NEW VISION ON THE MANUFACTURING PROCESS CONTROL

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Abstract: Nowadays technical & social revolution lays on the development of a new working space, namely the cyber space. It is expected that in manufacturing, as well as in the other fields, this revolution will induce a conceptual change in what concerns the working manner. In this context, the paper presents a new vision on the manufacturing process control defined as a coherent ensemble of concepts, paradigms, and approaches, able to support the reaching of the ultimate goal, namely the conceiving of the next generation of manufacturing process control systems. The proposed vision is holistic, integrative, and friendly. This vision is sampled finally in the actual case of the turning process.

Key words: manufacturing process, cyber-physical system, process control, manufacturing system piloting.

1. INTRODUCTION

After 2011, the Industry 4.0 concept, also referred as the fourth industrial revolution, has been widely addressed in the literature dedicated to the evolutions in manufacturing field (e.g. Lu, 2017, Hodzic, 2015, Mittal et al., 2018, Schumacher et al., 2016, Alcacer and Cruz-Machado, 2019).

Industry 4.0 birth is due mainly to internet explosive evolution, which enabled to talk about cloud computing & cloud manufacturing (Sang and Xu, 2017, Wu et al., 2016), and about web-based manufacturing control systems (Tsai and Lin, 2005).

On this base, major progresses can be noticed in what concerns the manufacturing process management (Zhu et al., 2017, Fradinho et al., 2015), leading to the smart manufacturing concept (Kusiak, 2019).

One of the most interesting issues related to Industry 4.0 is the Cyber-Physical Production System CPPS (Hodzic and Jurkovic, 2016, Liu and Xu, 2017). Such a CPPS is presented in Figure 1. It comprises three layers: Physical Level, Cyber Space and Service Cloud. The Physical Level contains all the physical elements, including the machine tools and their components, the cutting tools, the workpieces, the industrial robots, the AGV-s, and various data acquisition devices. Critical objects, which may generate valuable data during the manufacturing process (such as the spindle of the machine tool, the cutting tools, the workpieces, etc.) are equipped with sensors and actuators so that real-time data from the Physical Level can be collected.

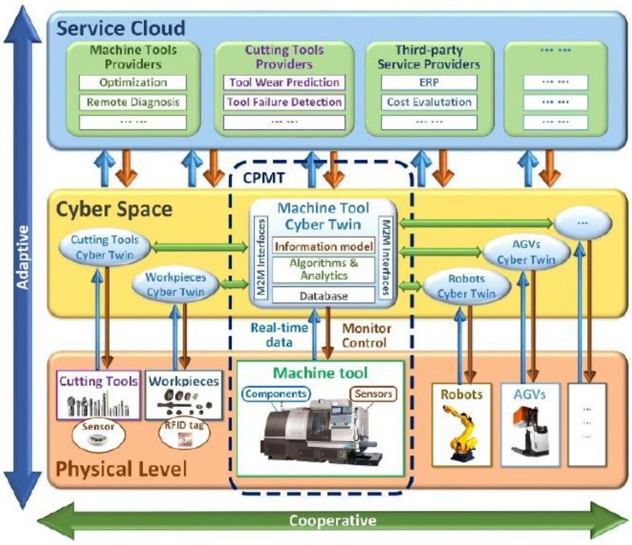

Fig. 1. The Cyber-Physical Production System [6]

The Cyber Space is a networked space comprised of interconnected Cyber Twins of the critical objects. Each Cyber Twin in the Cyber Space represents a digital abstraction of its physical counterpart. On the one hand, embedded algorithms and analytics take advantage of the real-time data collected from the Physical Level such that the Cyber Twins can monitor and control its physical counterpart with intelligent and autonomous functions. On the other hand, the Cyber Twins communicate with each other, thus enabling autonomous cooperation between field-level manufacturing devices. In addition, the Cyber Twins record the historical information of their physical counterparts and provide them to the cloud through various networks.

The Service Cloud contains various software applications provided by different equipment manufacturers and third-party service providers. For example, machine tool manufacturers may provide machining optimization service for their machine tool users; cutting tool manufacturers may offer tool wear prediction service for their cutting tool users; third-party software developers may provide Enterprise Resource Planning applications for enterprise managers. These applications reside in the Service Cloud. They are able to access the information in the Cyber Space through networks.

Specific algorithms for manufacturing process (MP) control have been also released, according to the newly immagined production systems (Sadoyan et al., 2006, Zapcevic and Butala, 2013). However, because new criteria defining the performance in manufacturing have been replaced the classic ones, and because the actual vision does not fit any more to the resources issued by nowadays technological advance, the need for a new vision on MP control becomes more and more obvious. This paper proposes such a vision, meaning a coherent ensemble of concepts, paradigms, and approaches, which aims to support the conceiving of the next generation of MP control systems.

In what concerns paper structure, the next section introduces the new vision, the third samples its application in the case of the turning process, while the last section is for conclusion.

2. PROPOSED VISION

2.1 Key-features

Here the process is seen as causality, which is defined by a set of variables, together with the causal links existing between them.

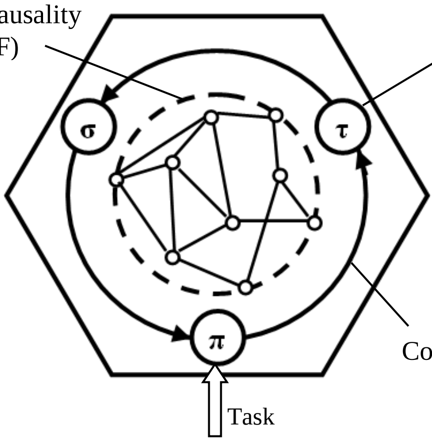

Fig. 2. The control loop

The Figure 2 illustrates the basic element in MP control, namely the control loop. The dashed circle in the middle represents the process causality. Here the points are meaning variables, while the lines between them – causal links. The control loop is represented through three smaller circles, meaning control modules, and the arc-arrows between them showing information transition. The hexagon represents the controlled workstation.

The control strategy means to select a set of observable variables, at first, and then to adjust their values according to a given target. A set of values for these variables represents an instance.

The variables are of four types: MP parameters describing the target (e.g. cost, timespan, consumed energy etc.), piloted variables (p_i), programmed variables (t_i), and monitored variables (s_i).

The MP control consists in taking the appropriate, optimal decisions concerning MP and it is accomplished by control loop. A control cycle means running once the control loop and corresponds to a manufacturing process sequence (e.g. to a part rotation, in turning case). During the control cycle, the variables do not change their values.

The control cycle consists in the successive application of three algorithms, namely piloting (π), programming (τ) and monitoring (σ). The piloting algorithm aims to establish target values for the piloted variables, depending on the accomplished task and on the monitored values of s_i variables from previous sequence. The programming regards the workstation setting through the values of programmed variables. The monitoring concerns the actual manufacturing process and consists in the evaluation of the monitored variables, by measurement or calculus.

2.2 Key-paradigms

The Table 1 presents the key-paradigms of MP control, according to the past, present and proposed visions. Among them, the ones from below especially worth to be highlighted, being essential and defining the new vision.

- At the *entry* of the control system we should input the aimed result of the MP instead of the program of the actions to be performed, which is autonomously generated by the control system.
- Process *modeling* is causal and the model is updated at each control cycle. In this purpose, the causal model is at first formalized, on the base of the previously collected data, and then used for establishing the values of the control variables. In what concerns the control itself, this is performed by joining cyber modules from a knowledge assets workshop, running on the base of the knowledge derived from previously performed, similar MP-s.
- The MP *surveillance* is enhanced from the passive monitoring level to the piloting level, meaning the adjustment in real-time of the MP parameters, such as the result fits to the managerial directive.
- The *architectural configuration* of the manufacturing system evolves to the level of reconfigurable cyber-physical system, highly addaptable to a wide range of manufactured products requests.

Table 1. The paradigms of past, present and proposed visions about MP control

Subject	**The paradigm**		
	Past vision	**Present vision**	**Proposed vision**
1. Asset entity	Machine-tool	Workstation	Worksystem
2. Entity type	Master-slave entity	Manipulator entity	Autonomous entity
3. Architectural configuration	Part-tool-machine assembly Adjustable	CNC system Fixed	Cyber-physical system Reconfigurable
4. Tool material	Steel	Carbide	Nanostructures
5. Programming	Analogical	Numerical	Logical
6. Entry	How to do?	What to do?	What to result?
7. Modeling	Physical	Mathematical	Causal
8. Control	Manually	Automat	Autonomic
9. Inspection	Off-line	Off-machine	On-machine
10. Surveillance	Observing	Monitoring	Piloting
11. Administration	Administrative system	Quality assurance system	Optimality assurance system
12. Human status	Worker	Operator	Designer

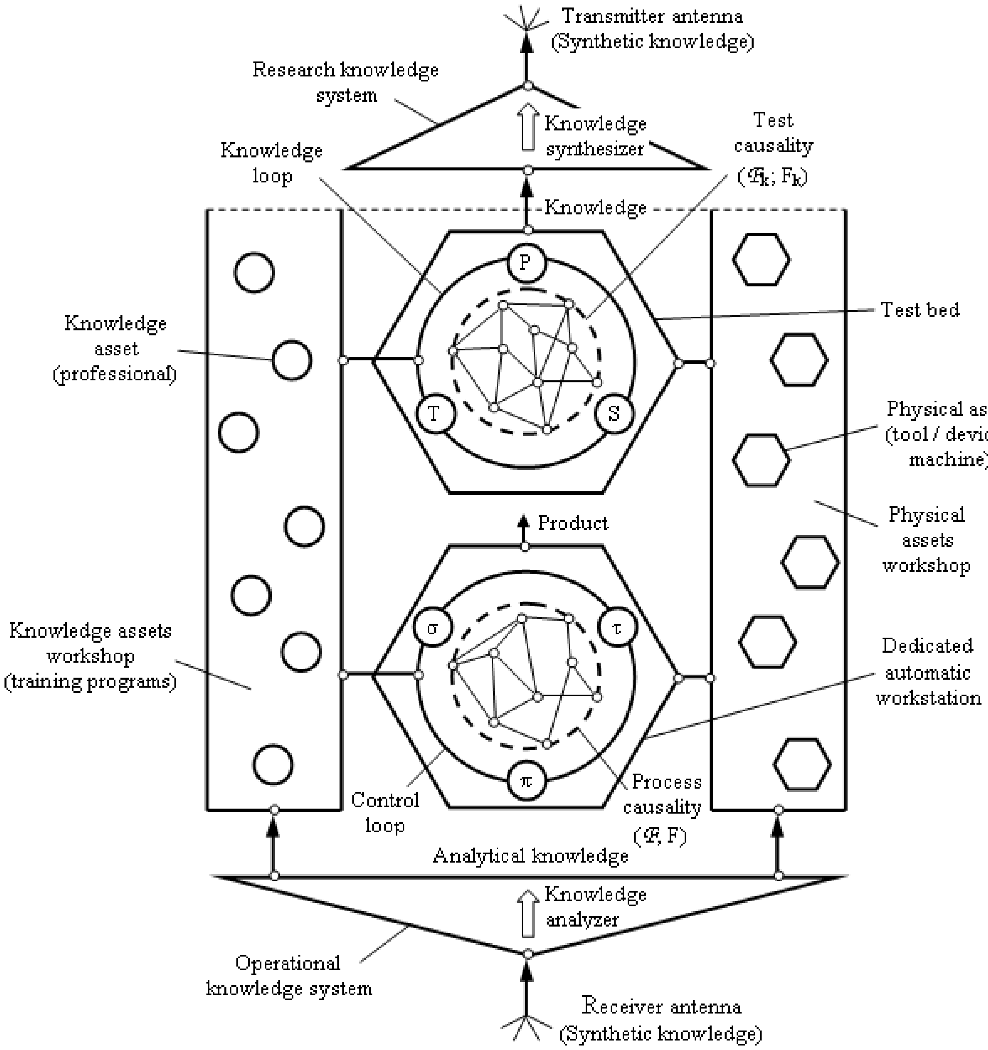

Fig. 3. Present vision on MP control

2.3 Proposed vision versus present vision

The understanding of the main issues of proposed vision on MP control is easier by comparison between the present vision and the proposed one.

In present vision (Figure 3), human professionals perform the piloting and programming algorithms from the level of the dedicated automatic workstation. They are trained on the base of the operational knowledge system, which delivers analytical knowledge to both the workshop for knowledge assets and the manufacturers of the The needed product is obtained by running the dedicated automatic workstation. The MP monitoring is performed with the main purpose of detecting the occasional abnormalities.

In parallel to the manufacturing activity, the research activity takes place on test-beds composed by similar physical assets. Here the control loop is replaced by the knowledge loop, performed by humans with scientific qualification (researchers), also trained inside the workshop for knowledge (Garbuz and Topala, 2017). The result of research is new knowledge, which, after being synthesized by the knowledge synthesizer system, is disseminated towards the interested ones.

In contradistiction to this, according to the proposed vision (Figure 4), the dedicated automatic workstation is replaced by the autonomous reconfigurable worksystem, composed by some physical modules selected from the physical assets workshop including inter-connectable modules. The worksystem reconfiguration concerns both the hard and soft aspects.

physical assets (tools, machines, devices, etc.).

The control & knowledge loop is performed outside the worksystem by joining cyber modules that are selected from a network developed inside the workshop for knowledge assets and connected to the worksystem through the cyber-physical interface. The conception of the three control algorithms is based on the knowledge of process causality, described through the instances dataset $\mathcal{F}$ and the model F.

The only human involved in MP control is the process designer, who physically configures the worksystem, building it by assembling the needed modules and then connects the worksystem to the cyber-physical interface.

The values of all variables measured or calculated at each performed control sequence are recorded in the local knowledge system and become instances dataset. At its turn, the local knowledge system is interconnected to the global knowledge system.

As general approach, similar control loops can be performed in every stage of the manufacturing chain – namely ordering, design, planning, programming or driving.

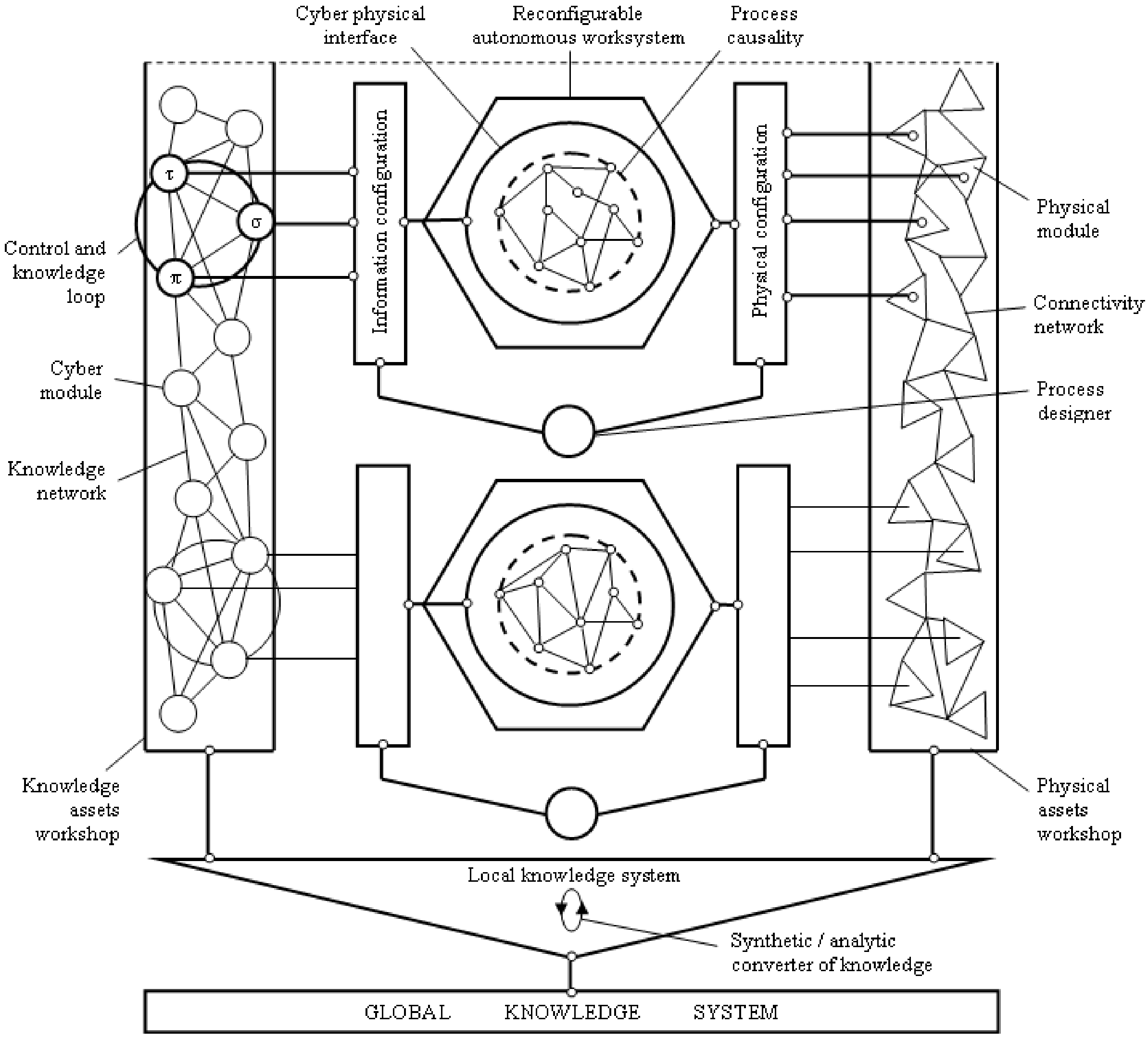

Fig. 4. Proposed vision on MP control

3. ILLUSTRATIVE EXAMPLE – TURNING PROCESS CONTROL

The way on which the new vision on MP control could actually work is further sampled in the case of a turning process.

In Table 2 there are presented some values of a potential set of piloted, programmed and monitored variables, as they were established, set or measured / calculated, respectively, in both the cases of a turning phase (level 1), and a turning operation (level 2). These values are supposed to be stored in a dedicated database.

The MP current state is permanently visualized on a dedicated graphical interface (Figure 5). The current values of s_i monitored variables of interest (such as machining cost, time, consumed energy, deviation, cutting force etc.) are displayed (in red) on a graphical interface, together with the values established in the piloting action (in purple).

There are also depicted (in green) the limit-values of the piloted variables, as they are imposed either through the managerial directive or by technical limitations.

In the addressed example, lathe control materializes in autonomously programming, for each phase, based on the mentioned database, of the most convenient tool, and of the optimal values for cutting speed and feed, such as the MP target is reached.

Table 2. The set of variables describing the turning process

Crt. No.	Level	Piloted variables								Programmed variables			Monitored variables											
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
13	1	0.7	2.1	0.15	6.1	110	5.2	20	30	A	0.3	105	0.9	2.4	0.12	7.8	109	5.2	22	37	-	-	-	-
19	2																				1.7	6.2	4.1	81
		Cost [Euro/dm^3]	Time [min/dm^3]	Energy [kWh/dm^3]	Deviation [·0.01 mm]	Force [daN]	Power [kW]	Wear [%]	Stability [%]	Tool code	s [mm/rev]	v [m/min]	Cost [Euro/dm^3]	Time [min/dm^3]	Energy [kWh/dm^3]	Deviation [·0.01 mm]	Force [daN]	Power [kW]	Wear [%]	Stability [%]	C_{op} [Euro}	T_{op} [min]	E_{op} [kWh]	V_{op} [cm^3]

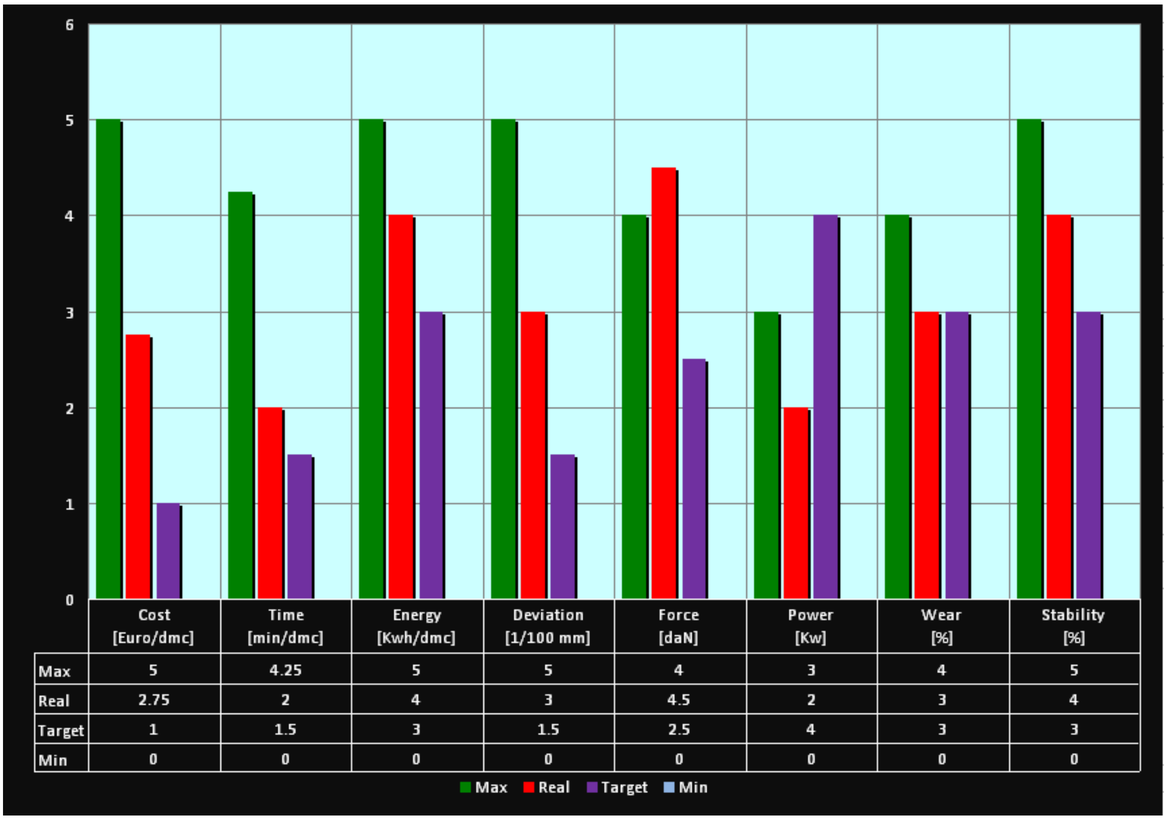

Fig. 5. The graphical interface of the control system

4. CONCLUSIONS

The paper presents a conceptual building that should ground the conceiving of the next generation of manufacturing process control systems.

The proposed vision is holistic, integrative, and friendly.

It is holistic because each concept is treated after all relevant aspects. For example, the *manufacturing process* concept is regarded as *holarchy* – in structural aspect, as *causality* – in functional aspect, and as *metamorphosis* – in operational aspect. As well, the *process control* concept is seen as *ordering* – when the processed object is commercial relation, *design* – when the object is idea, *planning* – when it is information, *programming* – when it is data.

The vision is integrative because the paradigms regarding manufacturing process control are built such as the available resources are used as completely as possible. This can be accomplished by symbiosis, socialization, colonization, and twinning, e.g. *control loop - knowledge loop symbiosis*, *cyber socialization*, *physical colonization*, or *machining - measuring twinning*.

At the same time, the proposed vision is friendly in what concerns the control techniques, because of expressing the control by „what-variables" instead of „how-variables", because of its implementation through „dialog" instead of „search", because it stands on „causal models" instead of „quantitative models", and because it is accomplished by „comparative assessment" instead of „absolute evaluation".

5. ACKNOWLEDGEMENT

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