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Opportunities for integration of modern systems into control processes in intelligent buildings

***Abstract**. This paper presents different approaches to development of modern methods and control systems based on analysis and implementation of modern control methods. They utilize principles of robust control for thermal processes in intelligent buildings and method of Internal Model Control to calculate robust regulator parameters at non-parametric and parametric uncertainties in process model. The paper describes realized increase in robustness of control algorithm by means of programming module implemented into distributed control system based on LONWORKS technology.*

***Streszczenie.** W artykule przedstawiono odporne sterowanie procesami ogrzewania w inteligentnym budynku. Uwzględniono niepewności modelu. Wykorzystano technologię LANWORKS. (**Możliwości integracji systemów sterowania w inteligentnym budynku**)*

Keywords: Methods, intelligent buildings, LONWORKS, regulators, temperature.
Słowa kluczowe: budynek inteligentny, sterowanie temperaturą.

Introduction

Complex control systems nowadays are designed for wide range of industrial applications. They are focused on effective management of composite processes, energy savings and optimization of production and technological processes. Intelligent buildings utilize synergy of software and hardware representing one of the widest area for application and integration of information systems, information technologies, communication systems, modern control systems and control algorithms.

Application of automatic building control aims for creation of such conditions so that technically complicated and complex building could become „intelligent". It means that it should be able to adapt to the change in internal and external conditions and so meet requirements of the owner, user and residents. This objective could not be fulfilled solely by application of advanced and most sophisticated automatic control. Automatic control needs to be combined with intelligent technologies and intelligent architecture [1].

The paper describes possibilities and potential for application of modern information, communication and control systems and technologies in control processes in intelligent buildings.

Methods of designing automatic control systems

Designing automatic control system requires complex analysis of the solved problem. Functionality and reliability of the entire system depends on the correct selection of suitable solving method. The main task is to identify system behaviour and define its mathematical model.

The term identification represents determination of properties of examined object based on measured operation factors. Amongst them, the most appropriate seem to be system responses to standardized signal: jump change of input variable and harmonic input signal. Image of dynamic properties are obtained in form of differential equations or directly in form of transfer. Similarly to mathematical system description, there is a difficulty in defining exponent of the system. It is a compromise between accuracy and simplicity. As a next step, there is a need to determine model structure and respective coefficients in a way so that the difference between real object and model in a particular criterion is minimum.

If we concentrate on deterministic task of identification of linear systems, then from the practical point of view it only is appropriate to evaluate stable systems. Evaluation should be carried out as follows.

The most simple and basic control structure is feedback structure. Aim is to select structure of feedback regulator and calculate coefficients of the regulator. By the design of continuous regulators following methods are utilized [2],[3],[4].

- Method of Optimal Module,
- Ziegler-Nichols Method,
- Naslin Method,
- Method of Time Constants ,
- Method of Standard Shapes,
- Method of Reverse Dynamics,
- Method of Direct Synthesis IMC.

By the design of discrete regulators following methods are utilized which enable to determine indicial functions of regulators:

- Deatbeat Regulator,
- PSD Regulator,
- Poleplacement Regulator.

When designing optimal comfort for people in intelligent buildings it is very important to achieve so called internal well-being. One of the areas contributing to human well-being in buildings is heating. Therefore is the appropriate design of regulation as well as suitable heating regulator the most important factors by the design of heating system in buildings.

Following parts of this article present characteristics and application of selected LONWORKS technology for heating system in intelligent buildings.

Analysis of application of lonworks technology in intelligent buildings

LONWORKS (local operational networks) represent distributed control system utilizable in control applications of intelligent building technology and in industrial automation. LONWORKS are data oriented networks which carry information in form of so called network variables and explicit messages. System stands for network cross connection of intelligent nods with neuron chip – LON sensors, LON actuators. LONWORKS provides favourable environment for integration of systems from different producers.

Basic idea of the technology is a split of single device or system into a group of intelligent elements (called nods) which are interconnected by means of communication medium (twisted pair, etc.) creating network. Network LONWORKS does not require a central element and is not even Master–Slave type of network. Intelligent nods communicate among each other, which represents Peer-to-Peer network type [5].

LONWORKS technology supports a wide range of communication media which enables to optimize transfer considering permeability of channel while keeping minimum price and simplicity of installation. Nowadays, protocol supports following communication media: twisted pair, RS-485, radio channel, power lines from ~230V to ~10KV, optical cable, infrared transmission, input power = 48V feeding and communication realized through the same wires.

LONWORKS technology is supported by all network topologies (bus, circle, star or any of their combination).

Advantages of the system are summarized in the following five points:

- total openness of system for future expansion,
- supports wide range of communication media,
- principle of LONWORKS network secures its function even if one of the elements breaks down,
- supports all network topologies,
- by means of LONTALK protocol and using network communication agents - routers, it supports construction of extensive networks.

Nods are intelligent devices as well as network elements interconnected among each other through communication medium which operates in LONWORKS network. Nods consist of the following components (Fig.1)

- neuron chip,
- transceiver for the given type of communication medium,
- hardware interface which secures application activity of the nod.

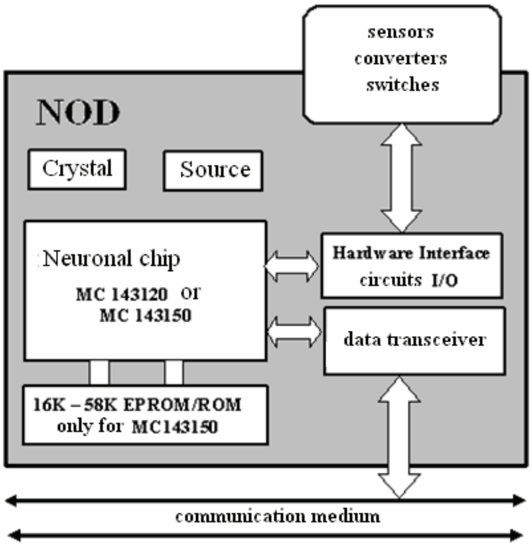


Fig.1. Block diagram of neuron network nod

Neuron chip is usually realized through MC 143120 or MC 143150 circuits with implemented LONTALK protocol.

Design of optimum parameters of discrete regulators

Discrete structure URO is characterized by following block diagram (Fig.2), according to which the regulated process is continuous and calculation of regulator coefficients can be based on two different approaches.

Approach 1: conversion from continuous form of PID regulator. Discrete form PID regulator is as follows

(1) $$G_R(z) = \frac{Q(z)}{P(z)} = \frac{q_0 + q_1 z^{-1} + q_2 z^{-2}}{1 - z^{-1}} = \frac{U(z)}{E(z)}$$

where q are coefficients of discrete form of PID regulator. They are function of sampling period T and coefficients of continuous regulator P, T_i, T_d.

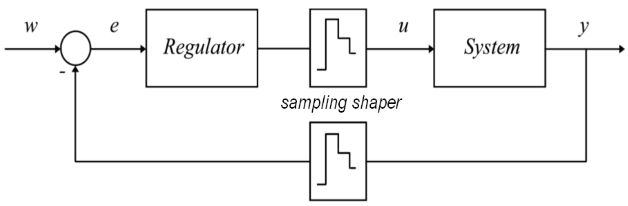


Fig.2. Block diagram of discrete URO

Approach 2: direct calculation of coefficients of so called general discrete regulator.

Indicial function of general discrete regulator is shown below

(2) $$G_R(z) = \frac{Q(z)}{P(z)} = \frac{q_0 + q_1 z^{-1} + .. + q_m z^{-m}}{p_0 + p_1 z^{-1} + .. + p_n z^{-r}} = \frac{U(z)}{E(z)}$$

Final indicial functions of regulator were designed by following methods:

a) Deadbeat Method,
b) Poleplacement Method,
c) Method of designing discrete regulator with optimum structure (algebraic theory).

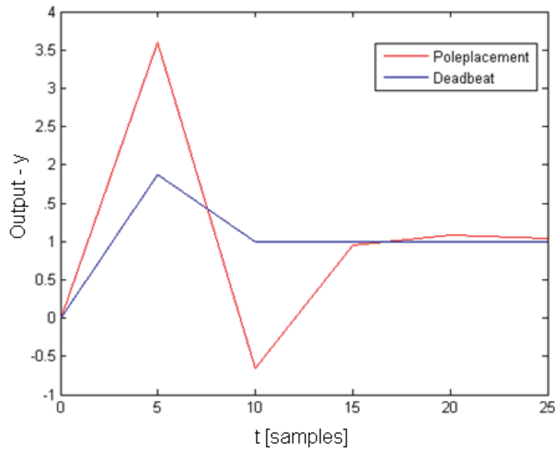


Fig.3. Time behaviour of indicial response of discrete URO

For comparison of quality of URO realized by Deadbeat and Poleplacement regulator, there is an image of their indicial responses showed on Fig.3 [6].

Increasing robustness of methodology and procedures used for design of optimum algorithm in control of heating processes

Increase in robustness was based on IMC method. Block diagram of IMC control (Internal Model Control) is presented on Fig.5, where the controlling block consists of regulator as well as model and is highlighted blue. Referential signal and measured process signal are inputs of control system. Output is action intervention entering the process. Comparing with classic structure on Fig.4, IMC structure has several advantages. Role of output from the parallel model is to subtract impact of action intervention from process output.

If assumed that the model represents the process ideally, then the feedback signal only interprets a breakdown. Concurrence of model and process mean that the system is actually an open circuit, does not have classic feedback structure and thus lucks the problem of feedback stability. Complete system is stable when process $G_P(s)$ as well as IMC regulator $G_C(s)$ is stable.

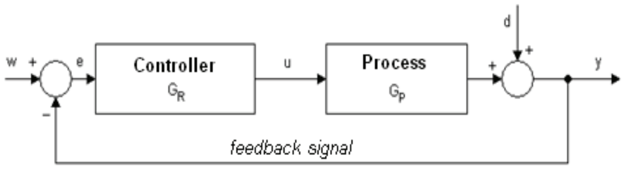


Fig.4 Block diagram of classic feedback control

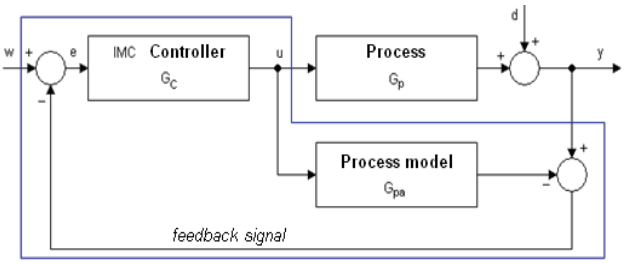


Fig.5. Block diagram of Internal Model Control

Relations between classic feedback and IMC regulator

(3) $$G_R(s) = \frac{G_C(s)}{1 - G_C(s)G_{Pa}(s)},$$

(4) $$G_C(s) = \frac{G_R(s)}{1 + G_R(s)G_{Pa}(s)}$$

Control intervention is defined as follows

(5) $$U(s) = \frac{G_C(s)}{1 - G_C(s)(G_P(s) - G_{Pa}(s))}(W(s) - d)$$

Output regulated parameter

(6) $$Y(s) = d + \frac{G_C(s)G_R(s)}{1 - G_C(s)(G_P(s) - G_{Pa}(s))}(W(s) - d)$$

Based on these relations, below properties of IMC structure are determined

- If model is ideal and $G_P(s) = G_{Pa}(s)$, then following is valid $U(s) = G_C(s)(W(s) - d)$,
$$Y(s) = G_{Pa}(s)G_C(s)(W(s) - d) + d$$
- IMC structure secures "ideal" control $Y(s) = W(s)$ in each time period and under all conditions.
- If $G_P(s) = G_{Pa}(s)$ and $G_C(s) = (G_P(s))^{-1}$.

For practical application it is necessary to consider

- $G_{Pa}(s)$ never equals $G_P(s)$.

Relation $G_C(s) = (G_{Pa}(s))^{-1}$ is possible to achieve sporadically, due to inaccuracy of indicial function, time lags and positive zeros in model of process.

Experimental verification of the designed control system in intelligent building

Generally speaking, intelligent building needs to be designed correctly. Design methodology, realization of information and control systems and verification of designed URO in intelligent building runs in several phases:

Phase 1 – planning of structured cabling in intelligent building which is the base for well-functioning IB. Considered is power, information and also communication cabling. Power cabling consists of the following elements: main switch, protective switches of particular circuits and end elements (socket, light).

Phase 2 – realization of designed cabling including end elements.

Phase 3 – design the amount of input-output nodes and their function.

Phase 4 – installation of power elements and input-output nodes into particular panel switchboards. Cross connection of multiple panel switchboards by means of communication lines.

Phase 5 – installation of ready-made software into particular nodes according to the function they are supposed to perform.

Phase 6 – testing and functional adjustment of all realized systems.

By design of heating process control following elements were determined: natural gas boiler PROTHERM 30KLO with nominal power of 30KW - Fig.7a), circular pump with three power rates of 50W, 100W a 150W and heat exchanger KORAD -Fig.7.c). Block scheme is on Fig.6.

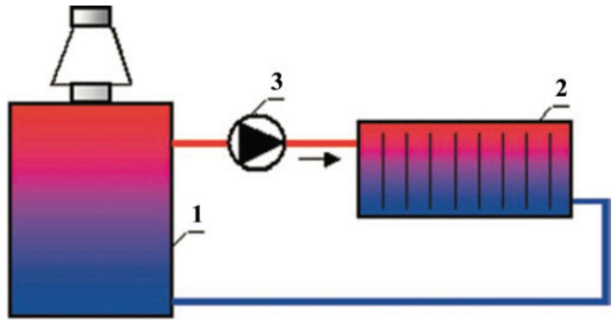


Fig.6. Regulation of heating power by change of temperature in power boiler water (1 – Heat source – gas boiler, 2 – heat exchanger, 3 – circular pump)

Thermometer DALLAS DS18B20 was used as a sensor of internal temperature in room. The digital thermometer works in a rage of 9-12 bites +/- 0.5°C from -55°C up to +125°C (resolution of 0,5; 0,25; 0,125; 0,0625°C) [7].

Fig.7a), b) c) provide images of real photographs of thermal system: gas boiler with pump, distributor unit and heat (KORAD radiator).

Fig.8a) views a „power" switchboard which contains following parts:

- main switch and protective switches of light and socket circuits are placed on DIN bar 1 from the top,
- three-phase circuit breaker and circuit breakers of socket and light circuits are placed on DIN bar 2,
- gas boiler circuit breaker and breaker protecting measurement and regulation (module) circuits are placed on DIN bar 3. For future purposes there is prepared an input-output LON module for regulation of exterior parts of intelligent building (lawn watering, garden lightning, etc.).

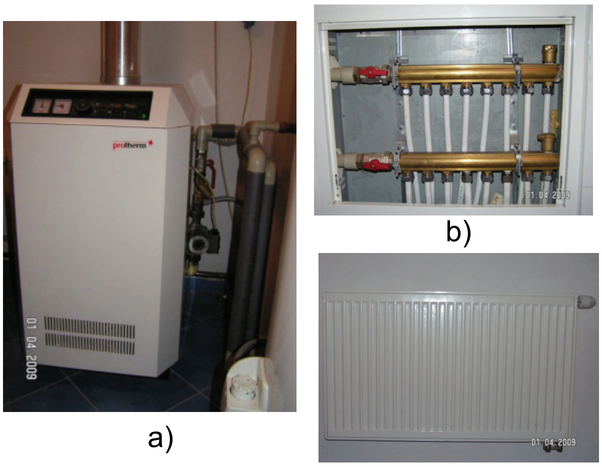
Fig.8b) views a „communication" switchboard which contains following parts:

- relays which connect particular light circuits and gas boiler control are placed on DIN bar 1 from the top,
- output LON modules which control switching of particular relays are placed on DIN bar 2,

- input LON modules which are entered by signals from thermometers of DALLAS type, signals from PIR sensors (checking presence of humans in different rooms) and signals from particular light switches are placed on DIN bar3.

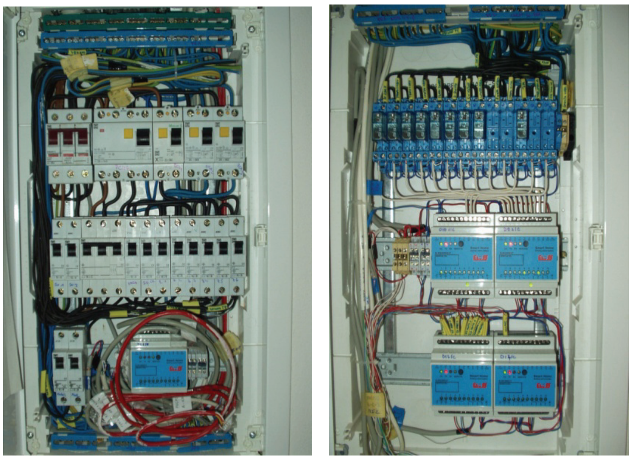
Based on this methodology, functionality of intelligent building – family house was designed, realized and verified. LONWORKS technology was applied for control of heating system with integration of designed regulator, lightning and electronic security system.

In the next stage, systems of exterior parts of IB will be solved and realized (lawn watering, garden lightning, etc.).



a) b) c)

Fig.7 a) Gas boiler with circular pump, b) distributor unit, c) heat exchanger



a) b)

Fig.8 a) “Power” switchboard, b) “Communication” switchboard

Conclusion

The article provides analysis of selected thermal processed from theoretical as well as practical view and design of their mathematical models in Matlab-Simulink. Measured data were scanned from the real object and were used as basis for determining continuous and discrete mathematical models. These were used to design optimum structure of control processes and calculation of optimum parameters for continuous and discrete control algorithms. It was observed that conventional control methods can not fully filter uncertainties and changes of process parameters. Therefore, increase in robustness of conventional methods was designed utilizing IMC (internal model control) approach. It was modified and implemented into control system so as to reach stability and quality of control. Control methods based on IMC were implemented into control systems and verified in real operation. Numerical and graphical solutions together with implementation into control system confirmed effective application of these methods and technologies into practical life.

Success of application of modern control systems is dependent on its intelligence, robustness and reliability. Systems mostly applied into intelligent buildings are specifically LONWORKS system. It acts as a technology of the century. As well it represents a new category in building extensive control networks considering space and number of controlled areas, which secure scanning, monitoring, control and communication. It is a solid technology designed for solving problems of intelligent distributed control systems.

Implementation of robust control algorithm through programming module into LONWORKS system significantly raises quality and reliability of complex control system.

REFERENCES

[1] EHRENWALD, P.: *Is automatic control guarantee of more intelligent buildings creation? (2)*. In: AT&P Journal, 4/2000, SK, p. 19

[2] MIKLEŠ, J. - FIKAR, M.: *Simulation, identification and control processes I. Models and dynamic performance linear processes*. STU Bratislava, 1999, SK, p. 189, ISBN 80-227-1289-2

[3] SKALICKÝ, J.: *Management theory,* VUT FEKT in Brno, CZ, 2002, p. 98.

[4] HARSÁNYI, L. - MURGAŠ, J. - ROSINOVÁ, D. - KOZÁKOVÁ, A.: *Theory of automatic control*. STU, Bratislava, SK, 1998

[5] MIKULOVÁ, Z.: SCADA a LONWORKS – futurism or today? AT&P Journal, 2000, SK, No. 7, p. 31-32

[6] KOZÁK, Š.: *Program system SYNREG 7.3 in MATLAB*. FEI STU Bratislava, SK, 2002.

[7] LACKO, B. – HOLÝ, M.: *Integrated unproductive automation*. VUT FSI in Brno, CZ, 2003, p. 61

[8] ŠEBÖK, M., KUČERA, S. KUČERA, M.: *Diagnostics of electrical equipment using radiance sensors*. In: Proceedings of the 7. International Conference, ELEKTRO 5-2008, Žilina, SK, p.154-157

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