Design and Implementation of Air Conditioning System in Operating Room

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Abstract-The system is an air conditioning system in operating room. The main objective of the system was implemented to provide air balance and temperature necessary conditions and to control airflow system for ventilation units in operating room. The operation room can be controlled with fuzzy expert system and describes the desired outputs. Input parameters such as temperature, humidity, oxygen and particle are used and output parameters are chosen as air conditioning motor speed and exhaust motor speed. Input parameters of the system are taken into account optimal conditions based on oxygen as medium and other parameters are chosen minimum condition for operating room. The airflow control system is determined the two components: the airflow block and the thermal block for ventilation units in operating room. The mathematical modeling of each such system based on a computational procedure and to combine them together in an efficient manner. Whether it supports to the most suitable control for the system prototype was determined by simulating the operation with varying the number of personnel and duration of time. Finally, according to the combination of temperature and airflow regulations with PI controller, the results of simulation of the entire ventilation unit control system is obtained.

Keywords- Fuzzy controller, operating room, airflow control, ventilation unit, simulation

I. INTRODUCTION

Nowadays, the air conditioning system is widely used in many countries. The air conditioning system of operating room is important for patient and staff. Fuzzy logic controller in air conditioning system provides a comfortable environment together with energy save [1]. Fuzzy expert system was used in the control of operating rooms where complex and uncertain parameters play a crucial role. Air condition and ventilation system for hospital have some standards and publications. These standards, the design of hospital air condition and ventilation system and the technical specifications of the device are taken into account [2]. This system discusses an implementation of a fuzzy inference unit and algorithms for fuzzification, rule-based and defuzzification of a fuzzy control system for air conditioning system. There are many fuzzy inferences however in this article Mamdani inference mechanism was favored as it both easy and suitable for the system design of fuzzy system. The overall block diagram is shown the control system for operating room. It consists of three portion: Fuzzy logic controller, operating room and feedback sensor.

The four input parameters such as temperature, humidity, oxygen and particle are specified as the follows, Temperature(low) 0 ≤ a ≤ 18, Humidity (low) 0 ≤ a ≤ 15, Oxygen (medium) 17 ≤ a ≤ 25, Particle (low) 0 ≤ a ≤ 280 which is applied to the FLC. It has four modules which consist of fuzzification, rule-based, inference engine and defuzzification. The process comprises the operating room related to the ventilating air can be considered as temperature control and airflow control. The ventilation unit in operating room is predefined conditions. An essential feature for laying out air conditioning systems is air flow, which can be designed to be constant or variable. The system selected depends on the overall concept of the operating room. A constant system is only possible where other systems ensure zone-based temperature control, e.g. the heating surfaces, or where temperature control is not required [9]. Therefore, a closed-loop control system for airflow regulation applied with conventional PI controller can be fashioned to implement the performance of the entire regulation system. The performance of the
Design and Implementation of Air Conditioning System in Operating Room

Airflow control system is stable and accurate [5]. If the process system meets the specific condition, the outputs corresponding with inputs will be generated. Otherwise, the sensor section senses the predefined conditions and then sends to the fuzzy logic controller.

In that system, temperature, humidity, oxygen and particles are used as inputs parameters and adjusted air conditioning motor speed and exhaust motor speed. Fuzzy rules are developed and based on the situation of operating room. As there are four inputs parameter and three levels for each input, total of 81 rules are fashioned.

For the inference mechanism the Mamdani min-max inference is used. In defuzzification process, Center of Gravity or centroid method (COG) is used. It presents better performance with short time and dynamic response very close to the one an efficient. The four inputs have been classified into three levels of Low, Medium and High for each. And then, triangular membership function is used for each input’s membership function.

Number of active rules= m, m= maximum number of overlapped fuzzy sets, n= number of inputs

According to the data taken from the user, the system calculates the situation in operating room using fuzzy rule base is shown in Table-1.

This is the most widely used Center of Gravity method. It can be defined by the algebraic expression:

$$Z^* = \int \frac{\mu(z)zdz}{\mu(z)dz} \ .... \ (1)$$
For input parameters (low),

\[
\text{Numerator} \quad \rightarrow \int_{11.5}^{17.5} \frac{1}{17.5} dz + \int_{17.5}^{19.2} \left( \frac{19.2-z}{20.5-17.5} \right) dz + \int_{19.2}^{23.5} \left( \frac{23.5-z}{23.5-14.5} \right) dz = 116.897
\]

\[
\text{Denominator} \quad \rightarrow \int_{11.5}^{17.5} \frac{1}{17.5} dz + \int_{17.5}^{19.2} \left( \frac{19.2-z}{20.5-17.5} \right) dz + \int_{19.2}^{23.5} \left( \frac{23.5-z}{23.5-14.5} \right) dz = 7.569
\]

\[
z^* = \frac{116.897}{7.569} = 15.4
\]

For output parameter,

\[
\text{LOW} \quad \text{MEDIUM} \quad \text{HIGH}
\]

For Low, Numerator \( \rightarrow \int_{750}^{950} \frac{1}{950} dz + \int_{950}^{1150} \left( \frac{1150-z}{1150-950} \right) dz = 271666.6 \)

Denominator \( \rightarrow \int_{750}^{950} \frac{1}{950} dz + \int_{950}^{1150} \left( \frac{1150-z}{1150-950} \right) dz = 300 \)

\[
z^* = \frac{271666.6}{300} = 905.55
\]

For Medium, Numerator \( \rightarrow \int_{950}^{1150} \frac{1}{950} dz + \int_{1150}^{1350} \left( \frac{1350-z}{1350-1150} \right) dz = 230000 \)

Denominator \( \rightarrow \int_{950}^{1150} \frac{1}{950} dz + \int_{1150}^{1350} \left( \frac{1350-z}{1350-1150} \right) dz = 200 \)

\[
z^* = \frac{230000}{200} = 1150
\]

For High, Numerator \( \rightarrow \int_{1150}^{1350} \frac{1}{1350} dz + \int_{1350}^{1600} \left( \frac{1600-z}{1350-1150} \right) dz = 497083.33 \)

Denominator \( \rightarrow \int_{1150}^{1350} \frac{1}{1350} dz + \int_{1350}^{1600} \left( \frac{1600-z}{1350-1150} \right) dz = 350 \)

\[
z^* = \frac{497083.33}{350} = 1420.25
\]

Rule 1 (For input), Temperature (LOW) \( 0 \leq a \leq 18 \)
Design and Implementation of Air Conditioning System in Operating Room

Humidity (LOW) \( 0 \leq a \leq 15 \)
Oxygen (LOW) \( 0 \leq a \leq 17 \)
Particle (LOW) \( 0 \leq a \leq 280 \)
For Output, Air con motor speed & Exhaust motor speed --- High \((1350 \leq a \leq 1600)\)

Table-1 The Fuzzy Rule Base

<table>
<thead>
<tr>
<th>Number</th>
<th>Inputs</th>
<th>Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Temperature</td>
<td>Humidity</td>
</tr>
<tr>
<td>1</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>2</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>3</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>4</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>5</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>6</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>7</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
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</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>77</td>
<td>H</td>
<td>H</td>
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<tr>
<td>78</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>79</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>80</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>81</td>
<td>H</td>
<td>H</td>
</tr>
</tbody>
</table>

L=Low, M=Medium, H=High, ACMS=Air con Motor Speed, EMS=Exhaust Motor Speed

Table-2 and- 3 Membership Function for Inputs and Outputs

The relationship between inputs and outputs of the membership values are assigned the following specification.

<table>
<thead>
<tr>
<th>Temperature(\degree C)</th>
<th>Humidity (%)</th>
<th>Oxygen (%)</th>
<th>Particle(ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low (0 \leq a \leq 18)</td>
<td>Low (0 \leq a \leq 15)</td>
<td>Low (0 \leq a \leq 17)</td>
<td>Low (0 \leq a \leq 280)</td>
</tr>
<tr>
<td>Medium (18 \leq a \leq 24)</td>
<td>Medium (15 \leq a \leq 33)</td>
<td>Medium (17 \leq a \leq 25)</td>
<td>Medium (280 \leq a \leq 380)</td>
</tr>
<tr>
<td>High (24 \leq a \leq 35)</td>
<td>High (33 \leq a \leq 42)</td>
<td>High (25 \leq a \leq 35)</td>
<td>High (380 \leq a \leq 430)</td>
</tr>
</tbody>
</table>
III. MATHEMATICAL MODELING FOR VENTILATION UNIT OF THE ENTIRE SYSTEM

Temperature and airflow are the main parameter in this sequence and the procedure which takes place as a controlling sequence. In a closed-loop control system, two parts are controlled: the outlet temperature from the heat recovery model and the airflow of the supply and exhausted air from the airflow model. The system is applied with conventional PI controllers and the performance of the entire control system. This control system includes a number of different models which are linked together. Some of their inputs/outputs can develop from externally.

1) Frequency Converter

The frequency converter is controlled to start and stop the motor using a ramp function for the performance of the frequency converter. The frequency converter of the system can be defined as

\[ F_{req} = \frac{6}{1+\frac{G}{S}} \quad \text{...(2)} \]

Where, \( F_{req} \) = require frequency, \( G \) = gain, \( S \) = saturation

![Schematic block diagram of frequency converter model in SIMULINK](image)

2) AC motor

When AC voltage is applied to the stator current flow through the windings and then a rotating magnetic field will be generated in the space between stator and rotor and the speed will be produced between the rotating magnetic field and the stator. Three-phase induction motor for the motor speed can be defined as

\[ n = \frac{120 \cdot f \cdot (1-s)}{p} \quad \text{...(3)} \]

Where, \( n \) = rotor speed (rpm), \( p \) = number of pole for AC motor, \( f \) = frequency, \( s \) = slip. The functional block in SIMULINK can be established the relation between the input and the output of the motor illustrates in figure3.
(3) Air Axial Fan

The function block for the fan is constructed on the based on eq\(^4\) and one can be calculated the performance of the fan with the developed model.

\[ P_{\text{total}} = \frac{1}{2} \rho \left[ \pi d_{\text{tip}} N/60 \right]^2 \psi + \frac{1}{2} \rho \left[ \frac{\nu}{A_{\text{fan}}} \right]^2 \ldots (4) \]

Where \( P_{\text{total}} \) = total pressure difference between input and output (Pa), \( A_{\text{fan}} \) = area of the fan (m\(^2\)), \( \nu \) = volumetric airflow (m\(^3\)/s), \( \rho \) = inlet density at the fan face (kg/m\(^3\)), \( N \) = fan speed (rpm), \( d_{\text{tip}} \) = fan diameter (m)

(4) Ductwork

The duct model is implemented through the function block construction in SIMULINK with depending on eq\(^5\)

\[ \Delta P_{\text{duct, loss}} = \left( \lambda L/D + \Sigma \xi \right) \rho/2 \left( \nu/A \right)^2 \ldots (5) \]

Where, \( \lambda \) = friction factor, \( \xi \) = local hydraulic coefficient

For a laminar flow (Re \( \leq \) 2300), the friction factor can be determined as eq\(^6\)

\[ \lambda = 64/\text{Re} \]

\[ \text{Re} = \rho \nu D/\mu \]

Re=Reynolds number, \( \nu \) = kinetic viscosity (m\(^2\)/s), \( \mu \) = absolute viscosity coefficient (kg/ms)
(5) Air Filter

The temperature of flowing air varies with a pressure drop, induced by the airflow. The bigger the pressure difference over the filter will be, the faster velocity of the airflow is. The pressure drop can be defined as follows:

\[
\Delta P_{	ext{pressure, drop}} = C_f \rho f \frac{1}{2} \left( \frac{v}{A_{\text{duct}}} \right)^2 \quad \ldots (8)
\]

Where,

\[\Delta P_{	ext{pressure, drop}} = \text{pressure drop over the filter (Pa)}\]
\[C_f = \text{pressure loss coefficient of filter}\]
\[\rho f = \text{density of filter material (kg/m}^3\)\]

The function block is presented a SIMULINK implementation for the computation of the pressure drop over the filter. The relationship between the pressure difference and the volumetric airflow will be established as the output of the plant model.

\[
v = \sqrt{\Delta P_{\text{total}}} / C_1 + C_2 - \sqrt{C_2} \quad \ldots (9)
\]

Where \(\Delta P_{\text{total}} = \text{total air pressure (Pa)}\), \(C_1, C_2\) are constants taken as \(C_1 = 3003, C_2 = 0.000782\) respectively.

The function block developed on the basic of (9) acts as the feedback conversion component within the entire control system.
Design and Implementation of Air Conditioning System in Operating Room

(6) PI Controller
The airflow control system, the proportional was set at 0.003, while the integral gain was set 20. A proportional controller will be applied to reduce the rise time and steady-state error. The function block for the airflow plant model by adding a PI controller in SIMULINK is implemented. The relationship between the proportional controller and integral gain is based on

\[ G_{PI}(s) = K_P + \frac{K_I}{s} \quad \ldots \quad (10) \]

Where, \( K_P \) = the control gain of the proportional, \( K_I \) = the control gain of the integral.

![Figure 7. Schematic block diagram of PI controller for airflow control system](image)

![Figure 8. Diagram of block surface for constant airflow control system](image)
The airflow control system of test data listed in Table-4.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Specifications for constant airflow system at a specific condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air flow Set point</td>
<td>0.35m³/s</td>
</tr>
<tr>
<td>Density of air</td>
<td>1.2542kg/m³</td>
</tr>
<tr>
<td>Diameter of duct</td>
<td>0.3m</td>
</tr>
<tr>
<td>Pole</td>
<td>2</td>
</tr>
<tr>
<td>Slip</td>
<td>0.03</td>
</tr>
<tr>
<td>Diameter of fan</td>
<td>0.27</td>
</tr>
<tr>
<td>Friction resistance factor inside duct</td>
<td>0</td>
</tr>
<tr>
<td>Length of the duct</td>
<td>1m</td>
</tr>
<tr>
<td>Pressure coefficient of air fan</td>
<td>0.4362</td>
</tr>
<tr>
<td>Output temperature from heat exchanger</td>
<td>20°C</td>
</tr>
</tbody>
</table>

IV. SIMULATION RESULTS AND DISCUSSION

Figure 9(a) represents the frequency converter is controlled in order to start and stop motor using a ramp function. When the user sets the input frequency as ramp function 53Hz is applied to gain in which determine the saturation value can be controlled the required frequency. According to the result, a ramp function between 0 to 25s and then gradually reaches at remain constant.

According to figure 9 (b), the AC motor of speed is obtained with around 3142 rpm due to the attain frequency from Frequency converter is applied to feed gain and slip and pole are chosen 0.03 and 2 respectively.

As represented by figure 9(c), the total pressure depends on the relationship between the input and output of the airflow, density of air and properties of the fan is determined in developed model.

Figure 9 (a) Simulation of frequency converter model in SIMULINK for soft start by using a ramp function (b) Simulation of AC motor model in SIMULINK (c) Simulation of axial fan model in SIMULINK
Design and Implementation of Air Conditioning System in Operating Room

The figure.10 (a) shows the output of total pressure drop is determined by the area of duct model, friction resistance factor, airflow, temperature.

Figure.10(b) illustrates the outcome of the pressure drop over the filter can be influenced by the input airflow, pressure coefficient of filter and density of filter. The more rapidly the velocity of the airflow (is), the greater the pressure difference over the filter (will be).

V. CONCLUSION

In operating room of air conditioning systems have been done by using fuzzy control system. These air conditioning systems have been provided a more comfortable environment for the patient and staff. The airflow control system is essential for ventilation units in operating room. Laminar airflow used the required place such as near the operating room table without giving the overall operating room in order to save energy depletion and reduce spread of diseases. The active attained from simulation with mathematical models advanced for each such block has been associated with the measurement and experimental data. Finally, the difference between the test results and the experimental results has been found due to neglect the thermal properties of duct model.

REFERENCE

[3] Fuzzy logic control system