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Testing a Method for the Generation of the Systems Control Schemes for Buildings

Ardeshir Mahdavi and Birgit Rader
Department of Building Physics and building Ecology
Vienna University of Technology, Vienna, Austria
bpi@tuwien.ac.at

ABSTRACT

In previous publications, a method was introduced to derive a general scheme for the distribution of the control logic regarding systems control and automation in complex buildings. This scheme is generated based two initial layers of information pertaining to an architectural space. The first layer enumerates the different zones in the space that are targeted for environmental control via heating, cooling, ventilation, illumination, etc. Each zone is represented via a sensor that monitors the state of that zone. The second layer enumerated all the devices (and their respective terminals) that are intended to control the zone via introduction or removal of some amount of energy or mass (e.g., windows, blinds, luminaires, diffusors, radiators). To empirically explore the viability of the scheme generation method, a test was conducted involving a number of architecture and engineering students. Thereby, the information for the generation of scheme was collected and documented for a number of actual spaces. Subsequently, the scheme generation method was deployed to generate for each case a general scheme for the distribution of control logic. The results of the experiment and their implications for the further development and application of the method are discussed.

KEYWORDS: building systems, building control, zones, sensors

1 INTRODUCTION

In previous publications, a method was introduced to derive a general scheme for the distribution of the control logic regarding systems control and automation in buildings (Mahdavi 1997, 2001, 2004, Mertz and Mahdavi 2003, Mahdavi and Schuß 2013). The proposed control systems schema generation method has the potential to address certain problems associated with environmental systems control, particularly in large and complex buildings. Such problems include, for example, the extensive initial periods of time necessary for system tuning and debugging, subpar energy performance, intensive maintenance requirements, and user dissatisfaction (Mahdavi and Schuß 2013).

In this context, we argue that the design methods of systems control architecture in buildings have not kept pace with the integration requirements of increasingly complex technologies for heating, cooling, ventilation, and lighting of buildings. Decisions regarding the environmental control systems' type and devices, the number and extent of control zones, as well as the type, number, and position of sensors neither follow a structured approach, nor reflect a traceable reasoning. Rather, such decisions seem to be frequently made on an ad hoc basis. Moreover, decision processes in one domain (e.g. thermal control systems) are rarely coordinated with other domains (e.g. visual control systems). Such lack of structure and integration is likely to cause inefficiencies in design and operation of buildings and their systems. Classical literature on control theory does not address this problem (see, for example, CIBSE 2000, Franklin et al. 2006, Unbehauen 2008, Mosca 1995).

The proposed generative system uses two initial layers of information pertaining to an architectural space to derive the control logic distribution scheme. The first layer enumerates the different zones in the space that are targeted for environmental control via heating, cooling, ventilation, illumination, etc. Each zone is represented via a sensor that monitors the state of that zone. The second layer enumerated all the devices (and their respective terminals) that are intended to control the zone via introduction or removal of some amount of energy or mass (e.g., windows, blinds, luminaires, diffusors, radiators). Subsequent to the identification of these two layers, the relationships between them are established. A relationship denotes either a physical intervention involving mass and/or energy flows instantiated by the device controller and acting on the control zone, or zone state information flow via zone sensor to device controller. The architecture for the distribution of the control logic of a building's technical systems can be derived cogently from these initial relationships between two entity layers, control zones and control devices, in an automated rule-based fashion (Mahdavi 2004; Mertz and Mahdavi 2003). This architecture can be seen as a template of distributed nodes, which can contain partial methods and algorithms for control decision making. Generative rules could be applied to derive such nodes in the control schema for the accommodation of well-formed pieces of control logic in terms of rules, algorithms, and simulation code. A set of such generative rules toward generating a multi-nodal control logic schema, i.e., a unique hierarchical multi-layered configuration of nodes for a specific control task is provided as follows:

1. Arrange distinct control zones as the basis layer of the schema. The state of these zones is captured via respective zone sensors.
2. Arrange device controllers (DCs) in the next layer. Every individually controllable device is assumed to have a DC.
3. Connect device controllers (DCs) to the zones, whose states are appreciably influenced by the operation of DCs.
4. Generate the zone controllers' layer as follows: If more than one DC influences the same zone, a respective zone controller is required to coordinate their operation. This layer accounts thus for the need for zone-specific coordination across multiple devices.
5. Generate the high-level controllers (HC) layer as needed: If a DC receives requests from more than one zone controller, a high-level controller (HC) is generated. This layer accounts thus for the need for device-specific coordination across multiple zones.
6. If high-level controllers overlap in terms of devices involved, merge them into one meta-controller.

Such a schema may be generated for an entire building or any part of a building that may be regarded as closed (well bounded) in terms of control actions and their implications. The following simple control task (Mahdavi and Schuß 2013) pertaining to a simple office space as depicted in Figure 1 allows for the illustration of the schema generation process. The control task is to maintain a number of zone state indicators or control parameters within target values. These are in this case air temperature (□), relative humidity (RH), carbon dioxide concentration (C), and illuminance (E1, E2). The control task is to be accomplished via the operation of windows (W1, W2), a shading device (B), radiators (R1, R2), and luminaires (L1, L2). Following the steps described above, the distributed multi-layered multi-domain systems control schema of Figure 2 emerges. Layers 1 (zones) and 2 (device actuators) result from steps 1 to 3. Layers 3 (zone controllers) and 4 (high-level controllers) result from steps 4 and 5 respectively. Layer 5 (meta-controller) results from step 6.

To empirically explore the viability of the scheme generation method, a test was conducted involving a number of architecture and engineering students. Thereby, the information for the generation of scheme was collected and documented for a number of actual spaces. Subsequently, the scheme generation method was deployed to generate for each case a general scheme for the distribution of control logic. The results of the experiment and their implications for the further development and application of the method are discussed.

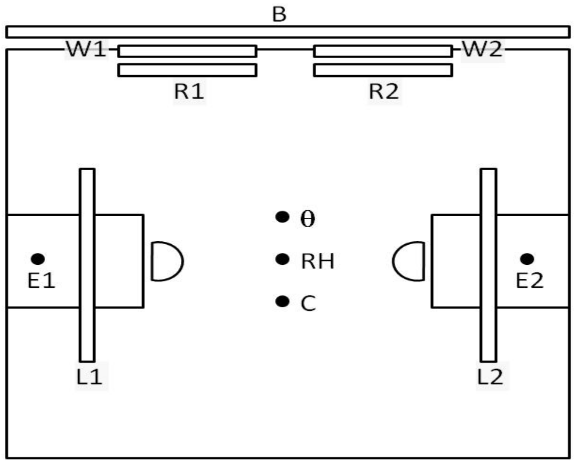

Figure 1: An office space with seven devices (windows W1 and W2, radiators R1 and R2, luminaires L1 and L2, external shade B) and five sensors (illuminance sensors E1 and E2, indoor temperature, relative humidity, and carbon dioxide sensors □, RH, and C).

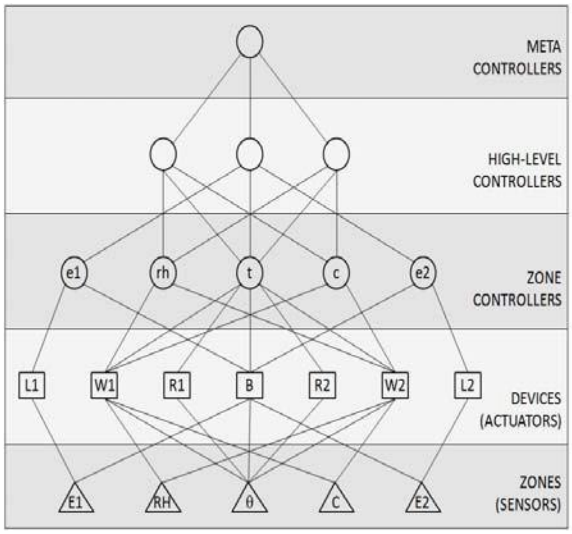

Figure 2: A control logic distribution schema for the office space of Figure 1.

2 APPROACH

2.1 Participants

To empirically explore the viability of the scheme generation method, we conducted an experiment involving a number of architecture (84%) and engineering (16%) students. Altogether 29 students participated in the experiment. As some students worked in groups of two, 22 projects were submitted in total. 24% of the participants stated that they did not learn about buildings' technical systems in their education. The rest stated that they have at least some background in this area. 52% of the participants had no experience in designing of building systems. The rest had at least some experience. Most of the architecture students did not have any experience in communicating with building service systems engineers. Out of those architecture students who did have experience working with engineers, the majority suggested that the latter were open for system design suggestion by architects. All participants stated that architects must know more about buildings' technical systems.

2.2 Task

At the start of the experiments, the students were provided with a three-hour introduction session presenting the scheme generation method. Thereby, both the theoretical background of the method and examples for its application were presented. Each group was asked to select and document a real existing space in a building. No restrictions were imposed with regard to the function or size of the space. Using the plan documentation of the spaces, the groups were asked to:

i) Identify all control devices in the space and their associated terminals and actuators.

ii) Estimate the spatial impact zone of each device.

iii) Assign logical positions for proper sensor representing the zones identified in step ii. Note that the actual spaces were rarely equipped with relevant environmental sensors.

iv) Generate the control logic distribution scheme for the selected spaces based on information obtained through steps i to iii and following the scheme generation rules discussed in section 1.

v) Fill a questionnaire providing feedback concerning the scheme generation method (general effectiveness and the usability assessment of the method, common problems faced while generating the scheme, suggestions for improvement of the procedure).

Some two weeks after the first session, a second three-hour session was held where the participants presented their interim project results and received feedback. Once the final revised project versions were submitted, the experiment analysis phase began.

2.3 Analysis

At the end of the experiment, 22 projects and 25 filled questionnaires were submitted. We reviewed these submissions to evaluate the fidelity of the generated schemes and the perceived effectiveness and usability of the scheme generation method.

3 RESULTS

To obtain a general sense of participants' experience with the scheme generation method, a number of questionnaire results are summarized in Table 1. These results generally suggest that a majority of participants found the proposed schema generation method useful toward understanding and evaluating buildings' technical systems, improving the communication between architects and engineers, and support the improvement of buildings' energy performance.

Table 1 Overview of questionnaire results

	Participants' responses [%]				
Question	Not at all	Not so much	A little bit	Yes	Yes, very much
Does the method make the understanding of buildings' technical systems easier?	0	16	16	60	8
Does the method help identifying design problems of buildings' technical systems?	0	0	40	52	8
Could the method contribute to energy saving measures in buildings?	0	8	20	56	16
Was it clear and convenient to apply the method to the selected room?	0	16	36	48	0
Can the method improve communication between architects and engineers?	0	4	44	48	4
Could the method be feasibly applied to larger and more complex spaces/buildings?	0	4	24	60	12

With regard to the consistency and quality of the submitted schemes, a number of pertinent observations can be made. First, the initial component of the task was correctly performed by all participants: This means that the devices, terminals, and actuators were correctly identified. Likewise, participants consistently identified the spatial target of the devices, i.e., the zones. However, occasionally an unnecessarily too large number of zones were defined. For example, in certain cases multiple spatially close rather small impact zones were defined for multiple luminaires. This, although the luminaires could be switched on and off only simultaneously (see Figure 3). Note that definition of impact zones is not a simple problem. Even experienced professionals do not always define and configure such zones explicitly and exactly. Hence, zone definition may be perhaps seen as one of the fundamental shortcomings of the design process with regard to buildings' technical systems. Often devices and associated terminals are configured and located in a room without detailed – computationally evaluated – consideration of their spatial impact zone.

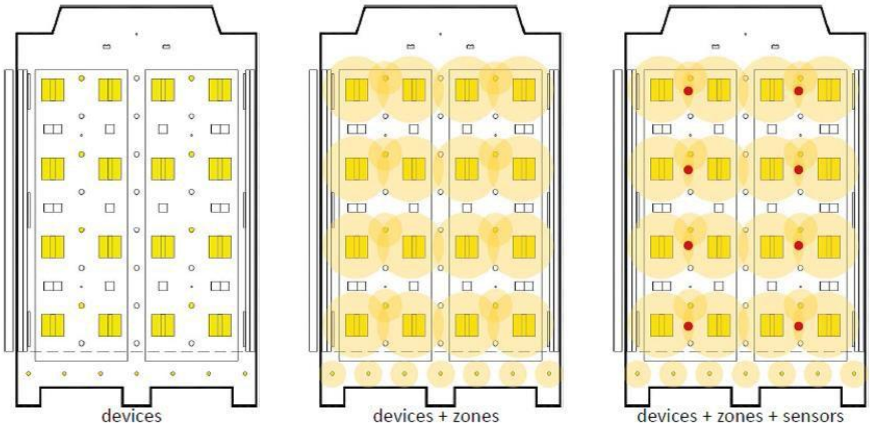

Figure 3: Identified lighting zones in one of the student projects. In this case (lecture room in a university building) an unnecessarily large number of zones are defined.

Many participants had problems with the definition of the number and location of the sensors. At times, given the previously mentioned large number of zones, too many sensors were assumed. In certain instances, the one-to-one mapping between zones and sensors was violated, i.e., multiple sensors were positioned to cover the same zone (Figure 4). Likewise, in a number of cases only one sensor was provided to cover multiple zones (Figure 5). Moreover, sensors were occasionally placed in inadequate positions, i.e. on the periphery or even outside the corresponding zone (Figure 6).

As to the process of schema generation, a number of problems could be identified in the submitted projects. One issue pertains to overtly complex instances of schema generation, where multiple devices are represented separately, even though they could have been combined. For example, if multiple devices are jointly controlled (i.e., if they share the same actuator), then separate representation is the schema would not be necessary. On the other hand, individual representation of multiple individually controllable devices of the same type would only be useful, if the schema would include a separate zone (and associated sensor) for each device (Figure 7).

The application of the schema generation rules was in certain cases inconsistent or simply false. A common problem concerned the generation of the layer with the high-level controllers. Most groups properly mapped the zones to the devices and correctly generated the layer with the zone controllers. However, the derivation of the high-level controllers occurred in some cases in an arbitrary fashion and not by following the layer generation logic. It is possible that some participants did not fully understand the meaning and purpose of the associated generation rule (Figure 8).

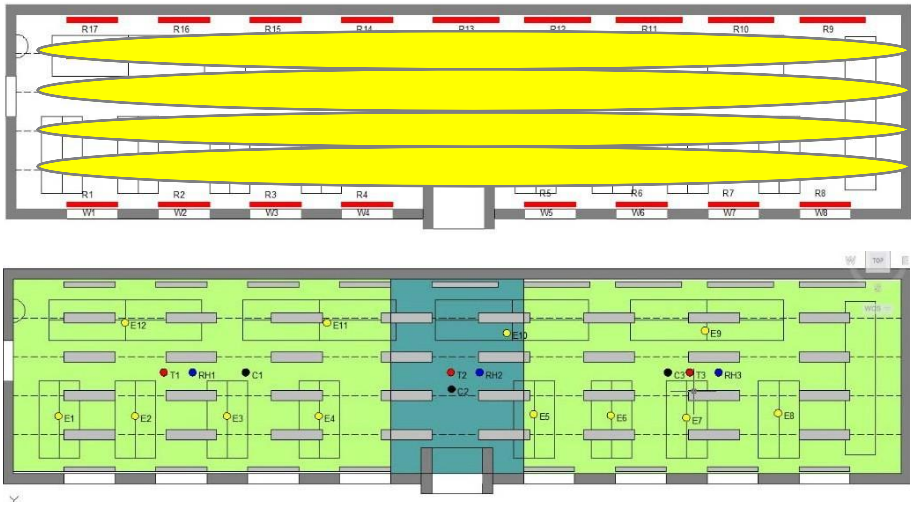

Figure 4: Identified lighting zones (above) and sensors (below) in a student project (drafting room in a university building). In this case, an unnecessarily large number of sensors cover a single zone.

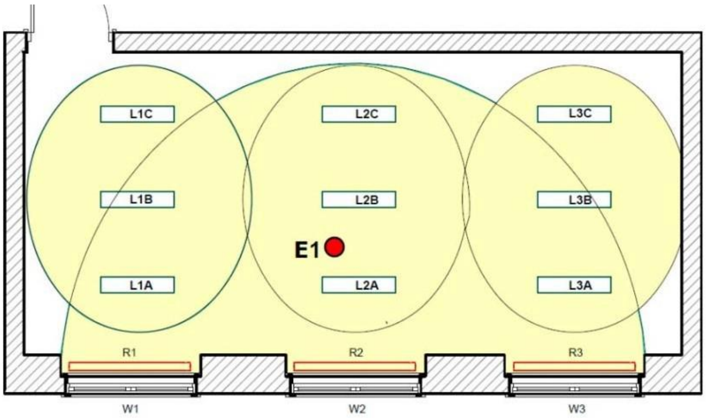

Figure 5: Defined lighting zones and sensor in a student project (seminar room in a university building). In this case, only one sensor is to cover multiple zones.

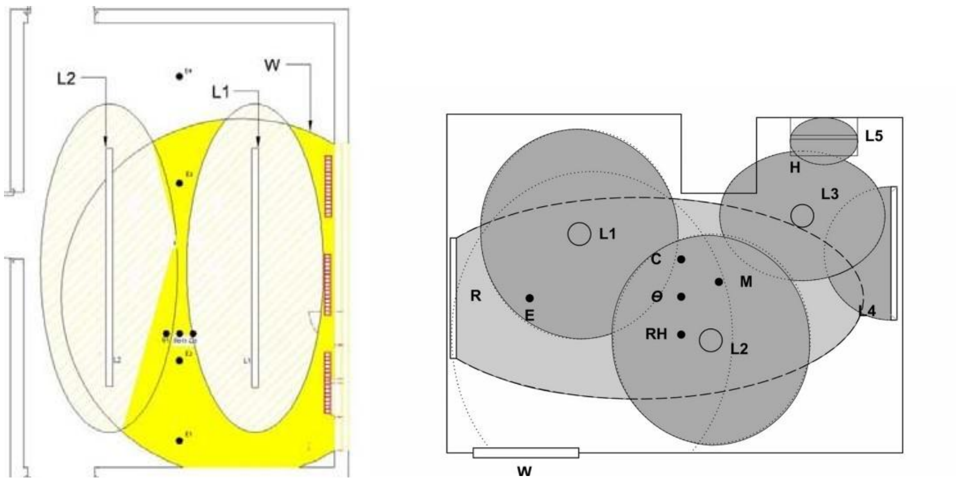

Figure 6: Misplaces illuminance sensor in two student projects (kitchen spaces in two student dormitories)

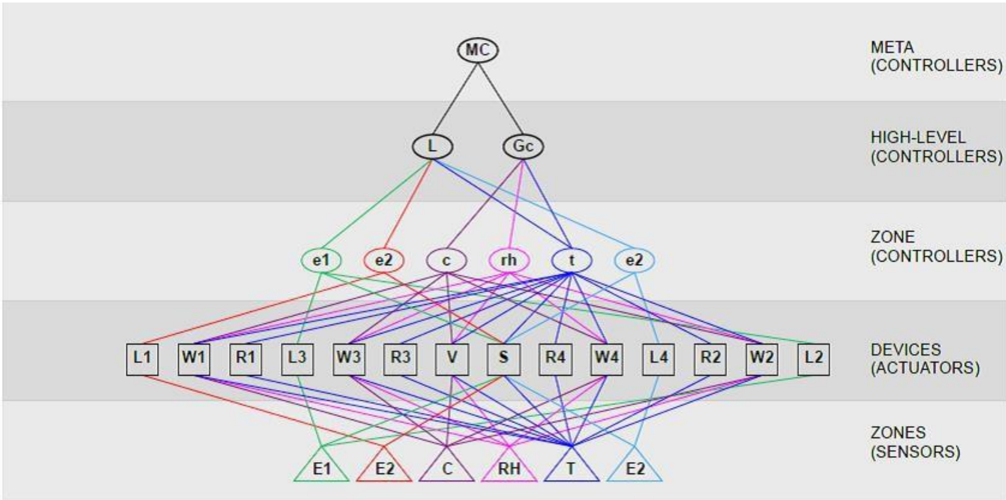

Figure 7: Overtly complex instance of schema generation in a student project (lecture room in a university building). Here, multiple devices are individually represented, even though they could have been combined, as they were jointly operated (i.e., shared the same actuator).

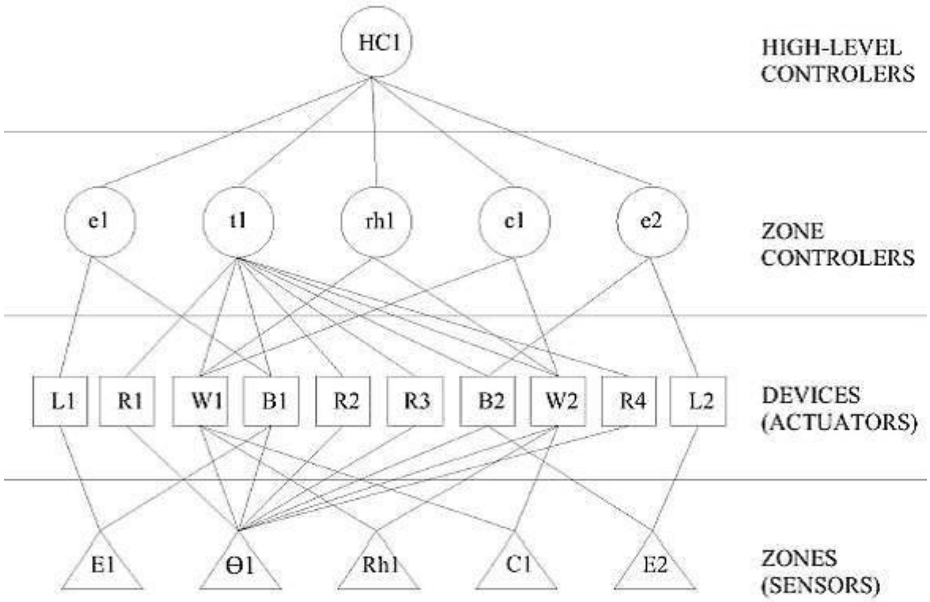

Figure 8: Generation of the high-level controller in a student project (gym in a student dormitory). Here, the derivation of the high-level controller from zone controllers is improperly executed (i.e., the pertinent rule of the scheme generation method is not followed).

Another scheme generation problem pertains to the general complexity challenge. Schemes involving a large number of zones and mutually influencing devices tend to grow very complex. In such cases, manual construction of the scheme with all entailed relationships and dependencies appear to overwhelm user with limited experience, resulting thus in scheme errors.

4 CONCLUSION

In this paper, we tested a previously introduced scheme generation method for the distribution of control logic of buildings' technical systems (heating, cooling, lighting, ventilation). Toward this end, a group of architecture and engineering students deployed and evaluated the method using a sample of real spaces. The participating students' impression of the method and its usability was largely positive. The method was found to be effective in supporting the configuration of buildings' technical systems and the communication between architects and engineers. Actual implementation results, however, revealed in some cases a number of problems with method application. These pertained both to zone and sensor identification/placement and to correct execution of scheme generation rules. In future, we intend to develop a user-friendly graphical environment for the selection of devices and marking of the zones. Moreover, the envisioned environment shall offer interactive features to the users, such that certain steps in scheme generation could be taken in a semi- automated fashion, thus reducing the probability of generating schemes that are faulty or unnecessarily complex.

REFERENCES

CIBSE 2000. Guide H: Building Control Systems. Butterworth-Heinemann; ISBN: 978-0750650472.

Franklin, G. F., Powell, J. D., Emami-Naeini, A. 2006. Feedback control of dynamic systems – 5.th edition; Pearson Prentice Hall; New Jersey; ISBN: 0-13-149930-0; 910 p.

Mahdavi, A. 1997. Toward a Simulation-assisted Dynamic Building Control Strategy. Proceedings of the Fifth International IBPSA (International Building Performance Simulation Association) Conference. Vol. I, pp. 291 – 294.

Mahdavi, A. 2001. Aspects of self-aware buildings. International Journal of Design Sciences and Technology. Europia. Volume 9, Number 1. ISSN 1630 – 7267. pp. 35 – 52.

Mahdavi, A. 2004. A combined product-process model for building systems control. "Proceedings of the 5th ECPPM conference" (Eds: Dikbas, A. – Scherer, R.). A.A. Balkema Publishers. ISBN 04 1535 938 4. pp. 127 – 134.

Mahdavi, A. & Schuss, M. 2013. Intelligent Zone Controllers: A Scalable Approach to Simulation-Supported Building Systems Control. "Building Simulation 2013 - 13th International Conference of the International Building Performance Simulation Association." ISBN: 978-2-7466-6294-0; 1498 - 1505.

Mertz, K. & Mahdavi, A. 2003. A representational framework for building systems control. Proceedings of the 8th International IBPSA Conference, Eindhoven, Netherlands; ISBN: 90-386-1566-3; pp. 871 - 878.

Mosca, E. 1995. *Optimal, predictive and adaptive control*. Prentice Hall; New Jersey; ISBN: 0-13-847609-8; 477p.

Unbehauen, H. 2008. Regelungstechnik. 1. Klassische Verfahren zur Analyse und Synthese linearer kontinuierlicher Regelsysteme, Fuzzy-Regelsysteme; Vieweg+Teubner; Wiesbaden; ISBN: 3-8348-0497-5; 401p.

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