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# Vehicle HVAC controller using Multi Variable Kalman Fusion

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***Abstract*—**An automatic HVAC can provide vehicular environmental comfort. The uncertainty of sensor readings makes this task complicated. This riskiness can be reduced to an extent by introducing a multi-variable Kalman filter with the HVAC. In this paper, an automatic HVAC controller using multi-variable Kalman is analysed. The controller used for this is a PID controller. The Kalman fusion gives a more accurate data by computing the sensor data. Here, for analysis six sensors are used. Depending upon the Kalman fusion output PID controller provides the controller output.

***Keywords***- *HVAC, Multi-variable Kalman filter, Sensor fusion, PID controller*

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## I. INTRODUCTION

The Automatic HVAC controllers are the part of many vehicles. It has an important role of providing thermal comfort inside the vehicle. They consist of temperature sensors and a control algorithm. The main problem, in this case, is the accuracy of the sensor data. In this paper, we are explaining how to solve this problem.

For the analysis, we have used six temperature sensors. The outputs of these sensors are fed to a Kalman filter. The outputs of the Kalman filter is combined by sensor fusion. This result is more accurate, since it does not rely on a single sensor, but it is the combined filtered output of six sensors.

The sensor fusion is used to combine the individual outputs. The controller used here is a PID controller. The output of the PID controller is used to control the inlet and exhaust fans of the HVAC.

## II. PROBLEM DEFINITION

The current automatic systems are not very accurate, due to the limitations in the filtering algorithm. They use the simple averaging method to estimate the temperature inside the vehicle. The distribution of sensors inside the vehicle also has a significant importance in the estimation of temperature.

Furthermore, if any of the sensors is faulty, it will give an entirely deviated value of temperature. So, when we include this value for averaging, the result will also deviate from the actual value of temperature. And thus, the HVAC will fail to provide a comfortable environment.

We can build an efficient HVAC by eliminating the sensor errors. This can be done effectively by introducing a multi-variable Kalman filter in the system. Kalman filter can give the corresponding weights to each sensor values depending on their deviation from the true value of temperature. The output of multivariable Kalman is fed to the sensor fusion algorithm where the filtered outputs are combined depending on their weights. Thus, a more accurate temperature value is obtained, which can be used for controlling the HVAC. So, the HVAC with multivariable Kalman fusion can provide more comfort inside the vehicle when compared to the currently using automatic HVAC systems with the averaging method.

The HVAC is controlled by implementing a PID controller in the system where the estimated sensor reading is the input to the PID controller.

## III. METHODS AND ANALYSIS

The Experiment was not conducted inside a vehicle, instead of that, we made an aluminium chamber with necessary arrangements, which can act as a replica of the vehicle's inside. The software parts are implemented by using an Arduino and a PC running on Ubuntu.

### A. *Experiment Setup*

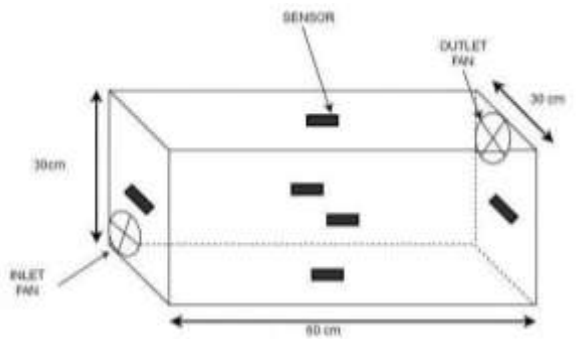


Figure 1 – experiment setup

There are inlet and exhaust fans in the container similar to the HVAC. Inlet fan is at the bottom corner of one side where the exhaust fan is fitted at the diagonally opposite top corner. Some incandescent bulbs are kept inside the container to warm up the environment. This is an optional part we can use any other heat source instead. We chose incandescent lamps because they are safe and they can provide the required amount of heat in a short time.

The block diagram of the entire system is given in figure 2. There are six sensors used for the analysis since the container has six faces.

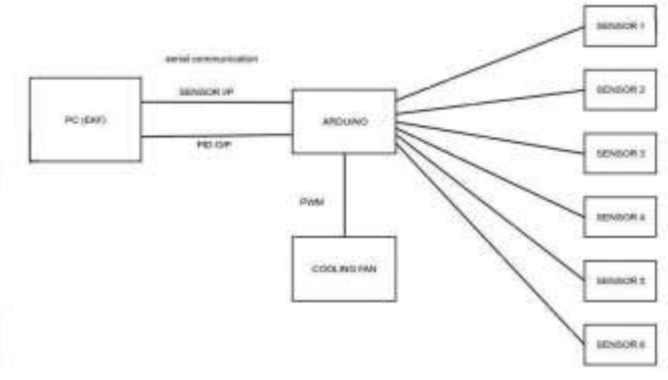


Figure 2 – Block diagram

The sensors are interfaced with Arduino. We have to use pull down resistors with the sensors to obtain correct readings. The Arduino will form a single string which consists of all the six sensor readings. This string is then sent to PC using serial communication. In PC the sensor readings are separated and fed to multivariable Kalman Fusion. The output of Kalman fusion is used for calculating the controller output using the PID controller. Then the PID controller output is sent to Arduino through serial communication. Arduino uses this controller output for controlling the speed of inlet and exhaust fans. The tuning of PID controller is done by trial and error method.

### B. Software Part

The software of this project consists of two main components

(1) Kalman Filter and (2) PID algorithm . Kalman filter is used here to filter out the errors and estimate the sensor values. Depending on the filtered sensor output PID controller will give an output to regulate the speed of inlet and exhaust fans. The steps of this entire algorithm is as follows:

- Read the string from Arduino.
- Decode the string to get PWM values
- Convert them into temperature using the formula temperature in °C =(PWM/1024.0)*500
- Apply Kalman Filter
- Combine the individual outputs using Sensor Fusion.
- Apply PID algorithm and send the output to Arduino.

While running these steps, the obtained temperature readings (before applying Kalman filter) and the sensor fusion output will be plotted in realtime using MATPLOTLIB since the programming is done in Python.

1) *Kalman Filter*

Kalman filter is used to deal with the uncertain information in any dynamic systems. In this project the temperature inside a vehicle is dynamic. Hence, we can use Kalman filter here to estimate the temperature inside the vehicle. This algorithm consists of two steps, Prediction and Correction. More times the Kalman filter runs , more accurately it will predict the output. The Kalman filter algorithm is as follows.

*Prediction*

$$\hat{t}_k^- = A\hat{t}_{k-1} + BU_k$$

$$P_k^- = AP_{t-1}A^T + Q$$

*Correction*

$$K = P_k^- H^T (HP_k^- H^T + R)^{-1}$$

$$\hat{t}_k = \hat{t}_k^- + K(Z_k - H\hat{t}_k^-)$$

$$P_k = (I - KH)P_k^-$$

***t= temperature state matrix A= State transition matrix***
***B= Control input model***
***U= Control variable atrix***
***P= Error covariance matrix Q= Process noise covariance***
***K= Kalman Gain***
***H = Observation model***
***R = Measurement noise***
***Z = Measurement***
***I = Identity matrix***

The filtered temperature readings are then combined by using Sensor Fusion. There will be unique weights for each sensor readings proportional to its reliability. If the sensor is giving readings which are very close to the actual temperature , then it will be having a higher importance. These weights will be changing in every cycle unless the sensors are giving constant readings.

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2) *PID Controller*

Proportional Integral Derivative Controller is a widely used loop feedback controller Mechanism. It has three parameters namely setpoint, process variable and control variable. Here, Setpoint is the desired temperature inside the vehicle. The error value is calculated as the difference between setpoint and process variable. Filtered temperature output acts as the process variable here. To control the temperature inside the vehicle we have to regulate the speed of inlet and exhaust fans of the HVAC. Thus the speed of blower is the control variable. The PID algorithm is as follows,

***error = set point – process variables***
***integral = integral + (integral*dt)***
***derivative = (error  previous error)/dt***
***controller output = (Kp*error) + ( Ki* integral) + (Kd* derivative)***

Here, ***dt*** is the time interval and ***Kp***, ***Ki*** and ***Kd*** are the proportional , integral and derivative gains respectively.

## IV. RESULT AND DISCUSSION

The temperature inside the container is controlled automatically in realtime. To analyze the efficiency of the system, the sensor readings and filtered output are plotted in realtime using MATPLOTLIB. Figure 3 shows the screenshot of the graph.

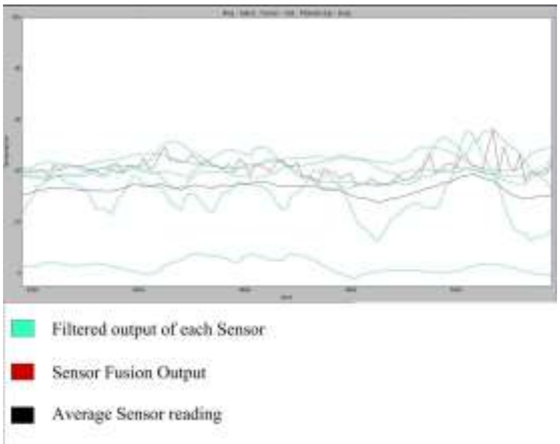


Figure 3 – Output Plot

There are total six sensors used in the system in which, one sensor is faulty. This is done to evaluate the tolerance of the system towards the inaccuracy of sensors. It is clear from the plot that the reading of the faulty sensor has not affected the final output. The currently used system uses the averaging system. We can see that the averaged value has dropped due the influence of defective sensor whereas, sensor fusion output is more accurate. We can smoothen the plot just by adjusting the measurement noise matrix. Here the measurement noise is taken as 10 to get desired distinctness.

## V. CONCLUSION

This project is proposed to develop a more efficient automatic vehicle HVAC control. The current system uses the averaging method, which is vulnerable towards the sensor errors. Implementation of an efficient filtering method will help to reduce this problem to an extent. This thought led to develop a new system, and it works accurately than the old system. Moreover, this system will not get affected even if any of the sensors got damaged.

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