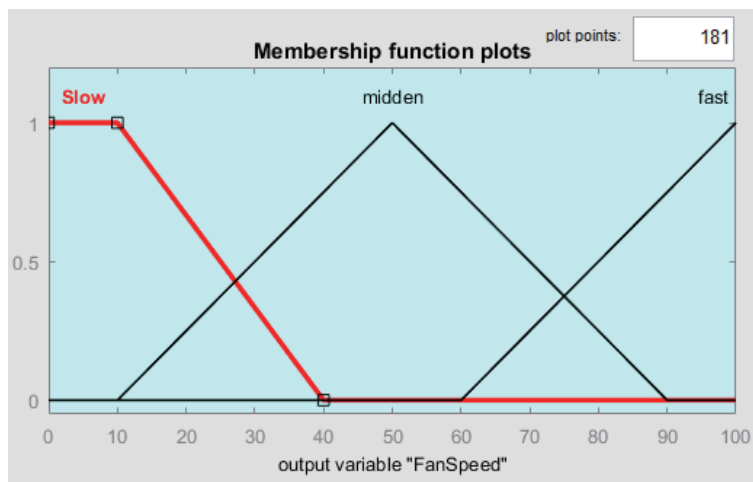


Fig. 13. (Color online) Membership function of fan speeds.

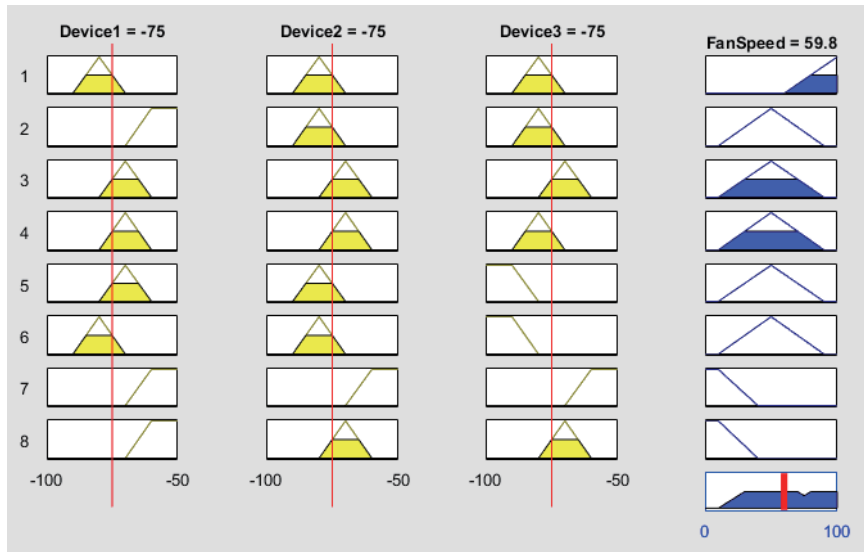


Fig. 14. (Color online) Results of fuzzy controller input and output.

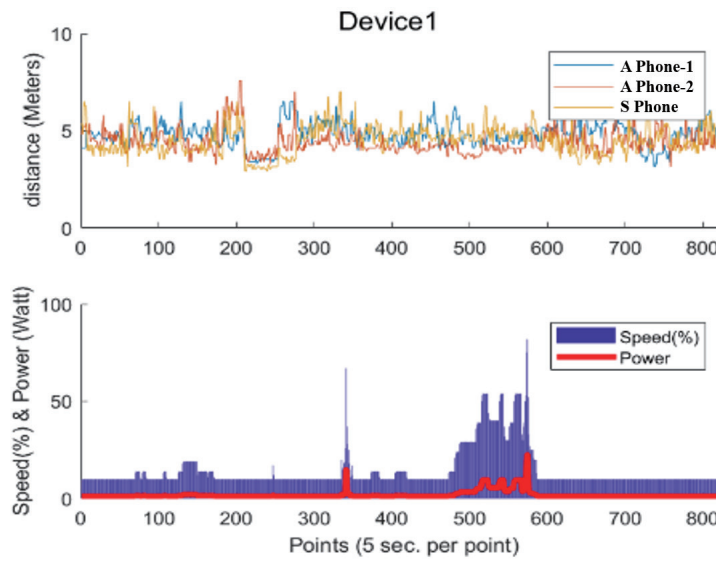


Fig. 15. (Color online) Distance, speed, and power consumption of the three mobile phones relative to Device 1.

RSSI value falls below this threshold, we assume that the handset is in a position beyond the fan’s reach and will therefore ignore the device.

From the experimental results of wind speed, we know that the fan speed is the best under the 40–60% condition. Therefore, we compare the total powers of two situations. The first is the system that is controlled by the fuzzy control algorithm, and the second is the fixed wind speed at 40%. With the fuzzy control algorithm, the total system average power is about 6.4 W. With the wind speed fixed at 40%, the total system average power is about 14 W.

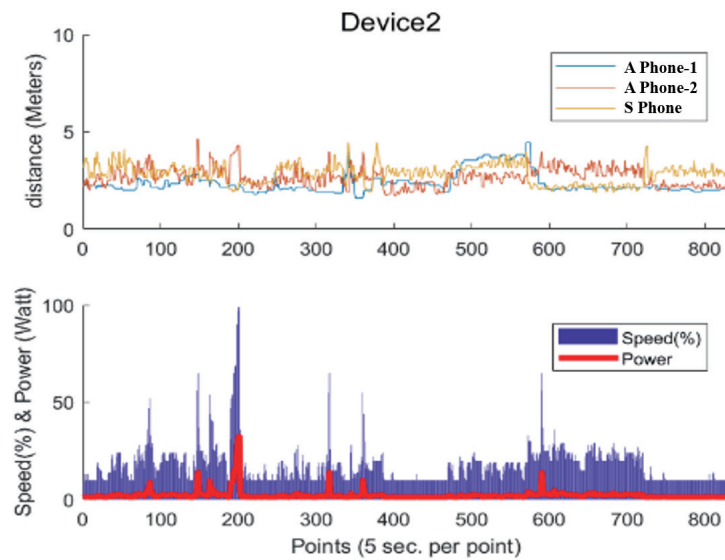


Fig. 16. (Color online) Distance, speed, and power consumption of the three mobile phones relative to Device 2.

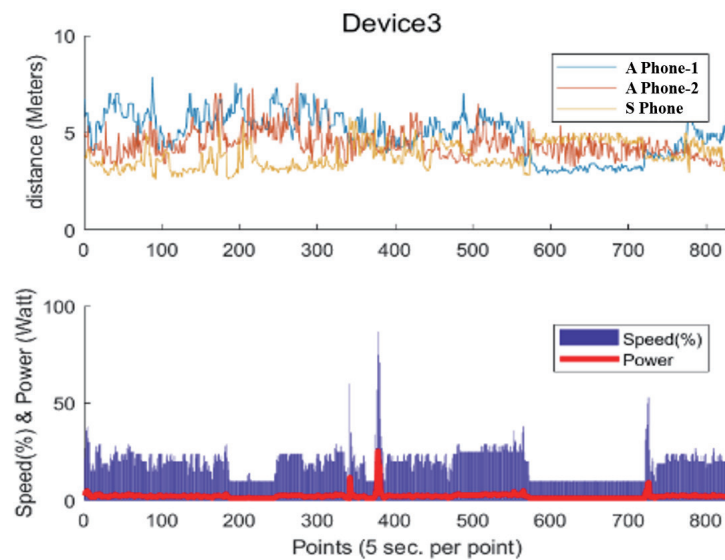


Fig. 17. (Color online) Distance, speed, and power consumption of the three mobile phones relative to Device 3.

The three fan group receivers simultaneously receive the Bluetooth strength information of the mobile phone, which can reduce the instability and nonlinearity error of the RSSI due to the control. The three signals are received by the three fan group receivers, the strong Bluetooth module signal is the main reference basis, and the other two weaker Bluetooth module signals provide additional information. Figure 18 shows the total power of the system.

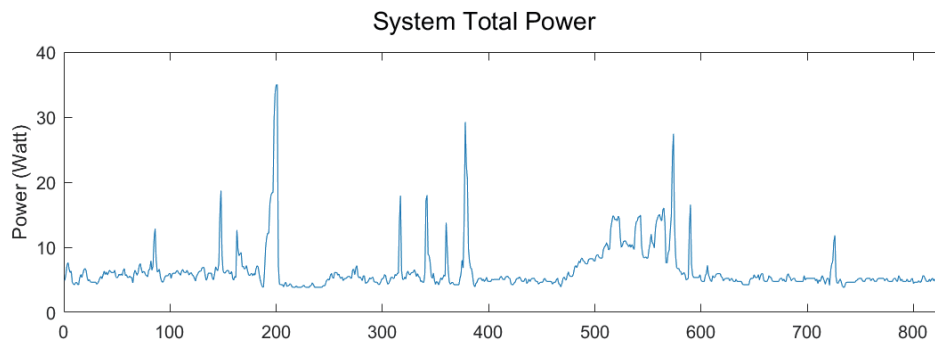


Fig. 18. (Color online) Total power of system.

5. Conclusions

In this study, we developed a smart control system of the RSSI sensing fan group. Although the use of fuzzy controllers can reduce the complexity of our control algorithm development and the complexity of the various models and channel estimation, in the design of fuzzy rules, the fuzzy rules will be improved with the number of inputs and outputs. It will take a long time to retest and adjust the system to achieve better control results.

By using the multi-position sensing fan group, compared with three fans at 40% of the maximum speed, an approximately 54% reduction in power consumption is effectively achieved. Moreover, the actual energy saving effect will depend on the usage situation and how people move around in the system.

Under the multi-receiver system, the complexity of the system is considerably increased. Whether using fuzzy control or other control systems, control algorithms and hardware are needed to achieve the available control. If we use the system of three transmitters and three receivers in the future, maintaining the stability of the algorithm and device computing performance will be a considerable challenge.

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