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Bio-inspired Autonomous Enterprise Systems

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Abstract: The socio-economical context of this century has faced enterprises with various challenges, thus resulting in a wide variety of enterprise control and management approaches. This paper underlines the correlation between specific functional requirements of different enterprise systems and the behavioral characteristics they should display. Bio-inspired models are analysed in correlation to enterprise systems. Evolving paradigms have focused on the importance of contextualized sensing in problem solving and the paper advocates the utility of the human brain inspired perception-behavior generation-learning approach in autonomous enterprise control.

Keywords: Cyber-Physical Systems, Bio-inspired Enterprise Systems, Autonomous Enterprise Systems

1. INTRODUCTION

Enterprise Systems has evolved from "monolithical" systems running in predefined environments towards autonomous, distributed, networked and modular structures, with adaptable and intelligent behaviours, enabling collaborative human-machine interactions, collaborative tasks and self-organization.

Such perspective shift has come with a set of complex functioning constraints which have in turn driven towards new approaches in enterprise systems control.

Such approaches are mainly centered on the requirements of adaptability and robustness in enterprise behaviour. It is extremely important for an enterprise, seen as a goal-oriented complex entity, to corectly perceive environmental changes either as important and thus requiring adaptation (in terms of stepwise goal reconsideration, system reconfiguration a.s.o) or as trivial and requiring rejection.

Proper management of such occurences represent a degree of enterprise intelligence that should be permanently updated and improved by a mechanism of learning and value judgment. It is an intelligence that biological systems are using for ensuring survival and evolution.

This focus of the present paper is to analyses Bio-inspired design in relation to the emerging paradigms of Cyber Physical Systems and Autonomous Enterprise Systems.

2. BIO-INSPIRED CYBER-PHYSICAL SYSTEMS

The Cyber-Physical Systems (CPS) paradigm addresses the relation between "Cyber" (virtual, computation environment) and "Physical" (environment) components of ICT enabled systems. Such systems interconnect sensors, actuators, control systems, information systems and humans via complex interfaces and heterogenous networks.

CPS address the complexity of the structure of systems and the interactions between sub-systems.

Complexity of a system can be related to the number of interactions between components, to the unpredictable behavior due to insufficient data or understanding and to the impossibility of emerging the behaviour of sub-systems modeled separately. Complexity is an important characteristic of biological systems. (Fass and Gechter, 2015) (Dumitrache et al. 2017)

Self-organization is another characteristic of biological systems. Self-organization can be related to a decrease in the entropy of a system or to an organizational structure achieved dynamically with the aid of adaptation to environment but without exterior intervention. (Fass and Gechter, 2015)

Cyber-Physical Systems have the capability to model the future of today's society having the capability to facilitate "smart" human-machine cooperation (H2M and M2M communication). These complex systems are becoming ubiquitous, and more and more present in every individual's daily life in various domains, such as: Energy, Transportation, Mobility, Intelligent Manufacturing, Intelligent Materials, Healthcare, etc. (Dumitrache et al. 2019)

Due to the fact that complex systems represents more than just a simple set of subsystems, the major challenges that have occurred in CPS-oriented modelling of enterprises are:

- The enterprise capability to self-organize and self-manage according to pre-required functionalities and available infrastructure;

- Transition towards Factories of the Future, including smart productivity and smart processes, which requires integration of a new perspective and use of new emerging architectures and business models;

- Integration of new technologies and architectures must include the capability of real time communication, both Human-to-Machine (H2M) interaction and Machine-to-Machine (M2M) interaction, integrated in intelligent environments;

- CPS oriented modelling even for simple systems, which requires a multi-disciplinary perspective.

Bio-inspired system control architectures are being used to solve engineering problems by adopting model characteristics and behaviours from nature. Bio-inspired models can be associated to a holistic approach, addressing all levels of product life-cycle and manufacturing processes. (Zang et al 2018) . (Bannat et all 2011)

There are two main reasoning lines in dealing with bio-inspired control, each of them mimicking the behaviour of an living organizational approach: insect-oriented and mammal-oriented. Each of them have their respective characteristics. (Park and Tran, 2010), (Dumitrache et al. 2019)

Insect-oriented approaches are based on the swarm intelligence, inspired by either bees or ants, where the individual is neither really "intelligent" nor differentiated. They are represented by agent-based architectures, agents being relatively simple, in terms of modeling, the intelligence being a systemic characterisc, resulted by the emergent behaviour of subsystems. They are interchangeable; the loss of a member of the colony is not very important with respect to goals to be achieved. However, when the colony becomes important in size, the overall behaviour become difficult to predict/ estimate. Ant or bee colonies inspired multi agent models provide support for the implementation of decision support systems. Such models can enable the integration of intelligent behavior in less sophisticated components. (Dumitrache et al. 2019)

Mammal-oriented approaches are based on a hierachy, is more structured, tends to centralization and inherently they include several different classes of agents, with more individual autonomy that in the case of swarm intelligence. Agents are usually organized in groups, their interaction (monitoring, control) being ensured by a specific type of supervising agents. It is easier to evaluate behaviours of relatively small groups of agents and they may be more efficient than insect-oriented structures in achieving well definde goals, but to design such a system a better knowledge of the process is necessary and the failure of a supervising agent is deprieving the architecture of the results of the cluster it is responsible for.

Research addressing the similarity between biological systems and enterprise systems points to the fact that a manufacturing enterprise system is closer to the organization of a mammal-oriented system than to a insected-oriented system. The similarities are related to parts that can function autonomously and can connect with the aid of a nervous system. Such components perform specific functions, are generally not interchangeable and when such a component is unable to function properly it usually affects the function of the whole system.

The CPS-oriented approach is furthermore underlining such an interpretation, as the stepwise decomposition od such a system is undelining classes of agents, already organized in clusters, differentiated by functionality and specific communication networks/ procedures, with approapriate sensing capabilities as ensured, usually, by IoT approach. (Lee 2015)

3. BIO-INSPIRED MODELS FOR ENTERPRISE SYSTEMS

3.1 Bio-Inspired Enterprise Systems

In order to facilitate the development and adoption of bio-inspired enterprise systems the authors propose a Bio-inspired Enterprise Systems Generic Framework and analyse the building blocks in the following sections.

The proposed framework is consisting of a structural layer compose of bio-inspired models and algorithms that can facilitate the development of enterprise system components, a behavioural layer consisting of bio-inspired system models and a functional layer consisting of enterprise and manufacturing systems.

The behavioural layer includes a Brain Inspired Decision Model that facilitates the selection of appropriate enterprise system components behaviour form existing behaviour Models, based on Knowledge Models, System Models and Cognition – Perception Models. Relevant aspects related to the framework are addressed in the following sections.

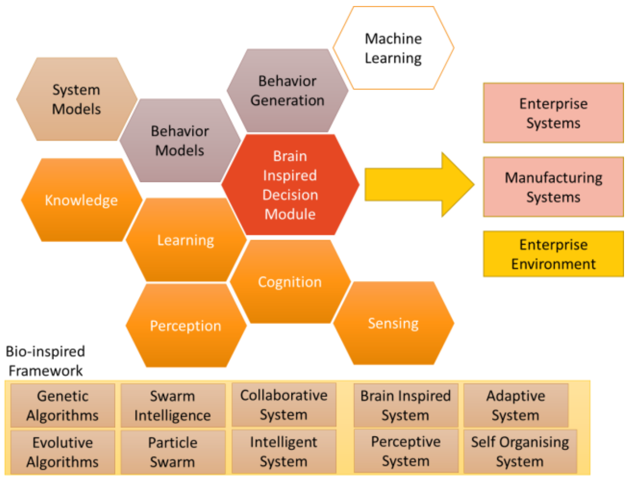

Fig. 1. Bio-inspired Enterprise Systems Generic Framework

The aim of the proposed framework is to facilitate the creation of hybrid sensor – actuator cyber –physical structures that can become an essential part of adaptive enterprise systems.

3.2 Sensing Systems in Enterprise Environment

A sensing system is a new paradigm that allows complex systems to easily reconfigure taking into consideration all constraints. In order to become sensing, systems need adequate resources and to fulfil specific tasks in order to be constantly under control. In order to fulfil these tasks, sensing systems can be modelled as Cyber-Physical Systems that can easily adapt and make the switch between physical and virtual environments.

Integrating sensor networks and actuating systems, a sensing system can have the capability to monitor all physical processes, collect necessary data and model this data in order to better use and to make it widely available for any connected application in order to better perceive the real world and the processes' behaviour that are involved.

Artificial intelligence is a concept that can be applied both from the traditional approach (as expert systems) but, more important, from the machine learning perspective, such as, a smart system will be capable to integrate and use specific components in order to extract only the required data. Thus, simulation tools can provide the required support in order to better understand the behaviour of the system.

A paradigm derived from the concept of sensing, integrating artificial intelligence and H2M interaction (eventually human in the loop) is that of *smart enterprise*.

In order to develop a smart system, capable to sense and perceive the real world, as well as to evaluate system's performances at any moment and even to predict them and to reduce critical risks that can occur, there is a necessity to develop a measurement mechanism and to integrate specific sensors and algorithms. If in the past it was possible to identify manufacturing systems because they were using only simple sensors, actuators and controllers, nowadays, due to systems' complexity, there is an urgent need to perceive the system's and environmental behaviour and thus to integrate them in the manufacturing system. This step is very important but also difficult to implement by every type of stakeholder, including academia and manufacturers. The main problem is to create perception technologies and afterwards to integrate them in existing software solutions. This aspect will lead to a better understanding of the process and will enlarge the research horizon.

Paradigms as *Agile Enterprise* and *Sensing Enterprise* are deepening the importance of "sensing" – as a complex functionality that involves measurements of environmental occurences and auto-diagnosis, and, furthermore, interpretation and contextualization of obtained information and data – in the goal achievement-proces, by different approaches and technologies, as hierachical modelling, Internet of Things, knowledge management, a.s.o.

Adaptability to changes in operating environment is a key aspect of both *Agile Enterprise* and *Sensing Enterprise* design. Control architectures are evolving from centralized towards intelligent thus increasing adaptability and integrating prediction functions. Prediction can lead to improved real-time response to disturbance by adopting a problem-solving model and by using a model based response and effect mitigation.

The *Sensing Enterprise* concept and model has evolved in parallel with Internet of Things model and Cyper Physical Systems and Industry 4.0 paradigms. Context awareness achieved by processing data from physical and virtual sensors. Thus, decision support systems can benefit from bouth information structuring and context awareness. The sensing enterprise model can enable the use of bio-inspired techniques addressing "stimuli"-response behavior modeling and organization.

3.3 Perception in Enterprise Environment

In order to model an enterprise system integrating the Intelligent Cyber Enterprise model, we must take into consideration the necessity to integrate perception, reasoning, learning and cognition within the model. These components have become very important and relevant in the development of perceptive interfaces that the Intelligent Cyber Enterprise (ICE) relies on. Intelligent Cyber Enterprise represents the future type of an enterprise that involves sensing functions in order to perceive the process' behaviour as well as the environment's behaviour.

The perception-reasoning-learning loop (PRL) is further addressed, seen from a functional point of view and with a special emphasis on the awareness concept.

The functionality of the Intelligent Cyber Enterprise is focused on problem solving. Normally, the problems related to the functionality of the ICE are mostly related to the system's productivity, achieving functionality related goals, achieving a certain degree of precision, evolving from a strategic perspective (profit oriented, sustainable enterprise, quality of services, quality of control, security, etc) to a resource oriented perspective, thus facilitating human-machine interaction and M2M interaction. Using this perspective, problem solving will be based on a sequence of specific activities, performed by the integrated resources, at a specific time correlation, seen as components of various workflows.

On the other hand, these problems must take into consideration predictable and well-defined workflows, operational and strategic aspects that require collaboration between available resources and according to specific context. Such problems can be solved in various ways, depending on the available resources and problem-solving approach, cost and time. These approaches depend mostly on the availability of resources, but also on the existing data and the complexity of the sensing / perception level as well as the complexity of the existing network.

In order to solve these multiple existing problems, the ICE has defined the need to use appropriate interfaces for information exchange and perception of the system's behaviour. In order to model these interfaces, it is important to take into consideration the capacity to adapt of each system and interface in order to achieve the required flexibility depending on every problem. Thus, in order to model these complex systems, one must take into consideration:

- Desired goals, in order to define the necessary parameters that must be measured, monitored and used in the information exchange process;

- Availability of system's resources, a crucial aspect due to the fact that every resource is involved in different sub-systems. These resources must handle the functionality of the system.

- Problem to be solved, as it is mandatory to correctly define the problem that must be solved, in order to define the desired outputs.

Developing such a model that takes into consideration the aforementioned criteria's in order to find the most appropriate solution, requires the usage of specific perceptive interfaces and to connect the sub-systems involved in the workflow, including humans and the environment.

From the Intelligent Cyber Enterprise point of view, perception can be seen as an active process that facilitates the interpretation of the environment by integrating information and "stimuli" from the sensorial system. Thus, two processing mechanisms become relevant in this context:

- Bottom-up approach that relies mostly on a passive function that listens to all sensorial channels;

- Top-down approach that relies mostly on anticipating and identifying the required "stimuli". This approach can be seen as the perception control aspect.

On the other hand, there is a necessity to model these enterprise processes and systems, adapting from the main functions of human brain, such as:

- *Predicting* the required information according to a specific situation

- *Focusing* on specific information and neglecting any other existing information

- *Interpolating* data based on existing patterns in order to fill the gaps (the so-called we see what we expect to see")

- *Structuring* all existing information (both relevant and irrelevant information) in order to better understand the reasoning function

- *Structuring* in a hierarchically method all interconnected networks

- *Connecting* all patterns based on the existing specifications and architectures

- *Correlating* every interface with the proper process

- Allowing every process to *integrate* adaptive changes based on the adaptability capacity of the network

- *Reconfiguring* dynamic models that are integrated in clusters and usage of adaptive agents

- *Interconnecting* structural and functional modules in parallel configurations, thus generating adequate behaviours.

Perception can be seen from different perspectives and in association with each person who has it's own perception system. Thus, perception can be structured in three phases:

1. Hypothesis related to perception – this stage is dealing with the selection, organization and interpretation of every "stimuli";

2. Acquisition of data from the sensing system – this stage is dealing with the gathering of data from the sensorial layer and, storing it and transforming in a machine-readable format;

3. Comparison of the sensory information – this stage is dealing with the involvement of specific algorithms in order to compare all the data that has been gathered from the sensorial layer.

The main function of the brain is considered to be the reasoning function. The main components of the reasoning process in an Intelligent Cyber Enterprise environment are: the problem identification, the problem categorization and the identification of the solution. In order to identify the adequate solution for every specific problem that exists within the ICE, we can make correlations with the reasoning mechanism. Thus, actions generate feedback that can be measured in interpreted in order to generate a new perception/ reasoning cycle. A generic perception/ reasoning cycle can include: pattern selection, identifying success criteria, filtering data, planning, validation and integrating feedback and evaluating success.

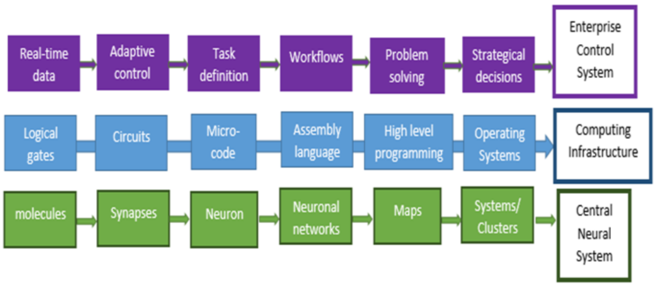

Fig. 2. A parallel between the enterprise control system and the central neural system

Within every Intelligent Cyber Enterprise we must integrate the learning capability in order to store and retried information using a knowledge model. Such as, a deep learning process must be also taken into consideration. Data mining, rule-mining and self-learning become components of a success model that require the development of a mixed-integer mathematical model.

3.4 Cognitive Systems

Cognitive Manufacturing represents a new organizational model that is based on perception and cognition, who integrates Internet of Things principles, Artificial Intelligence fundamentals and Machine Learning algorithms and technologies. Cognitive Manufacturing is related to the integration of processes in order to achieve specific improvements at business, technological and sensorial levels, based on decision-making models and data analytics models, enterprise integration of knowledge management models.

Cognitive Manufacturing integrates IoT principles, Artificial intelligence and data analytics technologies. The objective is to exploit manufacturing process as well as enterprise wide data and information, as to achieve:

- optimal use assets and equipment

- processes reengineering by integrating decision-making models and data analytics methods for workflows and working environment

- enterprise wide knowledge management

Cognitive manufacturing systems are emerging and address the following relevant aspects:

- improvement of product quality and by using and integrating enterprise and environment focused approach

- adaptive systems integration

- analysing manufacturing data obtained from sensors: production management systems are generating huge amounts of manufacturing data

- integrating manufacturing systems decision making models with business intelligence systems

- integrating knowledge management systems at enterprise level : cognitive enterprise is considering linking the overall decision-making procedures of the enterprise

Relevant concepts that can be related to the development of a conceptual model of a Cognitive Enterprise are:

- Cognitive Manufacturing technologies including Cognitive Robotic Process Automation

- Learning organization

- Composable organization

- Perceptive Systems

- Adaptability

- Artificial Intelligence including Machine learning and deep learning

3.5 Bio-inspired Manufacturing

Evolution and adaptation are key concepts in Next Generation Enterprise Systems. Evolutionary systems and self-organising systems are two system models observed in biological systems.

Bio-inspired Manufacturing System (BiMS) are emerging as a category of Manufacturing Systems that aims at solving manufacturing problems based on biologically inspired models.

Bio-inspired Manufacturing System (BiMS) are strongly corelated to a bio-inspired manufacturing cell (BiMC) models. A BiMC can be viewed as an autonomous system with the capacity of self regulation. The modelling layers associated to a BiMC are: control layer, sensing layer, acting layer and decision layer. A “modelon” can be associated to a BiMC. A modelon has been defined as an autonomous entity composed of a controller, actuating component and perceptron. The BiMC uses a decision layer for complex decisions related to perception and uses a control layer for predefined processes. (Tang et al 2010)

Reconfigurable Manufacturing Systems are designed to adjust production or product features in accordance with changes in product demand.

Bio-inspired Product Design integrates principles from technology, biology, and sustainability. Innovative product design is based on biological inspired models and principles. The use of biologically inspired principles and models can be extended to the whole product life cycle.

Bioinspired design has proven to provide important advantages for additive manufacturing based products, especially in the area of standardized bioinspired geometries. (Zang et al 2018)

Integration of Multi Agent Systems the design of Manufacturing Systems can also be related to bio-inspired systems. Ant inspired Multi Agent Systems have been proposed in order to solve manufacturing problems. Ant agent colonies consisting of exploration ants, intention ants and feasibility ants have been studied. (Ďurica et al 2015)

3.6 Perceptive Systems Interface

An interface has various interpretations across technical literature: a connection, a composition of connections, a boundary, a linkage, an interaction between functional entities, a logical relation, a specification. (Parslov et al 2015)

A generic system interface can be characterized by the following aspects: Proprieties of the system, Proprieties of the environment, Type of interaction or behaviour.

Examples of system interfaces in enterprise systems include but not limit to: human- machine (H2M); machine-machine (M2M), physical interfaces, hardware interfaces, software interfaces.

Developing bio-inspired systems interfaces, can be related to adaptation, learning and prediction principles and models.

Adaptation. System adaptation to changing conditions is directly connected to the behaviour of the interface. Thus adaptation can become a function of the interface.

Learning. Machine learning techniques can be used in association with interface components. Patterns in data exchanged through the interface can emerge as a result of machine learning techniques applied at interface level. Such patterns can be used to optimize the functions of an interface. An example can be related to the amount of time the interface is used.

Prediction. Prediction is not only associated with intelligent systems but can become a function of the interface. Prediction components can be used to predict relevant aspects related to the environment, data, behaviour or process associated to the interface.

In the current section the authors propose a bio-inspired model for a generic perceptive systems interface as a component of Intelligent Cyber Enterprise. In order to implement the perception function two facilitator systems are proposed: a behaviour identification system and a semantic routing system. (Dumitrache et al 2019)

The perceptive interface is designed in relation to the:

- internal structure, correlated to the corresponding system structure,
- external behaviour in relation to the transferred data,
- functioning in correlation with the requirements of the system

Interface behaviour is to be identified as a workflow, by data analysis, in accordance with pre-defined patterns. Patterns are issued from the process requirements and with the support of the semantinc routing. (Dumitrache et al 2019)

The proposed interface adapts to changes related to transfer necessities by selecting the appropriate behaviour form a behaviour repository. The proposed interface will allow the connection of both virtual and physical resources of an enterprise system.

6. CONCLUSIONS

The concepts proposed in relation to bio-inspired systems are becoming an important part of the research efforts leading towards the development of new enterprise systems.

Technological advances in the field of bio-inspired Cyber-Physical Systems will determine new perspectives and horizons, through the appearance of new applications that will be adaptive, reconfigurable and robust to various environmental conditions. Perceptive systems in particular, owing to its evolution are expected to issue new methods allowing humans to both benefit from - and increase the value of – technological advances.

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