Improvement in Development of Automatic Air Conditioning Control Using the Cabin Environment Simulation

Jun Tosaka* Norihide Miyashita*

Abstract

To improve the accuracy of the cabin environment model, humidity has been added to the calculation parameters. Using this cabin environment model, the MILS (Model In the Loop Simulation) environment for controlling the automatic air conditioner has been created. This enables us to conduct theoretical study of controllability of the automatic air conditioner before actual vehicle testing. This paper describes the means and results of the adaptation of the air conditioning control model to the cabin environment model. For a development tool, MATLAB®/Simulink® has been used as a standard tool for model base development.

Key Words: MBD, MATLAB/Simulink, Simulation, Software, Control/

1. Introduction

Currently the model applied for performance expectation of vehicle air conditioners is “the automatic air conditioning control model” (Control model), and “the cabin environment model” (Cabin model). Control model is applied for study of controlling in actual vehicle, and Cabin model is applied for cooling performance expectation with Cabin and an HVAC model.

Development of automatic air conditioning controls is done using an actual vehicle installed with a control programmed according to the study results by the above performance expectations. Development works involves using an actual vehicle. A Lot of time and expense is involved in programming the system and preparing the vehicle. The reason being (Fig. 1).

If any of the test results are unsatisfactory, the entire system including the software codes are reevaluated and errors are rectified, after which the entire test is repeated. Therefore Control model and Cabin model have been integrated, we could develop it without actual vehicle. We created MILS environment for controlling the automatic air conditioner, which enables us to validate the control before a vehicle test (Fig. 2).

2. Air Conditioning Control Model

Automatic air conditioning control enables HVAC to maintain the comfort in the cabin environment. The main controlled components are the following: a blower motor (to control air flow volume), a MIX door (to control air temperature of air outlet), mode doors (to control outlet mode), a compressor (to control outlet temp. of evaporator), and an intake door (to control

* Climate Systems Business Unit, Climate Systems Development Group
** MATLAB® and Simulink® are registered trademarks of The MathWorks, Inc. in USA.
Improvement in Development of Automatic Air Conditioning Control Using the Cabin Environment Simulation

intake air volume from outside). To control those components, the input data is received from a room temperature sensor, an outside air temperature sensor, and a sun load sensor (Fig. 3).

Each component is described in the model as an independent function block and its control can be changed according to system function requirement. For instance, in case Dual (right & left) zone temperature control function is required, the specifications can be met by changing the MIX door control block from single temperature control to a dual zone temperature control. It is possible to evaluate operation in the simulation environment (Fig. 4).

This Control model also can be easily applied to vehicle system (Fig. 5). Both models of environments are applied the same Control model. By adding blocks of CAN signal input/output, this control model can be controlled the HVAC on an actual vehicle. It is possible to confirm it on actual vehicle test immediately after confirmation by simulation. We install MicroAutoBox® on the vehicle for testing.

Fig. 3 HVAC System

Fig. 4 Simulation system

Fig. 5 Vehicle-mounted system

Fig. 6 Overview of the vehicle compartment environment Simulation
3. Cabin Environment Model

We have the data, the Cabin model reported this is added moist air model and occupant thermal comfort model. In this study, we developed the models to solve these issues. Fig. 6 shows the overview of the developed Cabin models. These development have be made possible to calculate the effect of passenger by changing in cabin temperature, humidity, or airflow volume, and the cabin environment by addition of heat radiation factor, and passenger sweating. The following describes the developed models.

3.1 Calculation Model of Humidity and Air Temperature in the Cabin

In the document. Heat balance is calculated considering that the cabin volume is divided into 12 areas. In this study, we developed a new model that divided each area is added the calculation factor of dry air, water vapor, and humid air. This model calculates the temperature, pressure, humidity, and density by calculating balance of heat and air mass with effect of air flow. Fig. 7 shows the overview of the developed model.

\[
m_{\text{air}} = \int m_{\text{dry}} \, dt + \int m_{\text{vapor}} \, dt
\]

\[
Q = \int \dot{Q} \, dt
\]

\[
m_{\text{dry}} = \sum_{j} f_{1}(T_j, X_j, V_j, p_j, \rho_j) + \sum_{j} f_{2}(T_j, X_j, V_j, p_j, \rho_j)
\]

\[
m_{\text{vapor}} = \sum_{j} f_{3}(T_j, X_j, V_j, p_j, \rho_j) + \sum_{j} f_{4}(T_j, X_j, V_j, p_j, \rho_j)
\]

\[
\dot{Q} = \sum_{j} f_{5}(T_j, X_j) + \sum_{j} f_{6}(T_j, X_j, V_j, p_j, \rho_j)
\]

\[
m : \text{Mass} \quad \text{[kg]}
\]

\[
m_{\text{air}} : \text{Mass balance per unit time} \quad \text{[kg/s]}
\]

\[
Q : \text{Amount of heat of air} \quad \text{[kcal]}
\]

\[
\dot{Q} : \text{Heat balance per unit time} \quad \text{[kcal/s]}
\]

\[
f_{1} : \text{Amount of movement of the dry air} \quad \text{[kg/s]}
\]

\[
f_{2} : \text{Effects of breathing} \quad \text{[kg/s]}
\]

\[
f_{3} : \text{Amount of movement of the water vapor} \quad \text{[kg/s]}
\]

\[
f_{4} : \text{Effects of breathing and sweating} \quad \text{[kg/s]}
\]

\[
f_{5} : \text{Heat transfer per unit time by convection} \quad \text{[kcal/s]}
\]

\[
f_{6} : \text{Transfer of heat per unit time by airflow} \quad \text{[kcal/s]}
\]

\[
T : \text{Temperature} \quad \text{[°C]}
\]

\[
X : \text{Absolute humidity} \quad \text{[kg/kg]}
\]

\[
p : \text{Pressure} \quad \text{[Pa]}
\]

\[
\rho : \text{Density} \quad \text{[kg/m³]}
\]

\[
V : \text{Airflow} \quad \text{[m³/s]}
\]

\[
t : \text{Time} \quad \text{[s]}
\]

\[
i : 1 \cdots n \text{ (interior pasts, exterior pasts, Occupant)}
\]

\[
j : 1 \cdots 1 \text{ (Vehicle compartment, Outlet air)}
\]

\[
air : \text{Wet air}
\]

\[
dry : \text{dry air}
\]

\[
vapor : \text{Water vapor}
\]

3.2 Occupant Thermoregulation Model

The former applied occupant model calculated the variation of human body temperature and the heat radiation mass by changing ambient temperature, air velocity, and radiation heat. Instead of the above model, the occupant thermoregulation model considering sweat and evaporation developed by YAMAMOTO and his team has made it possible to calculate passenger effect with humidity.

3.3 Effectiveness validation

We validated the effectiveness of the new developed Cabin model by comparing the calculations and vehicle test results. Assuming summer conditions. Fig. 8
Improvement in Development of Automatic Air Conditioning Control Using the Cabin Environment Simulation

shows the comparison between calculation results by Cabin model and actual vehicle test results. In this result, Cabin model can be calculated with the maximum error of 1.5°C, it could be applied to theoretical study.

### Table 1 Experiment conditions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab hour</td>
<td>30 min</td>
</tr>
<tr>
<td>Outside air temp.</td>
<td>35°C</td>
</tr>
<tr>
<td>Value of solar radiation</td>
<td>760 W/m²</td>
</tr>
<tr>
<td>Vehicle speed</td>
<td>40 km/h</td>
</tr>
<tr>
<td>Air conditioner</td>
<td>ON (Full cool)</td>
</tr>
</tbody>
</table>

Therefore, the number of calculation steps is unified to be 50 ms to study controllability. One of the advantages of model-based development is that it is possible to do trial and error without actual one. It is advantageous to have minimum simulation time. However, the calculation volume and time of Cabin model was increased by the unification of the number of calculation steps. To improve this, we change S-Functions (C language) in part of Cabin model which are modified not much. As a result, simulations was completed about 10 minutes from 1 hour.

4. Integration of Models

4.1 Unification of Environment

Since calculation method in simulation is different with Control model valued real-time properties and Cabin model valued calculated efficiency, it is necessary to unify their environments for operating both in one model.

The number of calculation steps is different between Control models: 2.5 ms and Cabin models 1000 ms.

4.2 Other Models

Only integration of Control model and Cabin model is not sufficient to develop by model-base. HVAC model and AC cycle model on Fig. 2 are necessary. Since components of each vehicle have large impact on performance, we need to create these models based on vehicle or specification (e.g. Idle-stop cars, hybrid cars).

4.2.1 HVAC Model

To calculate HVAC model as physical model, it will be complicated because it will need to calculate air flow and mixing of hot/cool flow in HVAC and so on. As the main purpose of creating MILS is for control development, at this time the HVAC model is simplified by creating maps that is calculate the physical values for control. The values mapped are the air temperature by MIX door opening angle, and air flow volume by blower voltage from each outlet. These values are modified for the purpose of simulation. For instance, in case it is applied to change control logics for current vehicle, these values are used through the actual HVAC bench tests result. In other case where HVAC performance is studied with automatic air conditioner control, these values used are target values of the under developed HVAC (Fig. 9).
4.2.2 AC cycle model

AC cycle models have many factors for physical modeling and can be complicated, particularly considering refrigerant's phase changing. Therefore AC cycle models are also simplified by creating maps. The model calculates cooling performance using outside air temperature, front air flow velocity (= vehicle speed), engine revolution speed, and air temperature. Cooling performance is adjusted again according to the heat exchanger size and other factors based on cycle performance.

In this model, heater core temperature is also estimated apart from AC cycle values. Normally it uses the engine coolant temperature, but once the engine is stopped, temperature change value is estimated according to outside temperature, blower voltage and so on. This enables to study the system control during an idle stop (Fig. 10).

5. Verification of Simulation

In order to validate the accuracy of this developed model, simulation results have been compared to results of by actual vehicle tests. (Fig. 11). Compared Data were used the result of driving on city traffic in summer. The actual vehicle is Nissan FUGA (Y50) and Input data of simulation are used “outside temperature”, “sun load”, “vehicle speed” and “engine coolant temperature” of vehicle on the test.

Comparing the simulation results and the test results shows that the outlet air temperature was increase on decreasing vehicle speed during cooling down, and cabin temperature is changed by sun load when cabin temperature is stable. On the other hand, the simulation results show undershoot of cabin temperature from a transition to a stable condition. This is due to a lack of simulation accuracy of cabin temperature sensor on transition condition. Future Improvements are under investigation.

6. Conclusion

In this study, we validated that the model-based development environment with automatic air conditioner control is simulated and the actual vehicle environment is re-created with accuracy. The developed model and process are already applied for system control study of a new air conditioner. Going further a constant value will be applied for verification of product development study and for other purposes.
Improvement in Development of Automatic Air Conditioning Control Using the Cabin Environment Simulation

Fig. 11 Simulation results

References


(2) Hiroshi Ezaki and other authors: CALSONIC KANSEI TECHNICAL REVIEW, Vol.6, p.34-37, 2009

(3) Yamamoto: Temperature regulation model of occupant human body for design and evaluation of auto air conditioning system, Watanabe Laboratory, Department of Electrical Engineering and Bioscience, Waseda's Graduate School of Advanced Science and Engineering, Master's Thesis, 2008

(4) Yamamoto: Temperature regulation model of occupant human body for design and evaluation of auto air conditioning system, Material for the 8th meeting of Control Division, The Society of Instrument and Control Engineers, 2008

Jun Tosaka
Norihide Miyashita