The Development of Enterprise Systems based on Cyber-Physical Systems Principles

Ioan Ştefan SACALĂ (ioan.sacala@acse.pub.ro)
Mihnea Alexandru MOISESCU (mihnea.moisescu@upb.ro)
Faculty of Automatic Control and Computers, University Politehnica of Bucharest

ABSTRACT

Research in the area of Cyber-Physical Systems (CPS) and Internet of Things (IoT) become, in the last 3 years a priority for both research entities and companies. Implementing Enterprise Systems based on the two paradigms is focused on merging real and virtual objects and thus deals with an increased degree of complexity. The aim of the present paper is to discuss an Enterprise Architecture and a Framework based on the integration of CPS and IoT technologies within Enterprise Systems. An important aspect is related to process mining implemented in two focus areas: the ability to generate business processes from data acquired from sensors and the ability to integrate sensor acquired data with existing business processes.

Key words: *enterprise systems, cyber-physical systems*

INTRODUCTION

Research in the area of Cyber-Physical Systems and Internet of Things has seen a tremendous development over that last few years, involving more and more entities and providing new solutions for problems both in business and manufacturing areas.

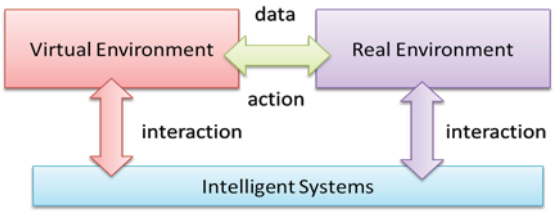
Cyber-Physical Systems are defined by the National Science Foundation as engineered systems that are based on the synergy of computational and physical components. The aim is to extend control theory to networks of devices but not necessarily at internet scale.

A Cyber-Physical System is composed of:

- Physical components: physical objects,
- Cyber-Physical interface devices: sensors, actuators,
- Cyber Systems: computing devices and communication networks.

DATA FLOW AND INTERACTIONS IN A CPS APPLICATION (MOISESCU, SACALA, 2014)

Figure 1



Sensors are devices that react to change in physical process and transmit a resulting impulse. A smart sensor has a processing unit and a communication interface thus processing the obtained data and communicating with other devices. Smart sensors bring the processing power closer to the point of measurement, and extend the sensing capability by using communication networks." (Sacala, Repta, Moisescu 2013)

"Actuators are mechanical devices that act upon physical objects by applying force or torque. Smart actuators are actuators controlled by devices equipped with processing units (Programmable Logical Computers). (Sacala, Repta, Moisescu 2013)

Using CPS and IoT concepts, Enterprise System can extend their capabilities towards the ability to "sense" both the internal and external environment. (Moisescu, Sacala 2014)

Other enabling building blocks for CPS oriented Enterprise Systems are:

- Smart environments represent environments that use data acquisition through sensors to describe its state, generate information and adapt to its inhabitants in order to improve predefined characteristics.
- Distributed Sensor Networks are networks of data acquisition that provide functions such as: collecting data, monitoring, processing, and decision-making.
- Context sensing as a capability provided by distributed sensor networks. By integrating different types of sensors such networks provide heterogeneous information flows
- Knowledge management provides organization methods to deal with: explicit knowledge, and tacit knowledge.

IoT enabling building blocks are represented by: Addressing schemes (Uniform Resource Identification), M2M Machine-to-Machine communication, Visualization of physical objects, Sensor and Actuator Networks, Service Oriented Architecture and Semantic Web technologies.

A generic model of the next generation of Enterprise Systems will be introduced, based on the paradigm of Intelligent Cyber-Enterprise. (Dumitrache, 2013)

Cyber-Physical System are expected to perform and consume 3 main service types, in relation to Enterprise Systems: Object Abstraction, Information Processing and Domain representation.

- Object abstraction represents the ability to provide, as web service, virtual representations for physical devices including: proprieties and capabilities.
- Information processing is performed with regard to existing business process technology and includes data and information acquired form physical objects.
- Domain representation is performed based on predefined ontologies with static or dynamic components. The domain representations uses information processing capabilities , relationships models, rule lists and schemas.

DESIGNING ENTERPRISE SYSTEMS BASED ON ENTERPRISE ARCHITECTURES

An Enterprise can be defined as „A complex system in a shared human endeavor that can exhibit relatively stable equilibriums or behaviors (homeostasis) among many interdependent component systems." (White, 2009)

New components have to be taken into consideration, with regard to the enterprise concept:

- capacity to adapt to changing business environment
- capacity to integrate resources transforming the enterprise into a complex adaptive system
- complexity of enterprise systems transforming the enterprise into a system of systems - a collection of systems that functions to achieve a purpose not generally achievable by the individual systems acting independently (Moisescu, Sacala 2014)
- globalization enabling the use of internet enterprise systems
- real and virtual environments mix enabling CPS transformation

In order to facilitate the implementation of Enterprise Systems based on Information and Communication Technologies, Enterprise Architectures have been developed. The main characteristics of the developed architectures are:

- focus on business strategy and business objectives
- holistic approach to systems and systems of systems by identifying perspectives
- integrate business cases with support systems
- adaptive approach to support systems design
- distributed and Internet focused IT&C systems

Architecture refers to: „fundamental concepts or properties of a system in its environment embodied in its elements, relationships, and in the principles of its design and evolution". Architecture framework refers to: „conventions, principles and practices for the description of architectures established within a specific domain of application and/or community of stakeholders". (ISO/IEC/IEEE 42010:2011)

An Enterprise Architecture can be characterized using several views: (Moisescu, Sacala 2014)

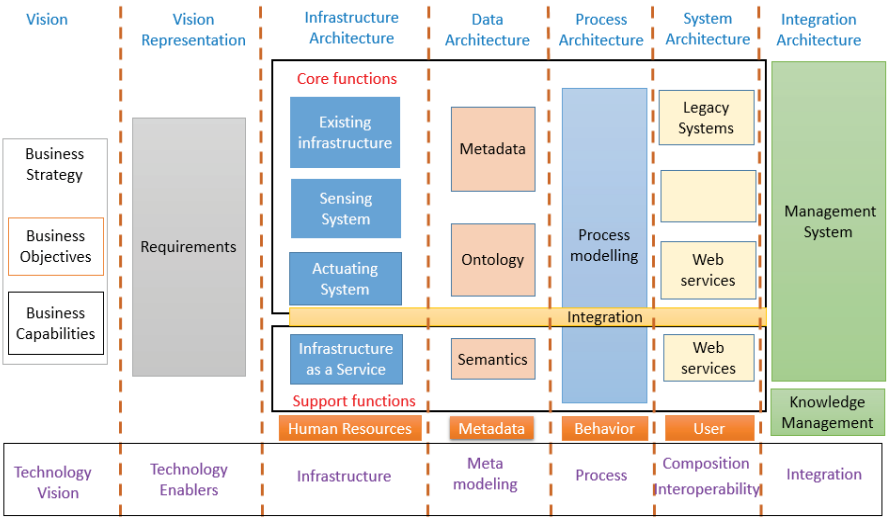
- Strategic view discussing enterprise objectives, roadmap, vision and values
- Socio-economical view discussing social, political or cultural aspects
- Process view addressing core business processes and support processes
- Organization view addressing the structure of the enterprise
- Information technology view addressing acquisition of data, data flow and data processing .
- Technology view addressing technologies, standards and methodologies involved in achieving business objectives.
- Product / Service view addressing products and services offered by the enterprise.

CYBER PHYSICAL SYSTEMS BASED ENTERPRISE ARCHITECTURE

Future Internet Enterprise Systems capable of implementing such changes have to be aligned with emerging enterprise paradigms: Inventive Enterprise, Humanistic Enterprise, Cognitive Enterprise, Community-oriented Enterprise, Agile Enterprise, Glocal Enterprise and Sensing Enterprise. (FInES, 2012).

CPS ORIENTED ENTERPRISE ARCHITECTURE

Figure 2

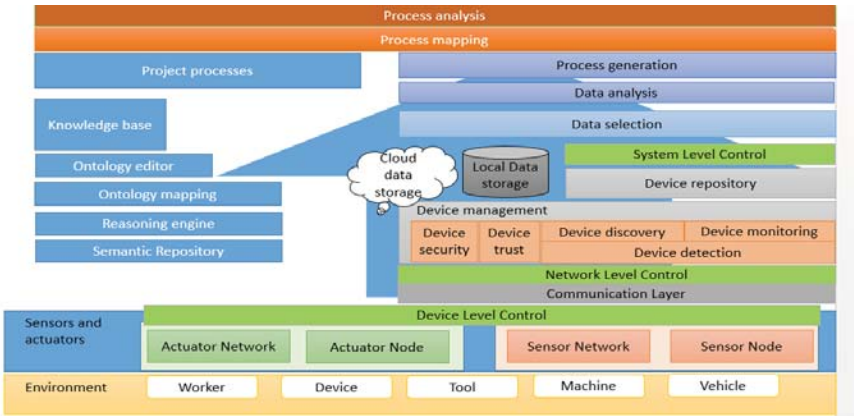


The most relevant paradigms, for future enterprise definition are further presented:

- The Cognitive Enterprise characterized by awareness or prediction of changes combined with the ability to act in accordance and to learn. The building blocks are: knowledge management, self – adaptation and learning organization. (FInES, 2012)
- The Agile Enterprise characterized by the ability to respond to business environment changes at strategy level, organization level, business process level, system level and technology level. (FInES, 2012)
- The Sensing Enterprise characterized by enterprise systems that mix real and virtual enterprise layers, integrate people, process, real and virtual objects. (FInES, 2012)
- Future Internet Enterprise Resource (FInER) a dual component of business and ICT capabilities. (FInES, 2012)

In order to integrate sensing devices with enterprises systems in general and business processes in particular the following framework is proposed.

Figure 3



The main characteristics of Systems developed using the proposed framework are:

- Capable of using virtual and physical resources at the same both sensing and actuating in real and virtual environments
- Capable of acquiring, generating and processing "big data"
- Acquiring data from heterogeneous resources form physical and virtual environments
- Reacting based on simple rules such as "if-then-else"
- Executing simple to complex behaviors based on generated events
- Adapting to changing environments based on simple to complex schemas
- Transforming business processes as to incorporate in execution sensor data
- Integrating Distributed Systems
- Communicate in large-scale systems
- Capable of constructing scalable systems

Several views designed in order to characterize the proposed framework are presented:

- Environment view taking into account the structure along with the internal policies rules and values.
- Sensor and Actuator View including constrains generated by complex environments and operation

- Network view including the technologies needed for data transfer and node communication.
- Process view including process represented as an abstractization of core business practices, relationships between different entities, the acquisition, flow, transformation and exploitation of data and information and the products and services.

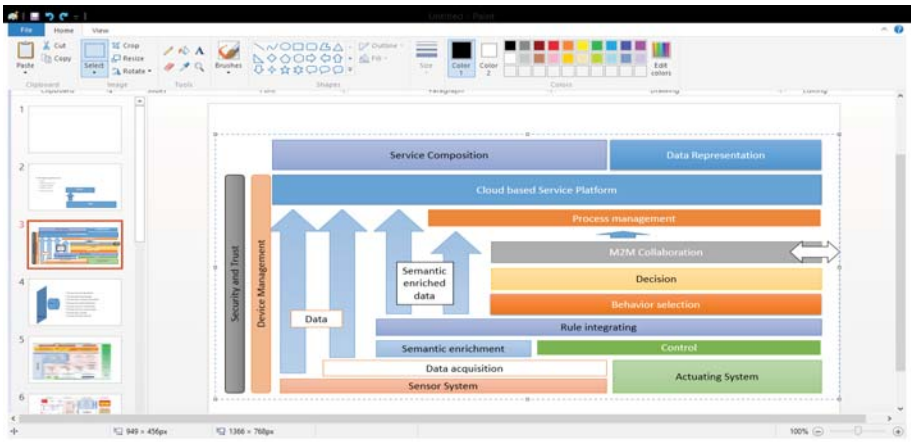
As presented in the diagram, a Cyber Physical Systems Space has 3 layers (Dumitrache, 2013), (Sacala, 2013):

- **Business Layer / Serious Games** – contains all the elements that are currently used to develop enterprise systems:
  - Business Processes both core and support, execution engines, process repositories
  - Other business applications: middleware, relational databases.

- **Physical Layer** – contains all the entities that collect data from the physical environment (sensors), interact with the environment(actuators) and relay the data and commands to the upper level(communication): Sensors, Actuators, Wireless sensors networks. The layer extends to:
  - Sensing capability: the type of data about the environment, physical or virtual that is acquired;
  - Identity: ability to differentiate from other entities;
  - Network: ability to interface to a network and communicate the acquired data.
  - Action capability: where the environment is shaped according to the planning capability.

- **Interface Layer** – has the role of connecting the upper and lower levels of the system and acts also as a human–machine interface; Interaction issues are integrated with regard to other entities.

Figure 4



The technology space includes:

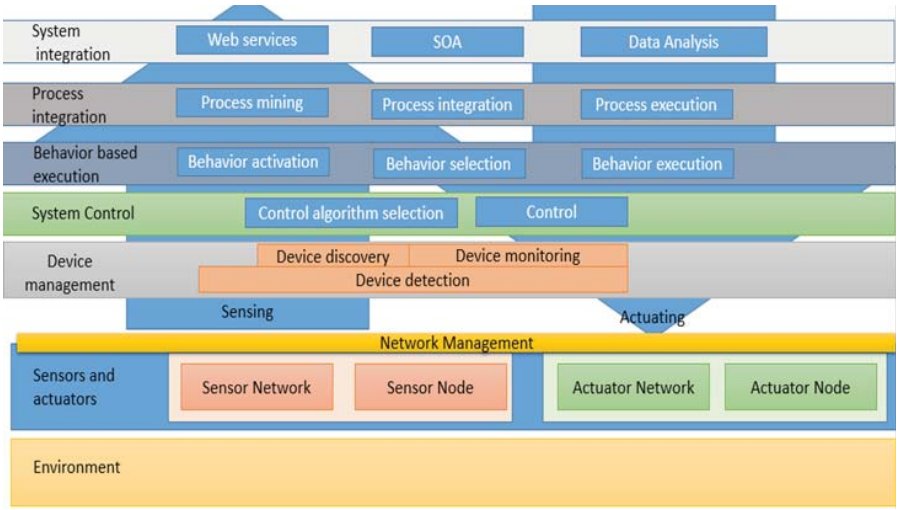
- A semantic interface to access the system's physical and virtual resources.
  - Resource Description Framework (RDF)
  - SPARQL Protocol and RDF Query Language
  - Rule Interchange Format (RIF)
- Business adapters / Business Objects – a set of components that connect (through APIs) to existing enterprise / business components
  - Uniform resource identifier (URI)
  - Universal Business Language (UBL)
  - Unified Service Description Language (USDL)
- Physical adapters – a set of components that expose physical devices in the system;
  - Sensor and Sensor Network ontology
  - Sensor ML
  - X3D
- Behaviors –a set of behaviors expressed in various languages / formalisms
  - Systems Modeling Language (SysML)
- Environment model: components of the external world are represented.
  - Web Ontology Language (OWL)

- Planning capability: simple or complex actions are predefined as sets of rules and behaviors, or identified as a result of necessity

- Knowledge layer: where acquired information through a basic process of learning is stored and methods are provided to integrate and download to other systems.

CONTROL SYSTEMS VIEW OF CPS ORIENTED ENTERPRISE SYSTEM FRAMEWORK

Figure 5



Process mining as principal mean to generate processes from aquired data is based on different techniques such as:

- Alpha alghoritm
- Finite State Machine
- Fuzzy logic
- Heuristic alghoritms - generating a CNet (causal network) process representation
- Genetic process mining
- Inductive inference
- Sequence mining
- Probabilistic: generating Bayesian networks or Markov networks

Using process description, various performance metrics can be implemented.

CONCLUSIONS

An Enterprise System Architecture must include capabilities such as: sensor and actuator virtualization, multi-level control systems, real object virtualizatio and semantic concepts for the description of system components and process mining.

Specific conditions must still be achieved in order to put into practice Enterprise System Architecture based on Cyber Physical Systems. Such conditions refer to: sensor networks, communication infrastructure, standardization, interoperability of systems and process mining techniques. This infrastructure is currently being developed and deployed as part of Internet of Things and Service.

Internet of Things Systems in particular are providing new tools, allowing humans and other systems to interact with real objects through internet.

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