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Emerging Smart Engineering: An Integrated Manufacturing and Management System

Jozef B. Lewoc[1], Antoni Izworski[2], Slawomir F. Skowronski[2], Antonina Kieleczawa[3], and Peter Kopacek[4]

[1]BPBiT Leader (Leading Designer), Wroclaw, Poland
[2]Wrocław University of Technology, Wroclaw, Poland
[3]IASE, Wroclaw, Poland
[4]Vienna University of Technology, Vienna, Austria

1 Introduction

The possible applications of complex Computer Integrated Manufacturing and Management (CIMM) systems seem to be a vary important emerging application of the industrial engineering in the future manufacturing.

In the case study country (Poland), the problems of manufacturing and management (including factory automation) have been tried to be solved together for a long time. Even the very first original Polish application of computer control systems [1] covered some problems of production control, factory automation and management. The last original case study country projects in the domain of the power industry computer control systems and networks [2,3] were, in fact, the large-scale distributed CIMM systems for big manufacturing plants. Unfortunately, due to the severe down-economy period in the case study country, when the political change occurred there (roughly 1990), the projects were abandoned.

After the political change mentioned hereinabove, the case study country became opened widely to possible technology transfer from well developed possible technology providers of the Western countries. But they never tried to resume the above mentioned projects. First of all, they were interested in lay labour only in the "technology transfer beneficiary countries" [4-8] and, in no case, in continuation of local projects. Secondly, there were hardly any references confirming that they had anything at all to offer in the CIMMs domain. Thirdly, in the case study country, they proved to be simple losers: though in the Lower Silesia and, specifically, in Wroclaw, i.e. ex-capital city of the case study country IT, ICT, industrial electronics and automation industries, wherein many people of deep knowledge and wide experience in the domain are still available, or perhaps just due to that, all big Western ICT and automation corporations have failed and have had to move out (in a shame, if this word means anything to big corporations).

A group of designers and research workers involved earlier in development of computer automation systems and networks [5], [8,9] (the Team) decided to resume their activities to continue the work began in late nineties and publish their results in spite of popular opinions:

- "For example, ISA 95 / IEC 62264 is a must for a reference in this area."
- "It should be better to separate concerns and to have two specialised systems supporting each other."

The two remarks touch the very bases of design and research work for novel large-scale industrial systems. The authors recognise two basic approaches to development of large-scale novelty: by-thinking and by-organising. The first consists in unassertive recognition of the lack of knowledge at the very beginning when a novelty is to be developed, defining the reasonable minimum configuration to be developed to learn as much as possible of the novelty and in attempting co control the whole project to ensure as low losses as possible and to enable fast and economic development of future implementations.

The by-organisation method consists in devising the complete standards and procedures for development of even the first implementation of the novelty and forcing other research and design teams to observe the standards and procedures developed by people incompetent in the area.

Assuming that *Historia est vitae magister* and not bunk [10], some similar earlier cases will be analysed, beginning from the OS MVT operating system project in the seventies. The team organised several comparative session of students' work in program debugging for two computers: R-32 (System /360 compatible) under OS MVT and TSO and Odra 1325 (ICL 1902a compatible) under EX2M. The function to cost ratio for Odra 1325 was by more that 100 higher than for R-32 [11]. Many people at that time realised that the operating system OS MVT was "the worst operating system in the world" but only a very few of them dared to criticise in open the biggest then provider of computers.

The researchers of the University of Cambridge Computer Laboratory, a very small team in comparison with that that involved in development of OS MVT/TSO, analysed the case and developed their own system Phoenix, eliminating the OS MVT defects one after another and increasing the performance characteristics of the system very significantly [12].

The work on public networking, in the seventies and eighties, is perhaps even more similar to the CIMM case. E.g. for the link level, the HDLC protocol was designed Stallings (2007). However, the task of developing public WANs with HDLC was infeasible until CCITT defined a subset of HDLC, the link level protocol, that made the task of development of public WANs realistic. The attempts to implement the full HDLC protocol by the by-organising method, resulted in spoiled human effort and time only.

The other "good advice" of separating the concerns, mentioned above gives some answer why the biggest world manufacturer of computers at that time could develop the worst operating system in the world: from the very well developed flow diagrams of OS MVT, one could guess the organisation of the project. The hardware issues were strictly separated from the software ones and, in a case of any dispute between a hardware designer and a software designer, the decisions were to be undertaken by their superior, of poor knowledge and experience in both hardware and software. And the superior, usually, undertook its decisions on the *divide et impera* principle

It seems also to be worthwhile to mention here the traditions of low cost and by-thinking approach to research work of the University of Cambridge Cavendish Laboratory. A good example could be Sir Martin Ryle (Nobel price in physics in 1974) [14] who talked to young engineers of the case study country about the traditions: the low-cost approach of the Laboratory to research work simply forced their research workers do develop themselves in a higher extent than other scientists did so that they could apply the by-thinking method effectively; to be successful, they had to do useful things. And the results were: the number of Nobel prizes won by the Cavendish Laboratory, more than half of the sky object in the atlas, identified by C-for Cambridge, etc., etc..

I. THE CIMM SYSTEM

A. General

Large-scale and very large-scale industrial systems have become a very serious social concern. Some people discuss even of the global systems. But, if one looks at normal industrial enterprises, the situation seems to be rather poor: on one hand, there are Computer Integrated ManufacturinG systems (CIMGs) developed by companies specialised in automation of industrial processes and Computer Integrated ManagemenT systems (CIMTs) systems developed by other companies, involved in automation of managerial activities. CIMGs and CIMTs are developed on heterogeneous hardware and software and, usually, the suppliers do not provide effective interconnections between the systems.

B. Goals of the First CIMM Implementation

The utilitarian goal: *To develop and implement the first thread on the CIMM network enabling a pilot interconnection between the CIMMGs and CIMMTs of an exemplary manufacturing enterprise.*

The scientific goal of the first implementation is: *To develop standards for design, investigation and implementation of CIMMs-es for industrial enterprises.*

The overall goal is: *To enable optimum operation of the enterprise involved, upon some objective criteria.*

C. The First Thread

The approach to development of CIMMs was described elsewhere [3], [15]. The general structure of any CIMM system could be planned only in a very general way at present. Therefore, it is not reasonable to design a solution for all possible CIMM problems at the very beginning of the design process since it would require a lot of unnecessary and expensive work. Thus, the *first thread* in the CIMM system, i.e. the minimum set of tasks needed for development a interconnection of the CIMMGs and CIMMTs useful and profitable for the enterprise involved, should be defined feasibly for being designed, worked out and implemented by a finite team. Basing on these experience and standards worked out, it should be possible to design and implement further CIMM threads.

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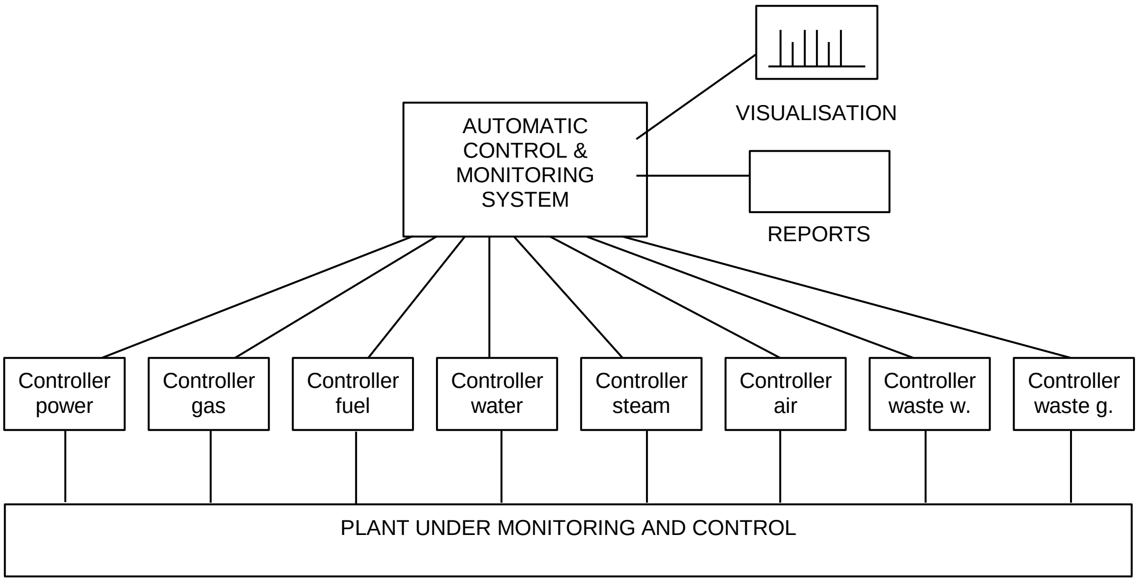
Fig. 1. General structure of System MEDIA



The best candidate for the first CIMMs thread seems to be the Working Media Department which exists in each medium or big manufacturing enterprise. The basic evidence:

- high share of working media in total enterprise costs,
- similar problems in many enterprises,
- a lot of experience in the power industry CIIMGs-es may be applied directly for CIMMs-es,
- power saving and sustainable energy problems are very important now what makes CIMMs-es even more attractive [16].

The first thread in CIMMs under design and investigations will be called the *System Media*.

A. System Media

The basic **media** (variables) proposed for the System Media include: **electric power** (active & reactive power, voltage, current), **gas** (flow, calorific value), **fuel** (weight), **water** (flow, temperature), **steam** (flow, temperature, pressure), **compressed air** (flow, temperature), **waste water** (oxygen demand, heavy metals, suspended solids, oil content, pH, flow), **waste gases** (flow, CO content, SO_x content, NO_x content).

The general structure of the System Media is presented in Fig. 1. This structure is commonly used in the power industry.

The Media software consists basically of the monitoring system software (the controller software are standard process variable acquisition and primary processing programs). The operating system should be selected taking into consideration its dependability features (e.g. [17]).

The software architecture of the System Media (Monos – Monitoring operating system) is presented in Fig. 2.

B. Economic Benefits

Basing on the power industry benefit evaluation guidelines, it can be predicted that that the System Media will provide benefits not lower than 20% of the media consumed / discharged under its control.

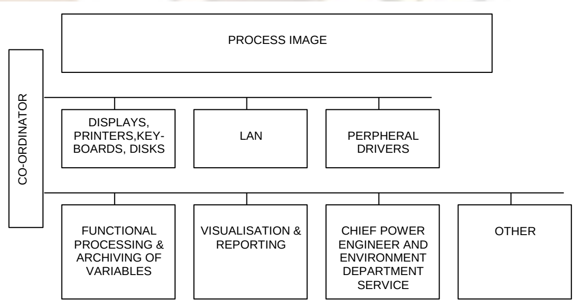


Fig. 2. Software architecture of Media

C. Development of CIMMs-es

CIMM should and, most probably, will become a domain of industrial and scientific organisations. Due to connection of the CIMG and CIMT domains, many new problems will appear, for sure. In the domain, the design Team have been involved, till now, in research work directly connected with design and development of novel computer systems and networks, including the System Media itself, i.e. robustness and performance evaluation [18-20] and in studies of cultural aspects of automation [4-7], [21]. But a lot of room can bee seen in the CIMMs area for research work connected with development of effective methods of running enterprises on the basis of the new information delivered by CIMMs-es, e.g. on-line information on media consumption for enterprise troubleshooting, validation of production processes, optimisation of production schedules, etc., etc.

For the star topology, the basic configuration of the System Media is shown in Fig. 3. Here, it can be assumed that the concentrators introduce some known delay only. Therefore:

$$G_{S,i} = k_i e^{-sT_i}, i = 1 \ldots n,\ T_i \geq 0 \qquad (1)$$

where
G is the transfer function symbol,
i is the system leg number,
S is the star topology index
T_i is the time delay in the i-th leg.
For the other case (e.g. Ethernet), the basic configuration is shown in Fig. 4.

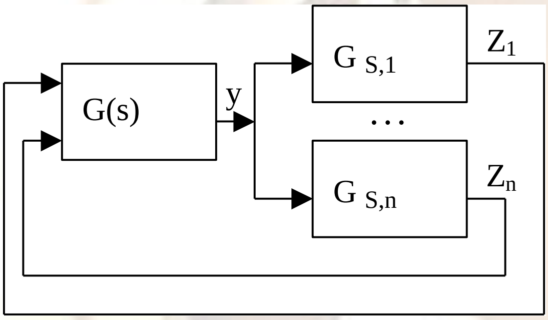
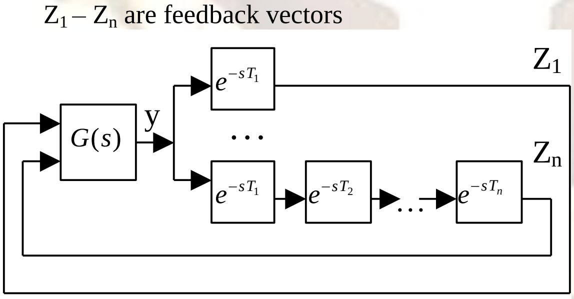


Fig. 3. Basic diagram for the star case
where
$Z_1 - Z_n$ are feedback vectors



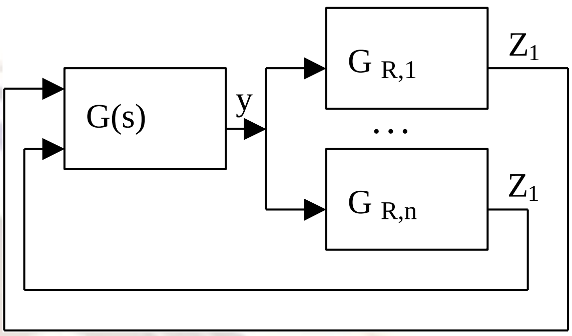
$$i = 1 \ldots n,\ n = 8,\ \bigwedge_{i=1 \ldots n} T_i \geq 0$$

Fig. 4. Basic diagram for the common-medium case

For the common-medium topology case, an equivalent diagram may be drawn (see Fig. 5).
In this case, the disturbance matrix is given by formula (3).

$$\Delta_R = diag\left\{ e^{-s\sum_{m=1}^{i}(T_m + d_m)} \right\}_{i=1}^{n} \qquad (3)$$

where
Δ_R is the disturbance matrix for the common medium topology



$$G_{R,k} = \prod_{i=1}^{k} \overline{G}_{R,i};\ k = 1;\ k = 1, \ldots, n$$

where R is an index of the common medium topology

Fig. 5. Equivalent diagram for the common-medium topology

In either case, a simple transfer function G(s) meeting the demand for stability defined in [22] is adopted. When a simple integrating type action of the plant is assumed in conformity with actual applications, G(s) may be given by the formula (4):

$$G(s) = diag\left\{ \frac{\Pi}{2\, s\, t_i} \right\}_{i=1}^{n} \qquad (4)$$

According to Doyle (1982) and Ferreres (1999), the structured singular value is defined by formulae (5) and (6) for the star arrangement case and the common-medium case, respectively.

$$\mu_S(G) = (\min_{i=1,..,n} \sqrt{2(1 - \cos \omega (t_i - \tau_i))} : \det(\mathbf{1} + G\Delta_S) = \mathbf{0})^{-1} \qquad (5)$$

where
Δ_S is the disturbance matrix for the star topology.

$$\mu_R(G) = (\min_{i=1,..,n} \sqrt{2\left(1 - \cos \frac{\omega}{i}\left(t_i - \sum_{m=1}^{i} T_m\right)\right)} : \det(\mathbf{1} + G\Delta_R) = \mathbf{0})^{-1} \qquad (6)$$

The value of ω is derived, in either case, from the condition that $\omega = \pi/2t_i$. To derive the formulae (5) and (6), it was assumed (in conformity with actual applications) that $d_i = d$, $i = 1,\ldots,n$.

IV. ROBUSTNESS EVALUATION

A. Assumptions Concerning Transmission Delays

To ensure fair comparisons, it was assumed that the data entities transmitted via the communication network have the same data field lengths (1 KB) while the overall data entity lengths (including data and control information) are defined by relevant data transmission protocols. This means, that for the star arrangement case, the asynchronous transfer mode (one start bit, one stop bit and 1 parity bit for each 8-bit byte plus two bytes for longitudinal check sum) is assumed while two synchronizing octets (flags), ca 10% for bit stuffing (insertion/deletion of 0 after a series of five 1's, to enable detection of flags) plus 32 bits for the redundancy check + 4 control octets are assumed for the common-medium arrangement.

B. Robustness Evaluation Cases

Case 1. A "fair" comparison of robustness for the two communication network cases. The μ values (μ_S for the star arrangement and μ_{CM} for the common-medium arrangement) versus the data transfer rate r are presented in Fig 6.

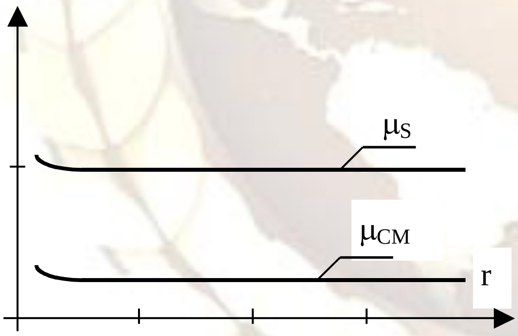


Fig. 6. μ values versus transmission rate, n=8.

Within the full transmission rate range investigated, the star arrangement was much better in the sense of robustness than the common-medium arrangement.

Case 2. In this case, it was assumed that the common-medium arrangement operated at the transmission speed of 10 Mb/second and the transmission rate in the star arrangement was changed in the region of several orders of magnitude lower. The plots of μ_S versus transmission rate r and μ_R (constant value) are shown in Fig. 7.

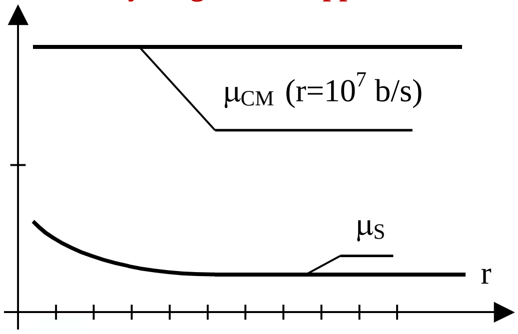


Fig. 7. μ_S values versus low transmission rates; μ_{CM} = constant.

The star arrangement operating at rather low transmission rates (several Kb/second) is more robust than the common-mode competitor operating at 10 Mb/second (and even at higher transmission rates) and it is feasible to employ low or medium transmission rate equipment.

C . Conclusions

For distributed computer control and monitoring systems, the star arrangement is much more robust than the common-medium one, when the "fair" comparison conditions are applied.

It is difficult to compute or approximate the μ function [23-25], but the robustness evaluation method based on the μ function defined already in [22], seams to be an interesting option for designing the topology of distributed control due to the fact that for systems constituted of pure time delay components, as is the case for topology of computer systems, it is not needed to find eigen-values since, on the unitary circle, all values are eigen-values [18], [26].

V. CIMMS PERFORMANCE

CIMMs include the CIMG part, where, usually, the basic performance measures are the maximum possible realisations of time delays, and the CIMT part, where the designer is interested primarily in throughput what makes the investigations are more difficult than usually. In addition, the well-known analytical methods [21,22] can not be recommended to designers of actual systems as too complex and incomprehensible. Therefore, the authors decided to investigate CIMMs with their own approximate method for actual computer networks [20}, [28]. Some exemplary results obtained are presented in Fig. 8 (mean throughput versus mean thinking time) in a closed route.

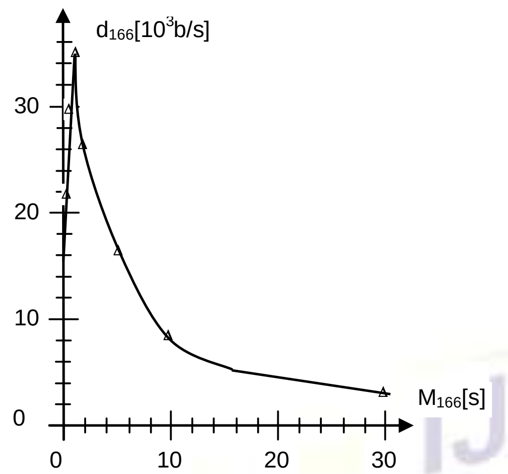


Fig. 8. Mean throughout versus mean thinking time for a closed route passing via two heavily loaded lines.

The method has proven to be simple and straightforward in comparison with those presented by [22], [27].

VI. Conclusions and Further Work

CIIMs-es are examples of distributed computer systems that are severely needed especially for medium and large scale manufacturing plants. Large-scale work on them should be commenced as soon as possible.

The work described in the present paper is intended to be a a starting point for future design and implementation work for the distributed systems for CIMM applications.

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