

Preface

This book is intended for engineers, technicians and people who plan to use fuzzy control in more or less developed and advanced control systems for manufacturing processes, or directly for executive equipment. Assuming that the reader possesses elementary knowledge regarding fuzzy sets and fuzzy control, by way of a reminder, Chap. 1 of the book contains concepts and description of operations related to four basic processes, which drive the action of fuzzy controllers in the Mamdani and Takagi-Sugeno structure.

Chapter 2 is dedicated entirely to the description of the tools to be found in the Matlab/Simulink environment, and which in an excellent way allow configuration of the controllers by introducing different term shapes in a defined universe for individual input and output variables, the “AND”, “OR” method selection, implication, aggregation and defuzzification. One very powerful tool is the ANFIS (Adaptive neuro-fuzzy inference system) editor, which is an excellent tool for the design of the Takagi-Sugeno controllers. In this case, the number of output variables is a constraint, which unfortunately comes down to a single variable. However, this is not a major problem since, as we know, the MIMO system could be substituted by several MISO systems, which as a consequence is the same. The third part of the book presents applications for fuzzy controllers in control systems for various manufacturing and engineering processes. It characterises seven processes and problems which have been programmed using fuzzy controllers. The issues discussed concern the field of Environmental Engineering, and this is the reason for the title of this book.

The first two issues (Chaps. 3 and 4) concern control flood wave passing through a hypothetical, and then the real (actually existing) Dobczyce reservoir in the Raba River, which is located in the upper Vistula River basin in southern Poland. The obtained results of reservoir outflow control taking into account conditions and flood regime, which is effective within the reservoir drainage area during a flood, could be characterised as very good and meeting the expectations regarding proper reservoir functioning due to its control in an open system which is executed by fuzzy controllers. An interesting solution is the hierarchic structure of the fuzzy controller. Modification of control system properties in function of the reservoir

state change definitely improves “control quality”, making the system an elastic tool reacting to any change in one of the most important variables, i.e. reservoir state. This change is possible as a result of using a hierarchic system for fuzzy controllers, in which the superior layer (“master”) controller governs operation of controllers in the subordinate layer of (“slave”) controllers. The application of this solution provides grounds to presume that in further attempts it will be possible to introduce other state variables of the object being controlled without the need to increase the size of the input variable vector.

The third issue (Chap. 5) concerns control and water management in a cascade of reservoirs (reservoirs connected in series), where different control rules apply compared to a single reservoir. Cooperation between reservoirs must be strictly controlled; in particular outflow from the upper reservoir (the first one in the cascade) is subject to an important requirement to ensure that the lower reservoir capacity is not exceeded. The control system includes Mamdani-type controllers, which, if properly adjusted, reasonably correctly reflect the troublesome dispatcher’s rule of control for two reservoirs. The control method proposed in this project may constitute an alternative control variant for a cascade of reservoirs when compared to conventional control methods, which in these cases are very restrictive (inflexible) and leave no margin for manoeuvre to decision-makers. In many situations related to the course of a flood, the decision-makers driven by their experience and knowledge of hydrological parameters in the cascade area would successfully interfere with the principles imposed by inflexible rules, which unfortunately is not possible due to very restrictive regulations. In this context, soft fuzzy control may work effectively.

The fourth issue (Chap. 6) is very interesting due to its subject matter. And so, the optimal control rule is one of the control methods for a multi-reservoir water system. As a result of this rule, in the function of the vector of predicted inflows into the system of reservoirs and targets contained in the quality coefficient, after having solved an appropriate optimisation task, we consequently obtain an optimal vector of outflows from the reservoirs and an optimal vector of transfers among reservoirs. Their trajectories in the optimisation horizon guarantee a minimum value for the assumed quality coefficient. As it has been emphasised, an optimal solution is the function of the vector of predicted inflows, which usually differ from actual inflows (inflows in real time). In order to maintain the vector courses of state trajectories for individual reservoirs, fuzzy controllers track the course of events in an open online system (predicted inflow, actual inflow), thus determining the correction for optimal control and at the same time implementing the objectives regarding reservoir system control. This issue involved testing both Mamdani and Takagi-Sugeno type controllers in various configurations. Comparison of the results obtained indicates the controllers which are most useful in solving problems of this sort. As it is shown in Chap. 6, currently existing programming tools and specialised editors allow free experimenting with controller input and output data volume. The free choice of shapes and quantity of terms in the universe of each variable, and then the capability to move, position, modify, etc., with reference to each of the

variables, gives an unlimited potential for controller design as regards Mamdani and Takagi-Sugeno architectures.

Depending on its structure, the approved rule base, predetermined T-norms, S-norms, methods of implication, aggregation and defuzzification, the controller changes its working point according to the changes in input signals, generating output signal(s) resulting from the dependencies approved in rule base, and appropriate to the specified parameters. This unparalleled flexibility in changing output signals, which results from the strict reaction to changes in input signals, is a very strong element of fuzzy controllers, and an irrefutable reason for their ever more common use in various technological and engineering problems.

The fifth issue (Chap. 7) concerns a control system for liquid temperature using Mamdani controllers. This issue is commonly used in many Environmental Engineering processes. In a closed control system, the Mamdani type controller guided by the deviation error $e(t)$ causes heating or cooling of a certain liquid volume (in the laboratory approach) as a result of using controlled heaters (water heating), and a controlled Peltier cell, which is responsible for liquid cooling. According to the assumed scenario of the required water temperature, fuzzy controllers operate the heaters and the Peltier cell, respectively, to ensure that as a consequence the liquid temperature matches the predetermined scenario for the required temperature, where the time variable is the trajectory. Physical implementation of the whole control system has been possible owing to new technologies being applied from the areas of informatics, electronics and thermodynamics.

The sixth issue (Chap. 8). Considering the broadly defined combustion process model, and in fact the model of operation of entire industrial systems with pocket or circulation beds, it should be noted that it is among the non-stationary models with changeable state properties and parameters. In particular, uncontrolled changes in proportioned fuel properties (type, calorific value, humidity and other), and consequently difficult to characterise in an unambiguous way changes in the properties of the combustion process in the bed that mean we are dealing with a typical control system from the control theory perspective. In this system, adaptation of the parameters for a model characterising the combustion process and the adaptation of settings for the controllers responsible for proper process operation will be decisive in the context of correct system operation as regards the predetermined working point, or, going further, with reference to the value of an assumed quality coefficient related to the possible optimisation of the system control process. The control process itself, used for these systems, belongs in fact among the highly complex ones due to the considerable number of controllable object state variables and many control signals, which implement the proper settings for various executive components of the system. There is a whole range of dependencies among the results of operations executed by these signals, which finally ensure a stable working point for the whole system; all external and internal disturbances affecting the system and causing deviations.

The predetermined working point may cause a drop in efficiency, higher emissions of harmful substances into the atmosphere, and in critical situations related to temperature adjustment for the fluidisation process they might lead to bed

backfilling or extinguishing, or to process interruption. All of Chap. 8 is dedicated to the technique of adjustment in time t , $\forall t \in [0, T]$ of a selected variable in an observed system (an installation with a fluidised bed), carried out using Mamdani type fuzzy controllers with various structures. Fluidised bed temperature $T(t)$ is the observed variable. Its instantaneous values should remain within an approved change interval. The change interval centre is usually defined by the required temperature: $T^W(t) \forall t \in [0, T]$. The equipment proportioning the fuel stream and air stream supplied to the bed is controlled in a closed control system where the deviation error $e(t)$ resulting from the difference between current bed temperature and the required temperature values activates the appropriate fuzzy controller, which generates a control signal being sent to the abovementioned executive devices. The structure definition for appropriate level controllers comes down to the principles and relations concerning the dependencies between controller input and output variables, and in fact their definition and further adjustment of controllers results from the parameters of a physically operated system. The superior objective of fuzzy controllers is to provide such control for executive installation components proportioning fuel and air, which will ensure that the bed temperature obtained fits within an approved (acceptable) change interval, in spite of bed temperature disturbances resulting primarily from the change in fuel calorific value, and to a smaller extent from the change in system load or in the temperature of air supplied to the bed. In the case of an absence of this information concerning the combusted fuel, and when the only source of information is current bed temperature, and possibly the tendency of its changes based on previous recordings, help is provided by fuzzy logic and tools allowing the formulation and design of fuzzy controllers reacting in feedback mode to changes in the observed state variable (bed temperature). Depending on the controller structure, the accepted rule base, the predetermined T-norms, S-norms, the methods of implication, aggregation and defuzzification, the controller(s) alter(s) the working point of the executive devices according to the changes in input signals (deviation error $e(t)$ resulting from the difference between current bed temperature and required temperature values), by way of generating output signal(s) (resulting from the dependencies approved in the rule base and appropriate to the predetermined parameters) which control the executive equipment. The principle of operation for a control system with feedback is to bring the deviation error value near zero, and thus to those changes in the operation of the executive equipment which would consequently make the current bed temperature correspond to the required temperature.

The seventh issue (Chap. 9). Modern water heating systems and the water installations connected with them are characterised by an efficient use of the thermal energy delivered by the source. This should be understood as maintaining working temperatures and water streams so as to ensure proper thermal comfort conditions independently of changes in external weather conditions, and a heating medium distribution which would guarantee cost-effective energy management.

The primary objective of temperature control systems within buildings is to operate the valve regulating the water stream in heaters so as to make the room

temperature correspond to the predetermined temperature value, treated as the required temperature, in spite of disturbances in the form of changes in ambient temperature outside these rooms, or possibly changes in the temperature of the water stream in the heaters. This task is seemingly relatively simple as regards the assumption itself, which conventionally could be solved by way of applying an automatic control system, this time using a fuzzy controller with an adequately chosen structure.

To recapitulate, Chap. 9 is dedicated to the technique of adjustment in time $t, \forall t \in [0, T]$ of a variable in an observed system, that is, the temperature in a room heated by a heater(s) supplied with heating water at a variable temperature. This adjustment is carried out in a system with feedback in which Mamdani and Takagi-Sugeno type fuzzy controllers have been used. As it has been stressed, room temperature is the observed variable, and its value should change depending on the desired temperature required for a given room(s). Heater valves are controlled in a closed system in which the deviation error resulting from the difference between current air temperature in the room(s) and the required temperature value activates the appropriate fuzzy controller, which generates a control signal to be sent to the executive equipment controlling the flow of heating water through the heater(s). The structure definition for the appropriate level controllers comes down to the principles and relations concerning dependencies between controller input and output variables, and in fact their definition and further adjustment of controllers results from the parameters of a physically operated heating system and room parameters. The superior purpose of fuzzy controllers is to control the executive equipment in the heating system (the valves regulating the heating water flowing to the heaters) so as to ensure that in spite of temperature changes occurring outside a room and changes in the heating water temperature in the heaters, the room temperature corresponds to the required temperature. A temperature control system in a single room is modular in nature—i.e. multiplying the system for many rooms allows the temperature for large facilities consisting of many storeys and many rooms on each storey to be programmed. Therefore, in this way it is possible to make a central programmable controller which will allow temperatures to be set for individual storeys and rooms, and flexible changes in the output signals of fuzzy controllers resulting from precise reactions to changes in input signals will allow implementing the programmed temperatures.



<http://www.springer.com/978-3-319-19260-4>

Fuzzy Control in Environmental Engineering

Chmielowski, W.

2016, XXVIII, 276 p. 258 illus., 250 illus. in color.,

Hardcover

ISBN: 978-3-319-19260-4