FEEDBACK CONTROL VS. INTEGRATED CONTROL. A CASE STUDY: VARIABLE VOLUME ROOM EXPERIMENTAL BENCHMARK

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Abstract: Systems are in continuous diversification of their application domains and functioning specification requirements. Now, control systems' development is mainly oriented towards completing of conventional feedback control with new techniques and design means. This work deals with integrated control problems compared to feedback control systems. The purpose is to extract defining characteristics of feedback and integrated control that emphasize the main differences between these two terms and manners to understand the control. Variable volume room experimental benchmark is introduced together by means a functional specification. Some design possibilities are introduced to demonstrate the general discussed aspects based on a real example.

Key words: *integrated control, systems design, feedback control, experimental benchmark.*

I. INTRODUCTION

The purpose of this work is to describe and to give a definition to integrated control concept as compared to feedback control. Based on real examples it is wanted to draw out defining differences between this two terms.

The integrated control term is used more and more often in reported papers concerning control systems, [1], [2], [3], [4]. Integrated control appears like an attribute of some developed or designed systems, without enough specification of theoretical defining elements concerning the integrated control systems, ICS. Also, it isn't specified when a control system belongs to the integrated control systems category.

The first part of the paper presents aspects about both feedback and integrated control and emphasizes the defining characteristics and differences between these two kinds of control systems.

The variable volume room experimental benchmark is introduced in the next part together with a functional specification. Some design structures for this benchmark are introduced in order to demonstrate the aspects discussed in the first part of the present work.

In the next part of this paper some remarks and interpretations concerning feedback control and integrated control terms are presented from the experimental benchmark point of view. At the end, the concluding remarks of the whole work are drawn out.

II. CURRENT BASE FOR INTEGRATED CONTROL SYSTEMS

General control fundaments

The need to control in an automated manner more and more systems that are more or less complex, from the real world together with the need to reduce the gap between theory and practice are current problems of interest from automated control of systems from different technical areas.

At present feedback control is incapable by oneself to assure the control system's normal functioning. However, by completing the feedback control with new means and techniques from different information technology field, superior control systems can be developed in order to accomplish the more and more numerous and exigent functional requirements.

In order to be easily put in practice, all the new theoretical aspects concerning the automated control development of complex systems must be detected and then integrated into unitary design platforms generally applicable for any kind of system no matter how complex it is.

These platforms offer universal architectures and structures for control systems design. Together with design methodologies, these platforms offer support for control systems particularization in accordance with process specifics and functional specifications.

Development of realist and intuitive experimental benchmarks is a solution for the study and research of theoretical knowledge, [5], [6], [7]. Many of the complex control problems from the real world can be studied by using experimental benchmarks because of the similarities between them. Therefore, the purpose of experimental benchmarks is multiple and interdisciplinary:

- applying, practicing and practical development of different theoretical aspects, based on real world systems;
- study and research of real world systems that are similar with the experimental benchmarks;
- introducing and developing of new concepts and techniques for design and implementation of integrated control systems, that respect the requirements of complex systems.

Manuscript received October 25, 2008; revised November 24, 2008

About feedback control and integrated control

Two parallel tendencies exist in the field of automated control: development of control algorithms that offer better control performances and development of new ways that provide the good functioning of the control algorithms.

Along this line, there are suggested for the time being the following delimitation of control systems:

- Inferior control systems;
- Superior control systems.

Inferior control systems, InfCS, are the systems where the state variables are continuously measured and together with the perturbation errors are used to modify the input variables, based on certain algorithm, in order to obtain a given behavior at system's outputs.

The general structure of an InfCS, Figure 1, contains four main parts: process (P), information processing system (IPS), actuators (AC) and measuring elements (ME) with feedback to IPS. Different control algorithms from IPS can be implemented on more than one computing device.

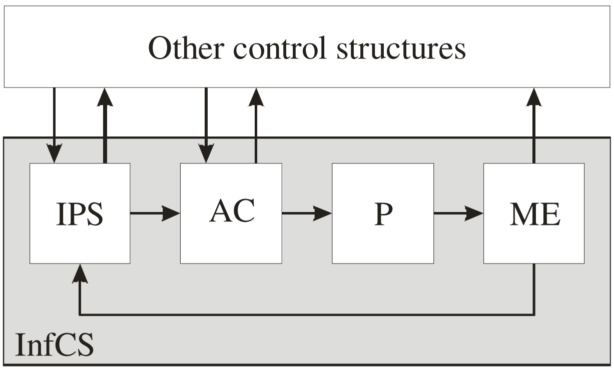

Figure 1. General structure of an inferior control system InfCS interfacing with other control structures.

Superior control systems, SupCS, are the systems that assure the normal functioning of all InfCS components, in accordance with the given conditions contained into the functional specification. SupCS system's purpose is to add to InfCS additional functions like: monitoring, supervision, protection, data recording, diagnosis, optimization, adaptation, planning, decision making, and others. These functions don't compile any of the commands that must be transmitted to the process, but take actions for modifying the InfCS system that is the control algorithms' behavior.

In other words, the SupCS's purpose is to control the InfCS in order to be in accordance with system's control specification. Therefore, it can be stated that SupCS systems control other control systems and that's why these are metacontrol systems, [8], [9].

The main purposes of SupCS are:

- To assure the normal functioning of control system in different conditions: uncertainty presence, high order nonlinear dynamics providing, extern and intern changes that influence the process functioning, faulty functioning of some system's modules.
- To improve the control system's global performances accordingly with the functioning requirements.
- To assure a raised autonomy by removing as much as possible the human factor influence from the control system.

InfCS system previously described is in fact a simple feedback control system, FCS, because it continuously generates the next commands based on process's current state:

$$FCS = InfCS$$

An FCS refers only to control algorithms and imply existence of at least: one feedback from the process, one execution element and one measuring element.

All the InfCS and SupCS systems that are of interest for the same process can be grouped into an integrated control system that is more ample and more complete than the feedback control system FCS.

An integrated control system, ICS, is a system that contains at least one feedback control system FCS and at least one optional metacontrol activity. A general structure of ICS systems is given in Figure 2.

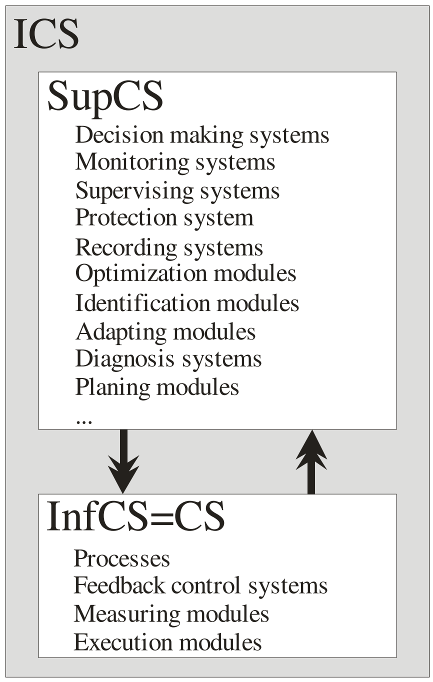

Figure 2. A general structure of integrated control systems ICS.

Based on previously presented aspects, between ICS, FCS and SupCS, the following relations can be identified:

$$ICS = FCS \oplus SupCS$$

$$ICS \neq FCS$$

$$ICS \neq SupCS$$

The simple adding of two or more FCS doesn't represent a real ICS, but a more complex and ample FCS:

$$ICS \neq FCS = FCS\_1 \quad \ldots \quad FCS\_n$$

It can be said that an ICS contains all the functional structures, organized on different levels that are necessary to fulfill all the control system's specification requirements.

From the temporal side of view FCS usually deals with repetitive activities at small time intervals. In the case of SupCS systems, beside small time intervals activities (like: recording and monitoring), there are other planed or not planed activities that take place at bigger time intervals (like: protection, optimization, diagnosis, planning and decision making). This temporal classifying is determined by the place and purpose of each functional module inside the ICS.

From Figure 2 it can be observed the great number of functional modules from SupCS system in contrast with the limited number of functional modules from InfCS. Therefore, it can be concluded that an ICS offer a larger range of functionalities than the FCS that is controlled by this ICS.

III. VARIABLE VOLUME ROOM EXPERIMENTAL BENCHMARK

System's description

The experimental benchmark with variable volume room, VVR, [10], [11], with a principle scheme given in Figure 3, consists of a closed room 1, in which are placed two heating sources 8 and 9. At one end of the room a variable speed blower 6 is placed that introduce air in the room. At the opposite side there is a mobile wall 2 that in his motion, restricted by a spring 4, opens more or less an orifice 5 by which way the air lives the room.

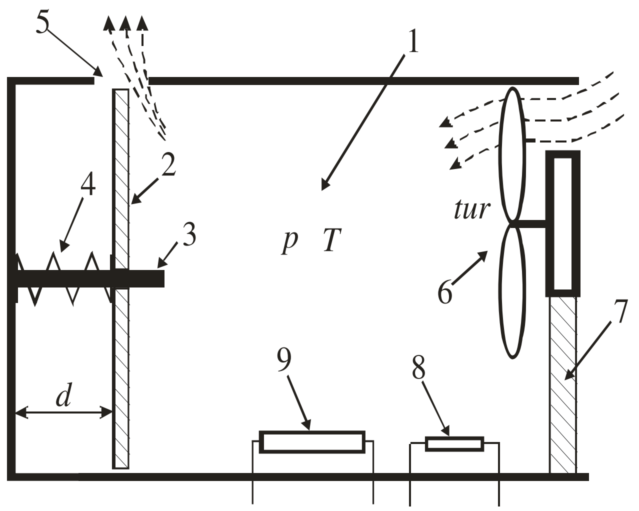

Figure 3. Variable volume room experimental benchmark. (1) closed room ; (2) mobile wall; (3) guiding axle for the mobile wall; (4) spring; (5) orifice; (6) centrifugal blower CB; (7) fixed wall for CB mounting; (8) and (9) controllable heat sources HS.1 and HS.2.

The variable volume room systems block diagram is given in Figure 4. From the functional point of view, it is wanted to assure different types control for the outputs:

- tur - speed of centrifugal blower 6;
- p - air pressure in room 1;
- T - air temperature in room 1;
- d - displacement of the mobile wall 2;

through imposed commands of the inputs:

- $cmdCB$ - command for centrifugal blower 6;
- $cmdHS.1$ - command for heating source 8;
- $cmdHS.2$ - command for heating source 9.

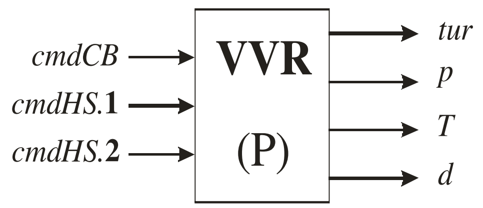

Figure 4. Block diagram with the inputs and outputs of the variable volume room benchmark.

Functional specification

From the set of possible functional requirements which can be associated with the variable volume room experimental benchmark, the following are considered:

1) To maintain a constant air pressure in the room by varying the input air flow when the thermal flow is constant or vary with a given profile.
2) To maintain a constant air temperature in the room by varying the input thermal flow when the room volume is constant or vary with a given profile.
3) To track a certain profile for air temperature by simultaneous varying of the air and thermal input flow.
4) To assure an oscillate dynamic of the mobile wall with imposed parameters by varying the input air flow.
5) Maximum temperature or air pressure can be limited by an operator.
6) If the maximum admitted temperature value is exceeded, than the power of all thermal sources is interrupted, a given centrifugal blower's speed is assured and the situation is reported to the operator.
7) If the maximum admitted air pressure value is exceeded, than the centrifugal blower's speed is driven to zero in the shortest possible time, the power of heat sources is interrupted and the situation is signaled and reported to an operator.
8) To notify the operator if the spring is suffering degradation that makes him less rigid.
9) If exists elements which impede the normal motion of the mobile wall, than the operator is notified.
10) The benchmark must offer to the operator current information about process's parameters of interest.
11) The experimental benchmark must offer manual controllability for actuators.

12) The benchmark must offer possibilities to realize different experiments.
13) The benchmark must allow transportation, maintaining and handling on storing devices of measured data from the outputs of VVR system.
14) The benchmark must have functional protection and protection for the operators.

The prior requirements are formulated in a simple common language and aim to describe a part of VVR benchmark's functional possibilities.

At a closer view it can be seen that requirements can be divided in two categories:

- Well defined – that contain most of the details regarding the particular functionality of the system in certain given situations.
- Poor defined – that contain insufficient details and therefore, the remaining details must be chosen by the designer of the system.

IV. INTEGRATED CONTROL SYSTEM DESIGN

A possible functional structure regarding variable volume room benchmark is given in Figure 5 and contains the following functional modules:

- Recording system, RS, (inputs: measured output variables from VVR system and commands for accessing recorded information; outputs: measured data at a certain time interval) – offers saving, maintaining and accessing possibilities for measured data in data bases (requirement 13).
- Protection system, PS, (inputs: current and/or recorded VVR system's inputs and outputs, that are needed to assure the protection functions; outputs: commands for system's protection) – has the purpose to permanently monitor the control system's states and to act accordingly to functional requirements regarding the parameters' exceeding of some limits or against damage of different control system's components (requirements 6, 7 and 14).
- Information Processing System, IPS, (inputs: measured values of process's outputs, commands from the SupCS; outputs: commands for process's inputs.) – contains different control algorithms implemented in order to fulfill the control system's requirements regarding the dynamic behaviors (requirements 1, 2, 3, 4).
- Diagnosis System, DS, (inputs: measured data from recording system; outputs: notification signals to operator and DMS) – identifies damages or defective functionalities of some control system components. In the VVR benchmark, the diagnosis assures normal functioning conditions for the spring 4 (requirement 8) and the mobile wall 2 (requirement 9).
- Human Machine Interface, HMI, (inputs: information of interest to display to operator; outputs: commands from operator that configure certain settings into the control system) – has the task to assure the interaction between the operator and the control system (requirements 5, 10, 11, 12, 13).
- Decision Making System, DMS, (inputs: information from the DS, HMI, IPS and PS; outputs: command signals to IPS) – has the task to take decisions regarding control system's functionality, in a priority order, accordingly to the information gathered from different functional modules.

In Figure 5 is detailed the functional block diagram for the VVR benchmark process, that is also given in Figure 4.

The modules are:

- actuators: centrifugal blower fan CB (for command $cmdCB$) and controllable heating sources HS.1 and HS.2 (for commands $cmdHS.1$ and $cmdHS.2$);
- measuring elements: encoder ENC (for), pressure sensor PS (for p), temperature sensor TS (for T) and linear distance sensor (for d);
- other constructive elements of VVR experimental benchmark.

From Figure 5 possible functional modules classification into the frame of some information processing equipments can be chosen. Equipments choosing can be made in different ways accordingly to the application specifics and the available equipments.

The following equipments are used:

- programmable logic controller CBM550;
- programmable logic controller Siemens SIMATIC S7-300 together with STEP7 and WinCC software platforms;
- personal computer PC with serial communication possibilities through RS232 for CBM550 and MPI for SIMATIC S7-300.

Two of the ICS's modules design cases are subsequently presented.

In the first case the IPS from InfCS will be implemented into the programmable logic controller CBM550. All the input and output signals from the VVR benchmark, represented in

Figure ***4*** and Figure 5 are wired to the CBM550 inputs and outputs.

Others functional modules (DMS, DS, HMI, PS and RS) from the SupCS are implemented into the PC on different software platforms (Visual C++ / C#, Matlab, Labview, etc). Communication between PC and CBM550 is realized through RS232 serial connection.

The second case differs from the first only by the implementation of the functional modules presented in SupCS. Thus, into the programmable logic controller SIMATIC S7-300 the functional modules PS and DMS are implemented through STEP7 programming platform.

The other modules: DS, HMI and RS are implemented into the PC through software platform Simatic WinCC. Communication between PC and SIMATIC S7-300 is achieved through MPI adapter, and between SIMATIC S7-300 and CBM550 it can be achieved through serial RS232 or RS485 connection.

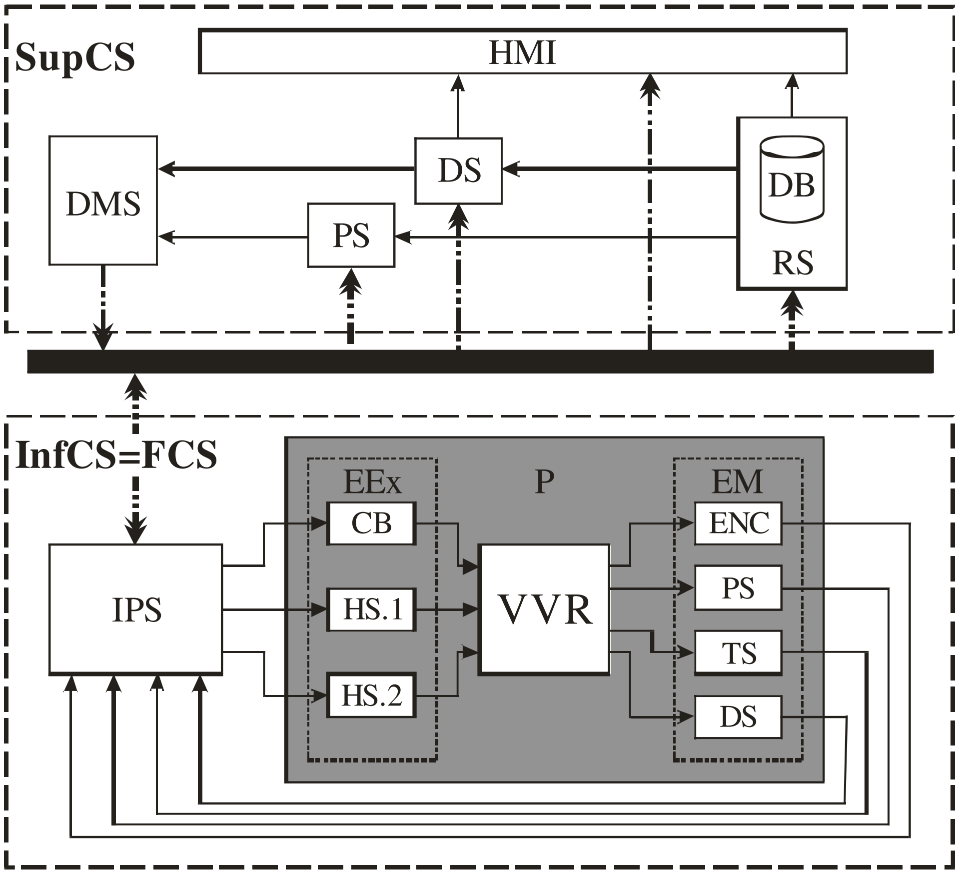

Figure 5. Possible structure of the integrated control system for the variable volume room experimental benchmark.

V. REMARKS AND INTERPRETATIONS

Unlike a FCS system, where only automated control theory is used, in ICS systems knowledge and resources from different areas:

- information technology areas: computer science, electronics and communications;
- controlled system's specific areas: mechanic and physics for this case, or others like: medicine, chemistry, economy, constructions, etc;

that are combined and used to solve a general problem or a global objective of a complex system.

Therefore, integrated control systems represent an interdisciplinary field meant to design systems that belong to a wide area of applications.

In both design cases it can be seen that the process P and the programmable logic controller CBM550 forms a FCS system, not an ICS system because:

- it implements only the control algorithms that evaluate the process's current state based on measuring elements and generates the new commands that are immediately applied to the process through the actuators;
- solves only those requirements from the control system specification that refer to dynamic characteristics to be imposed to some process's states;
- besides generating the new commands, this system doesn't executes any other function.

The two design structures prior presented include the implementation of all control system's specification requirements (InfCS together with SupCS). These complete structures belong to the integrated control systems ICS because:

- contain at least one FCS system;
- beside FCS include other auxiliary functions that solve all the others requirements from the control system specification.

The given design structures are not unique and can include a bigger or a smaller number of modules accordingly to the information processing equipments choosing.

In the second case the control algorithms from IPS module can be implemented into the SIMATIC S7-300, therefore the number of equipments is reduced from three to two: SIMATIC S7-300 and PC.

In the peculiar case when the functional specification contains only requirements that can be all implemented into the CBM550, the integrated control system ICS contains only one computing equipment in it's structure.

From the previous presented aspect sit can be noted that the functional modules of the ICS structured into FCS and SupCS doesn't imply to choose different equipments for each of these two control subsystems.

In conclusion, the delimitation of these two subsystems of an ICS, FCS and SupCS, can be realized both by software and hardware means.

VI. CONCLUDING REMARKS

In this paper a definition for the integrated control system is given and the differences between the feedback control and integrated control where drawn out.

Different design possibilities of variable volume room benchmark are introduced in order to emphasize the defining characteristics of integrated control systems.

As continuation for this work development of a general architecture together with common design methodologies for integrated control systems are foreseen.

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