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Review on Matlab Fuzzy Logic Based and Predictive (Radial Basis Function, Rbf) Hvac Controllers

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Abstract- The use of fuzzy logic controllers in refrigeration and air conditioning systems, RACs, has as main objective to maintain certain thermal and comfort conditions. In this sense, fuzzy controllers have proven to be a viable option for use in RACs due to their ease of implementation and their ability to integrate with other control systems and control improvements, as well as their ability to achieve potential energy savings. In this document, we present a review of the application of fuzzy controls in RACs based on vapor compression technology. Application information is discussed for each type of controller, according to its application in chillers, air conditioning systems, refrigerators, and heat pumps. In addition, this review provides detailed information on controller design, focusing on the potential to achieve energy savings; this design discusses input and output variables, number and type of membership functions, and inference rules. The future perspectives on the use of fuzzy control systems applied to RACs are shown as well. In other words, the information in this document is intended to serve as a guide for the creation of controller designs to be applied to RACs.

Index Terms- HVAC control, control engineering, fuzzy logic, artificial intelligence, (learning algorithm for multivariable data analysis)

I. INTRODUCTION

Buildings require most of the total supplied energy, with breakdowns of 40% to 42% in Western countries [1 - 4]. This energy feeds the elevators, plugged-in IT equipment, electronic devices, and lights, along with the HVAC system and the security and fire systems. Above all, the HVAC facility consumes most of the energy that is supplied to the building. As energy production remains contaminating and expensive and has substantial negative impacts on the environment and finances, the optimization of building energy with a focus on HVAC systems is necessary. The energy saving problem can be addressed by retrofitting the building architecture, renovating old installations or adding intelligence to the BMS, thereby leading to a savings of up to 30%. It is far more sustainable and cost-effective to improve the control algorithms to realize higher efficiency than to renovate the HVAC equipment with more efficient modern technologies [1, 2, 4, 5]. System automation enables operation with autonomous optimization principles that maintain comfort and reduce the amount of consumed energy. Automatic control is essential for coping with unforeseen user activities in smart buildings. IT achievements and industrial engineering breakthroughs enable the envisioning of smart buildings with self-adapting facades, shapes and autonomous behaviors, for maximizing the comfort of the occupants in changing contexts with nearly zero carbon emissions.

Therefore, the objective that is pursued with the automation of HVAC control is to maximize the thermal comfort while minimizing the energy consumption. The operational efficiency of an HVAC system strongly depends on its control system and optimization parameters. The construction of an accurate and effective model of an HVAC system is challenging. Modeling its characteristics, nonlinearities, dynamics and highly constrained parameters complicates the design and operation. Advanced control system engineering provides several approaches for improving control systems and reducing the energy consumption while ensuring the indoor thermal comfort with satisfactory robustness and stability.

Solving the problem requires the following steps, among others: focusing on the control problem; solving the multi objective optimization problem; synthesizing the system management at the supervisory level; and proposing new predictive or adaptive models that mimic the system behavior. There are interesting reviews that address the strengths, weaknesses and performances of HVAC control models and their applicability in practical contexts [4, 5, 7, 8, 9, 10, 11]. Each proposed control model in HVAC systems requires assumptions regarding the system properties and the environment, to balance its simplicity with its accuracy.

The air-conditioning systems now are usually used in the buildings. They are designed to make a good atmospheric environment for people to live or to produce a special environment for some special industrial places. So there are two categories for the different applications, one is for comfort living and the other one is for industrial. The control items in the air-conditioning include temperature, air quality and humidity in one room.

The indoor environment is very important for the health and also can affect the efficiency of production. People usually spend a lot of time in the buildings, so the air conditioning system is designed to keep a comfortable environment for human beings. Many researchers have donated much time on the comfortable environment indoors and they find temperature and humidity are the major factors to human comfort. So the temperature and relative humidity are the most important parameters in the air conditioning system.

Many of the systems indoors focus on the temperature and relative humidity control within some range. For temperature, it is from 23℃ to 25℃ in summer and 20℃ to 24℃ in winter. For relative humidity, it is usually need to be above 45%. The indoor environment also affects the performance for industrial places. Some industrial places require accurate temperature and relative humidity.

Greenhouse, some crops can just germinate and grow under accurate temperature and humidity. Not only for industrial but also for some scientific experiments, the air conditioning system for different special environment is needed. There are more and more requirements for air-conditioning systems, so the energy consumed in buildings for industry and commerce increases quickly. It constitutes about 50% of the world energy consumption [1]. And 50% to 60% of the consumed energy is for air-conditioning and mechanical ventilation (ACMV) systems [2].

II. BACKGROUND

An air conditioner is a home appliance, system or machine that builds to extract heat air to turn it into a cool air. Nowadays, lots of air conditioner use fuzzy logic, for example Mitsubishi Air conditioner. Conventional air conditioning systems use on-off controllers. When the temperature drops below a preset level the unit is automatically turned off. When the temperature rises above a preset level the unit is turned on. The former preset value is lower than the later preset value, providing a dead zone, so that high-frequency on-off cycling is avoided. The thermostat in the system controls the on-off action. For example, when the temperature rises to 25°C, turn on the unit, and when the temperature falls to 20°C, turn off the unit. The Mitsubishi air conditioner controls by using fuzzy rules such as, IF the air is getting warmer THEN turn the cooling power up a little AND IF the air is getting cold, THEN turn the power down moderately. The machine becomes smoother as a result. This means less wear and tear of the air conditioner, more consistent comfortable room temperatures, increased efficiency and energy savings. The same technique is going to be show using simulation that will be develop to be apply to University Malaysia Pahang's class rooms or Lecture Hall (Dewan Kuliah). The simulation will show how the speed of the fan rotates accordingly to the temperature that is set by user, and the current room temperature of the rooms or halls.

III. HVAC SYSTEMS CONTROLLING

The environmental conditions of human beings always been affect by their work performances. In addition, it is well known that the importance of the comfort of human beings gradually increases by the development of technology (Aereboe, 1995, Zheng and Zaheer-Uddin, 1996). That is why, humans try to design a more comfortable living environment. As a result, the studies related to the design and control of ambient conditions of buildings have been attracting interest in the last years. In a multipurpose building having shopping-center, offices and different usage areas, their desired temperatures and air conditions may be different. For this reason, flexible design of HVAC systems supplying different demands is substantially to decrease both the first investment cost and the operational cost. Further, the analysis of the performance and operational strategies of HVAC systems becomes very important for the effective usage of energy (Ashrae handbook, 1992). The studies on the parameters of HVAC systems as temperature, volume and control strategies in the last 50 years were shown that the high performance of HVAC systems could be obtained by minimizing energy consumption (Stanfort, 1998). Technological developments lead to obtain system models of HVAC systems by simulation programmes in PC media (Ellis, 1996, Geller, 1998).

1. HVAC PID and Fuzzy Logic Modelling

In this study, it was shown that the usage of modelling and simulation methods for analyzing, testing and developing of HVAC systems decreased the design cost as well as the design process. Furthermore, obtaining better performances of the simulated systems became easier. Soyguder and Alli studied the classical PID control of HVAC system having two zones with different properties (Soyguder & Alli, 2006). kp, ki and kd parameters of PID were obtained to minimize the system error in their study; however, the steady-state error was not totally eliminated.

In addition to PID control of HVAC systems, fuzzy logic control (FLC) of HVAC systems was studied by many authors (Huang and Nelson, 1994a, Huang and Nelson, 1994b). The obtained results were compared with those of PID control and these studies indicated that FLC had better results. FLC is extensively used in processes where systems dynamics is either very complex or exhibit a highly nonlinear characters and FLC is one of the useful control schemes for plants having difficulties in deriving mathematical models or having performance limitations with conventional linear control methods. FLC is designed on the basis of human experience, which means that a mathematical model is not required for controlling a system. Because of this advantage, fuzzy logic-based control schemes were implemented for many industrial applications. FLCs were successfully applied to many complex industrial processes and domestic appliances in the recent years (Tsang, 2001). The first FLC algorithm implemented by Mamdani was designed to synthesize the linguistic control protocol of an experienced operator. Although this type of FLC application has been successful compared to the classical controllers, the design procedure depends on the experience and knowledge of the operator and it is limited by the elucidation of the heuristic rules of control. To avoid this major disadvantage of depending on the control experience of the operator, MacVicar-Whelan first proposed some general rules for the structure of fuzzy controllers. These fuzzy rules devised by MacVicar-Whelan approach to a deterministic (PI) or (PD) controller in the limit as quantization levels of control and measurement variables become infinitely fine. It was shown that better results for the same system were obtained by using FLC with respect to PID control. However, control rule sets for FLC are quite difficult to redesign.

To eliminate this negative condition, self-tuning FLC can be designed and applied to HVAC systems. The obtained results showed that the self-tuning advanced FLC reached the optimal solution according to the described performance criteria (Huang & Nelson, 1999). In addition to PID control and FLC of HVAC systems, the studies on combining PID and FLC for HVAC systems were performed. Various types of fuzzy PID (including PI and PD) controllers have been proposed. In the literature, the application of FL to PID controller design can be generally classified into two major categories according to design type.

- The gains of the classical PID controller are tuned on-line in terms of the knowledge base and fuzzy inference, and then the classical PID controller generates the control signal (Zhao & Tomizuka, 1993).
- FLC is designed as a set of heuristic control rules, and the control signal is directly deduced from the knowledge base and the fuzzy inference as it is done in MacVicar-Whelan or diagonal rule-base generation approaches.

The second type controllers are referred to as PID-type FLC's because, from the input–output relationship point of view, their structures are analogous to that of the classical PID controller. The equivalence of PD-type FLC's and classical PD controllers has been established under the special conditions. Different control tuning methodologies have been proposed in the literature such as auto-tuning, self-tuning, pattern recognition, artificial intelligence, and optimization methods (Santos Coelho, 2007). A new approach has been proposed for tuning the coefficients of PID-type fuzzy logic controllers (FLCs).
In addition, Wei proposed a self-tuning method for a class of nonlinear PID control systems based on Lyapunov approach. The self-organizing fuzzy controller has an extension of the rule based fuzzy controller with an additional learning capability. By relating to the conventional PID control theory, Zhi-Wei proposed a new fuzzy controller structure, called PID type fuzzy controller. A fuzzy auto-tuning proportional-integral-derivative (PID) controller for the robot has been experimented, in which a simple method to tune parameters of the PID type fuzzy controller on-line has been developed (Sun, Xing, Zhao, & Huang, in press).

IV. LITRATURE REVIEW

1. Review of Past Research
S.M.A. Rahman et al. [1] This study focuses on the performance analysis of a novel solar-assisted heating, ventilation, and air conditioning (HVAC) system, using R407c as a refrigerant under United Arab Emirates (UAE) climate conditions. The energy recovery techniques and explicit passive techniques were investigated for the reduction of energy consumption and overall cost by using underground water. It was found that the space-cooling load was reduced by 38.4 % with the help of distinct passive methods. The underground average water temperature is stable at 28 °C in the UAE throughout the year and thus, was used to decrease the cooling consumption. A reduction in cooling consumption and of compressor capacity of about 13 % and 10 %, respectively was achieved using these approaches. Good agreement was obtained between the analytical model and the experimental results.

Alessandro Franco et al [2] One of the key elements for improving the energy performance of large-scale non-residential buildings is recognized as the correct management and control of the Heating Ventilation and Air Conditioning (HVAC) system. In real applications, the main shortcomings are represented by the lack of involving occupants presence and behavior, and by the lack of application of dynamic control able to guarantee optimality of operation with the aim of controlling building energy demand. This present study aims at evaluating the perspective of energy savings achievable with the broadening of the energy perspective to indoor air quality thanks to occupants' monitoring and at showing some of the potentialities arising from the implementation of an optimal control of the HVAC. This provides insights about the possibility of achieving significant energy savings by using measures of minimal complexity. The proposed measures involve demand-controlled ventilation as representative of occupant-centric control strategies, and an improved control of the heat pump and chiller supply water temperature, and of heat recovery equipment as representative of supervisory control strategies. The analysis which is carried out by means of dynamic simulation has been applied to an academic building situated in Pisa.

Ramin Rahif et al. [3] Global warming is widely recognized to affect the built environment in several ways. This paper projects the current and future climate scenarios on a nearly zero-energy dwelling in Brussels. Initially, a time-integrated discomfort assessment is carried out for the base case without any active cooling system. It is found that overheating risk will increase up to 528%, whereas the overcooling risk will decrease up to 32% by the end of the century. It is also resulted that the overheating risk will overlap the overcooling risk by 2090s under high emission scenarios. Subsequently, two commonly applied HVAC strategies are considered, including a gas-fired boiler + an air conditioner (S01) and a reversible air-to-water heat pump (S02). In general, S02 shows ~6–13% and 15–27% less HVAC primary energy use and GHG emissions compared to S01, respectively. By conducting the sensitivity analysis, it is found that the choice of the HVAC strategy, heating set-point, and cooling set-point are among the most influential parameters determining the HVAC primary energy use. Finally, some future recommendations are provided for practice and future research.

Md. Absar Alam et al. [4] HVAC (Heating, Ventilation, and Air-Conditioning) systems maintain a consistent temperature and humidity inside all year long, making it possible to provide pleasant working and living conditions in homes, businesses, and other buildings. HVAC systems are making human existence not only healthier and wealthier, but also more abundant. A variety of goods, with consideration for efficiency, excellence, and speed to market, are possible in a controlled environment. This study presents a thorough literature assessment of HVAC systems, with a particular emphasis on the improvements made to people's thermal comfort in the recent years.

Junke Wang et al. [5] Model Predictive Control (MPC) is an advanced process control method that has attracted much attention in building heating, ventilation, and air conditioning (HVAC) systems. This paper analyzes the optimal precooling performance in residential buildings using MPC with two different comfort indices, namely, temperature and predicted mean vote (PMV). It first formulates, for each comfort index, an optimization problem that accounts for different factors, such as weather, home thermal condition, prediction horizon, time-of use (TOU) utility rate, and rated cooling capacity. The problem is then solved, resulting in an MPC strategy that determines the HVAC on/off control signal and minimizes energy cost over a receding time horizon while maintaining thermal comfort. The energy performance difference between temperature-based and PMV-based MPC strategies is subsequently investigated, especially in light of the interior wall surface temperature and under different combinations of the factors. Extensive simulation results demonstrated that the proposed MPC strategies are adaptive and their performances depend primarily on weather, home thermal condition, and prediction horizon, while the impact of TOU utility rate and rated cooling capacity is relatively small. Because the PMV-based MPC strategy can take advantage of the lower interior wall surface temperature due to precooling, it resulted in 8–45% cost savings for the scenarios investigated and an average increase of 0.042–0.113 in the absolute value of the PMV index compared to the temperature-based MPC strategy.

Dian Zhuang et al. [6] Optimising HVAC operations towards human wellness and energy efficiency is a major challenge for smart facilities management, especially amid COVID situations. Although IoT sensors and deep learning were applied to support HVAC operations, the loss of forecasting accuracy in recursive prediction largely hinders their applications. This study presents a data-driven predictive control method with time-series forecasting (TSF) and reinforcement learning (RL), to examine various sensor metadata for HVAC system optimisation. This involves the development and validation of 16 Long Short-Term Memory (LSTM) based architectures with bi-directional processing, convolution, and attention mechanisms. The TSF models are comprehensively evaluated under independent, short-term recursive, and long-term recursive prediction scenarios. The optimal TSF models are integrated with a Soft Actor-Critic RL agent to analyse sensor metadata and optimise HVAC operations, achieving 17.4% energy savings and 16.9% thermal comfort improvement in the surrogate environment. The results show that recursive prediction leads to a significant reduction in model accuracy, and the effect is more pronounced in the temperature-humidity prediction model. The attention mechanism significantly improves prediction performance in both recursive and independent prediction scenarios. This study contributes new data-driven methods for smart HVAC operations in IoT-enabled intelligent buildings towards a human-centric built environment.

Junke Wang et al. [7] Model Predictive Control (MPC) is an advanced process control method that has attracted much attention in building heating, ventilation, and air conditioning (HVAC) systems. This paper analyzes the optimal precooling performance in residential buildings using MPC with two different comfort indices, namely, temperature and predicted mean vote (PMV). It first formulates, for each comfort index, an optimization problem that accounts for different factors, such as weather, home thermal condition, prediction horizon, time-of use (TOU) utility rate, and rated cooling capacity. The problem is then solved, resulting in an MPC strategy that determines the HVAC on/off control signal and minimizes energy cost over a receding time horizon while maintaining thermal comfort. The energy performance difference between temperature-based and PMV-based MPC strategies is subsequently investigated, especially in light of the interior

wall surface temperature and under different combinations of the factors.

Lei Liang et al. [8] In this study, standards of high-biocontainment facilities (including laboratories and large-scale production facilities) formulated by China and other countries were analyzed and compared, and the technical points and requirements for Heating, Ventilating, and Air Conditioning (HVAC) systems in different series of standards were discussed. The main focus was on expounding the design and verification of the containment area's indoor parameters, ventilation system, filter design, integrity test, fan standby, airflow pattern, and system reliability. This study expects suggestions and opinions on the construction and development of biosafety facilities in China and the possible future revision of relevant national standards.

Francisco Fernández et al. [9] Hernández This paper presents an analysis of a thermal zoning system integrated in a Heating, Ventilation and Air-Conditioning (HVAC) system based on an air-to-water heat pump with a ducted fan coil. Zoned systems are based on independently controlling the temperature of each of the zones of a building. When a zone is not occupied or not in demand, the control board sends a control signal to the zone's motorised damper which interrupts the airflow supply to that room. Although this control system is gaining popularity in the residential sector, the results obtained in terms of thermal comfort and energy consumptions are not evident and should be documented.

Besides, the control strategy is based on an algorithm that allows acting on the heat pump, setting the set-point temperature, and on the fan-coil, setting the fan speed. Based on this, it is possible to design an algorithm to optimize the performance of the installation ensuring thermal comfort and achieving energy savings.

Ragil Sukarno et al. [10] Heat pipe heat exchangers (HPHE) were widely applied as a recovery energy device in HVAC systems and significantly can reduce the energy consumption of HVAC systems. This study performs experimental and non-dimensional analysis using the Buckingham Pi theorem to develop a correlation of heat pipe performance as an energy recovery device in air HVAC systems. The experiment was conducted to investigate heat transfer characteristics in the heat pipe heat exchangers. The fresh-air temperature in the evaporator section ($T_{e,in}$) was varied at 30–45 °C, fresh air velocity varied at 1.5–2.5 m/s, and the number of rows HPHE varied at 3, 6, and 9 rows. While the return air temperature was entering the condenser's inlet side, HPHE ($T_{c,in}$) was kept at 23 °C. The procedures of the Buckingham Pi theorem were adopted to determine non-dimensional parameters and found a correlation between Pi forms. Each non-dimensional parameters value was calculated based on the measured data. The correlation between non-dimensional parameters can be solved simultaneously using the multiple linear regression with the logarithmic transformations method. The new correlation has been found in the form Sp Number. The results show that Sp numbers is affected primarily by the number of rows (n), effectiveness (ε), and Reynold numbers ($Re_{,D}$). The equation Sp number can be used to predict the thermal resistance of a single heat pipe and is very useful to know the performance of a heat pipe in the design and operating stages.

V. CONCLUSION

To summarize, in this review article an overview of different control methods applied for HVAC systems is provided. Also, specifically the nonlinear control method is studied in general and particular in the case of HVAC systems. The overview consists of different control categories divided into hard, soft and hybrid categories.

Although the hard control techniques are used widely and are still the first choice in building control, it seems that most hard control techniques did not take into consideration the variety of constraints on controls and states to reveal the real conditions. Generally the wide implementation of the traditional and hard control methods is only by reason of their simplicity in application and their low initial cost. Due to their high maintenance cost, energy usage and inefficiency for the MIMO structure, the interest and attention to intelligent or soft and hybrid methods would be increased.

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