Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 60 (2015) 362 – 370

Procedia Computer Science

19th International Conference on Knowledge Based and Intelligent Information and Engineering Systems

A perspective on Knowledge Based and Intelligent systems implementation in Industrie 4.0

Carlos Toro[a]* , Iñigo Barandiaran[a] , Jorge Posada[a]

[a]Vicomtech-IK4 research Centre, Donostia San Sebastian (Spain)

Abstract

A worldwide trend in advanced manufacturing countries is defining Industrie 4.0, Industrial Internet and Factories of the Future as a new wave that can revolutionize the production and its associated services. Cyber-Physical Systems (CPS) are central to this vision and are entitled to be part of smart machines, storage systems and production facilities able to exchange information with autonomy and intelligence. Such systems should be able to decide and trigger actions, and control each other independently and for such reason it is required the use of Knowledge based and intelligent information approaches. In this paper we present our perspective on how to support Industrie 4.0 with Knowledge based and intelligent systems. We focus in the conceptual model, architecture and necessary elements we believe are required for a real world implementation. We base our conceptualization in the experiences gathered during the participation in different ongoing research projects where the presented architecture is being implemented.

Peer-review under responsibility of KES International

Keywords: Advanced Manufacturing, Digital Manufacturing, Industrial Internet, Industrie 4.0, intelligent systems

---

1. Introduction

The fourth industrial revolution is an idea that little by little is taking its pace in the roadmaps of companies and researchers alike. Local and regional governments are aware of the importance of ICT in industry, and for such reason, novel initiatives and funding programs are being developed and launched. Initiatives such as the Industrial

---

* Corresponding author. Tel.: +34 943309230
E-mail address: ctoro@vicomtech.org

Peer-review under responsibility of KES International
doi:10.1016/j.procs.2015.08.143

Internet and the Advanced Manufacturing Partnership in USA, the Industry 4.0 (Industrie 4.0 in German) [7], la Nouvelle France Industrielle, etc. are just a few of different examples of this vision. Even smaller regions with a long tradition in manufacturing are following the trend from their own local perspective (e.g. the Basque Country with their intelligent specialization policy RIS3 in Advanced Manufacturing). The overall idea as can be seen in Figure 1 is that there is a paradigm shift in nowadays interconnected systems that will eventually generate a new industrial revolution comparable to the one that steam power brought in the late 18th century.

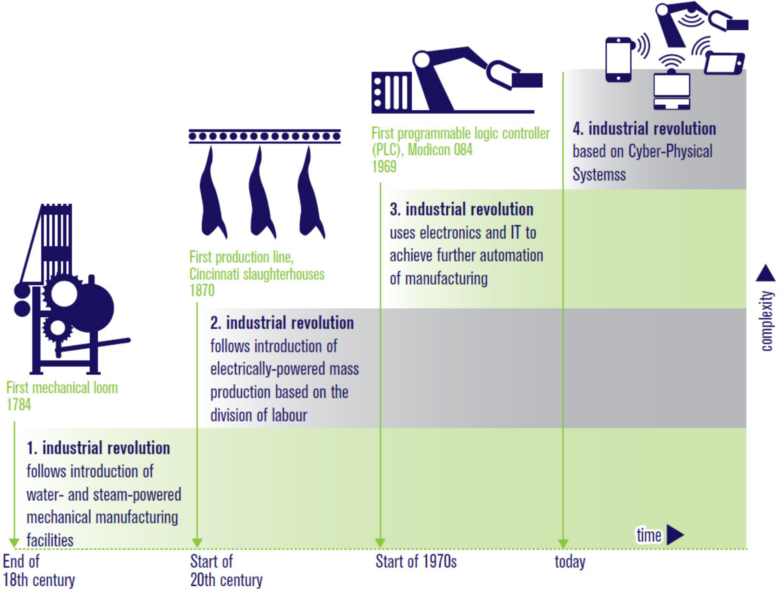

Figure 1. Industrie 4.0–The 4th Industrial Revolution with CPS [7]

The extensive use of IT systems in nowadays industries and the broad availability of technologies such as Big Data, Cloud and grid computing and of course semantics, promise to generate the added value that eventually will create a new interconnected factory [7]. A lot of talking has been taking place in different forums during the last two years concerning the Industrie 4.0 ideas and the possible ways to implement them in current manufacturing facilities [1]. The feeling of most managers of manufacturing companies is that this new revolution should be implemented as soon as possible in order to enhance their manufacturing lines with the so much desired intelligence that is promised. However the reality of many of the aforesaid companies is that they have to deal with the existence of legacy systems and monolithic solutions that in the best-case scenario would only provide limited interconnectivity by providing pretty basic data logs in sometimes-exotic formats.

In the aforementioned scenario, several important questions are to be answered. Arguably among those questions the first to come into mind could be:

- Q1: Which is the current status of my company? - In other words, in which stage of the evolution towards the next industrial revolution could my company be fitted?. Answering this question represents a good starting point in the process of considering strategies for bridging the existent learning and implementation gaps.
- Q2: What do I have to pay attention in order to implement the so-called next industrial revolution in the company? – Answering this question should inevitably lead towards software and hardware products, new normative, novel security and storage approaches, etc. It could also provide relevant information on which required elements are already present but incipient, which ones are not present and which ones are not relevant.

- Q3: How do I involve experience and decision makers and eventually monetize the company know-how that is currently in the heads of the experts in the company? – This question will lead towards a new parading shift where such contextual knowledge, user experience and in general semantics involved in manufacturing and production processes alike should be taken into consideration if a company aims to make its move towards the next industrial revolution.

In this paper we intend to focus on the last question. Is such question where semantic aspects related to the next industrial revolution implementation are to be mostly covered. We present and discuss a proposal on how Knowledge Based and Intelligent systems could play their role in the context of the aforesaid paradigm shift and take the close case of Industrie 4.0 as a motivational idea underneath.

In our work we focus in particular in the conceptual model, architecture and key elements needed for the support and enhancement of Industrie 4.0 with Knowledge Based and Intelligent Systems. We base our approach in the experiences gathered during the participation in an ongoing research project. Our scenario of application will serve as a platform for the developments proposed in the paper and whereas presented in this early stage, nonetheless is to be considered as the first real word implementation of our architecture.

This paper is organized as follows: in section 2, we present a brief overview on the state of the art, including relevant work in terms of research papers and projects where Knowledge Based and Intelligent systems can be concocted in Industrie 4.0. Section 3 presents our proposal for an architecture aimed towards the implementation of Knowledge Based and Intelligent systems in Industrie 4.0. Section 4 relates briefly some of the initial stages of the implementation of this architecture in different research projects our centre is involved in; and lastly in Section 5 we introduce some preliminary conclusions and present our future work.

2. Brief State of the Art

CPS refers to the convergence of the physical world and the digital world (cyberspace). When applied to production, CPS is specialized in CPPS or *Cyber-Physical Production Systems*. Even considering that there is some criticism regarding certain vagueness in the term and sometimes-excessive marketing [3]. It is now widely accepted that the vision and the related technologies of Industrie 4.0 have set already a real impact in current and future industrial manufacturing systems. Recent paper on the subject, [10] show that the potential of Industry 4.0 is already on its way, and that its international scope is clear, especially for Europe. For implementing Industrie 4.0, different technologies have to be taken into account; Figure 2 represents a vision adapted from [10] of some of the most important ones.

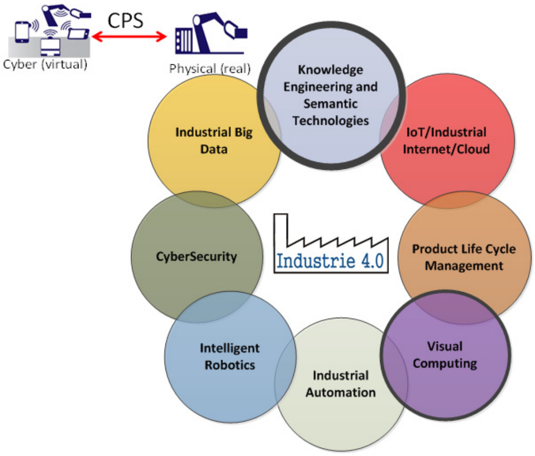

Figure 2. Technologies pool in Industrie 4.0 CP, adapted from [10]

At taxonomy level, it can be argued that the most well-known attempt to provide standardized vocabularies for the domain of industrial plants is AutomationML ([11],[19]). The aforesaid standard aims to describe real plant components as objects encapsulating different aspects of the domain. Any given object can be constructed with other sub-objects, and can itself be part of a bigger composition. Hence AutomationML can describe a screw, a claw, a robot or a complete manufacturing cell in different levels of detail. Typical objects in plant automation comprise information about topology, geometry, kinematics and logic, where logic comprises sequencing, behavior and control. Using the aforesaid approach some projects have started in the last few years. Relevant examples are: ReApp [11], which is a research project within the German technology program "*Autonomik für Industrie 4.0*". The goal of this project is the intelligent robot programming, which simplifies the development and reduces economic investment, so that not only the big companies but also the small and medium ones can bring robots into their production. ReApp aims at providing a tool chain for all participants in the development (including algorithm developers, application developers, system integrators, etc.). ReApp utilizes semantic descriptions and is capable to automatically build the skeleton of the program or even directly generate it. In ReApp a semantic-extension of AML utilizing an ontology in the domain of Robotics is used. Another effort within a similar approach is ZIM (The Central Innovation Program SME = Zentrales Innovationsprogramm Mittelstand – ZIM) project [19]. ZIM is motivated towards "Interoperable Semantic Data Fusion for automated generation of view-based process control visualization" (briefly: IDA). IDA deals with the interoperability of process visualization as an interface between man and machine. The goal is to create a more efficient engineering process and to improve and simplify processes during the operation phase. Process visualization is therefore generated automatically out of existing information. ZIM supports different views on the data. Existing data are interpreted and semantically linked, supporting its semi automatic enrichment by context. The result is a minimization of the manual and error prone effort of engineering and increases the quality of the results. Production system components and their geometry are described using AutomationML. As an example of the importance of formalizing the use of the different technologies in the context of Industrie 4.0, a recently presented paper by Posada et al, discussed the role of visualization [10] and mentioned the relevance of semantics and knowledge engineering. On the later topic, Wahlster discussed the approximation presented in the SEMPROM project [14] describing taxonomy and the definition on how a semantic product memory stores a digital diary of an individual physical object. The persistence of these semantic memories has to be assured in order to make the product's information available to its environment by wireless means. SEMPROM presented a great variety of semantic product memories with a wide spectrum of technical realizations in various fields of application that were designed, implemented and tested in the project [17]. SEMPROM actively researched the use of Active Digital Object Memories as Mobile Cyber-Physical Systems becoming also the first approach towards one of the many possible uses of semantics within the domain. Such ideas were widely extended in a seminal talk at the 30th anniversary of the Dept. of Computer and Information Science of the Linköping University (Sweden). In such talk, it was further discussed the role of Active Semantic Product Memories for Smart Factories [18]. Semantic product memories form a subclass of Digital Product Memories. Digital product memories provide machine-readable information about the product lifecycle, whereas semantic product memories go beyond that, since they provide a machine-understandable meaning description of their contents based on semantic technologies [17].

Quite aligned to the aforesaid view, Shafiq et al, [13], presented the idea of Virtual Engineering Object (VEO) and defined it as the representation of an artifact which can behave like an expert on that artefact and can help the practitioners in effective decision-making based on the past experience. The concept of VEO is powered by SOEKS and DDNA ([15],[16]). VEO is designed to have all the knowledge of the engineering artefact along with the associated experience embedded in it. This approach claims on providing a standard knowledge representation format that eventually forms various networks that based on their past manufacturing experience will allow a complete description of the experiences carried out by an engineering object. These networks of VEOs form a part of a bigger Cyber Physical Systems (CPS) umbrella [5].

In all presented cases and in general in any knowledge-based system, the data/information plays a very important role. Standardization and languages for standardization of communications in a machine-to-machine context like OPC (Object Linking and Embedding - OLE for Process Control,) and more recently OPC-UA, using an unified architecture not dependent on windows OS, play also a very important role [1].

As can be seen, relevant work aimed towards the enhancement of the PLC/PLM thought the better understanding of the data and information produced has been approached both from the academia and the industry, however, we believe that still some room for improvement exists for an alternative view using some of the already presented elements in a wider (more abstract context). Moreover, the approaches presented are focused on applying a certain standard for data exchange or the introduction of a proposed usability (e.g. the case of semantic product memories), but an easy to follow architecture for the implementation and enhanced of Industrie 4.0 through knowledge and intelligent systems is still an arguable necessity. This article deals directly with the aforesaid aspect proposing architecture and some implementation example.

3. An architecture aimed towards the implementation of Knowledge Based and Intelligent systems in Industrie 4.0

In our work, we consider that the classical separation (at a conceptual level) between a sensor and an actuator is becoming narrower and narrower every day with the upcoming of CPS. We believe that arguably such conceptual separation will eventually disappear when CPS will be broadly used in manufacturing facilities.

Nevertheless our architecture (depicted in figure 3), starts with a physical layer where collections of signals from sensors and actuators are consumed and produced, such information travels through the data bus to a standardization layer that is able to perform data-exchange and alignment in required time frames.

It is important to mention that every sensor/actuator has its own data capture/actuation timings and hence it is asynchronous by nature. The precision required for monitoring purposes or to act according to a perturbation (decision) is dependent on the characteristics of the machine/device element and the requirements of the manufacturing process. Since it cannot be predicted which timing will be the most adequate under operational circumstances, the synchronization of time and frequency signals is a matter of high importance and it is contextual by nature [15]. The aforesaid synchronization is implemented in the standardization layer where also the potential contextual information, parsing and in memory storage occurs. Once the data is aligned and synchronized, the communication layer is in charge of preparing the data packets to be transmitted to the cloud.

The communications layer is able to divide and control packages of information and should assure security and anonymity whereas necessary. It can be argued that up to this stage, the information processed is located in the physical domain and starting in here, a cloud based storage and management system houses the rest of the architecture.

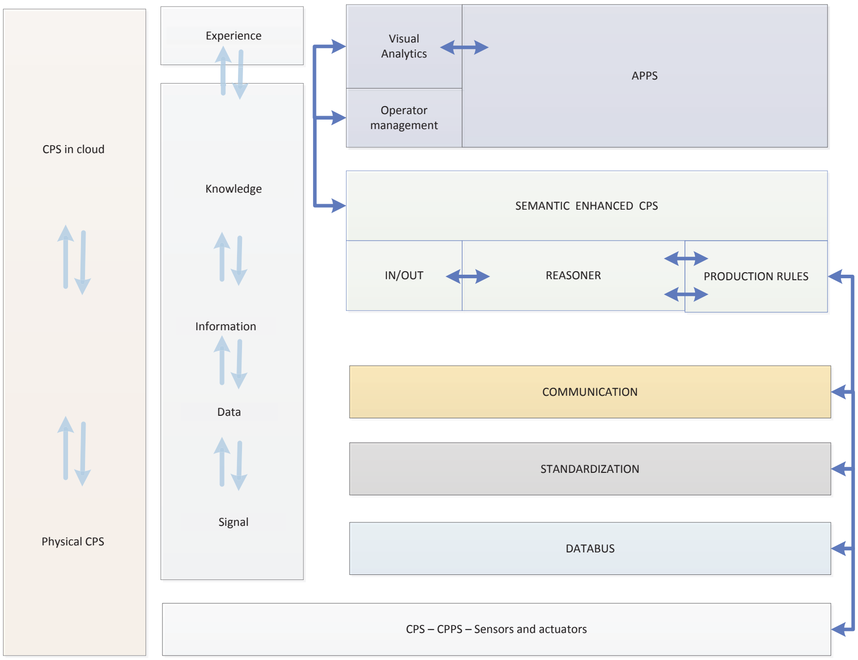

Figure 3. Proposed architecture

Within our approach we believe that CPS could support localized decisions on its own but also contextual knowledge has to be considered. The reason for the aforesaid functionality is no other than to be able to consider the impact of a given element in the machine or production line and vice versa. Contextual knowledge allows considering the whole picture and not only localized information or data gathered. A contextual knowledge manager has to be designed and implemented in a location where all relevant information would be reachable. Among some other reasons why the aforesaid feature is required we can mention the amount of data produced, the need of a flexible storage for such data and the always-important security considerations.

The semantic enhanced CPS agglutinates the whole reasoning process and contains three sub modules that allow the semantic enrichment of the CPS per se. The semantization process starts with an IN/OUT module that synchronizes the information to be enriched with the communication layer via HTTP messages/serialized-responses maintained between the server and the client. As it will be seen in the next section we propose using OPC/OPC-UA for the aforesaid component [2]. The IN/OUT module acts accordingly responding to the reasoner requests by pulling or pushing data streams and as consequence feeding the reasoning procedure with the necessary information to perform its duties. The reasoner module implements a logic backend which we propose to be executed following an open world assumption and First Order Logic (FOL) ([15],[16]). It also contains RETE [3] clauses and a rules management system with statistical methods supported by third party SDKs like for example Scikit Learn [9].

As the reasoner has to be fed not only with data but also with rules provided by domain experts, the production rules module is in charge of storing and interfacing such rules with the users via authoring tools or semi-automatic rule management and sniffing from other external resources like Business Information Systems (BIS), Enterprise Resource Planning (ERP) and the Plant Life Cycle Management (PLM) repositories and software applications [8].

At this stage, the physical layer is enriched through its counterpart in the cloud. Lastly this application layer comprises the different developed consumption applications that will exploit the semantic enriched information and aside it will contain two human to machine interaction modules. At one hand the operator management which between other tasks, interfaces with the rules storage mentioned in the semantic enhanced CPS layer and the Visual Analytics module that implements graphical output to the semantically enhanced information stored in the architecture. The importance of the Visual Analytics module relays on the fact that it will act as an agglutinating feature. An interested reader is invited to read the work by Posada et. al where the reasons are covered in deep [10].

4. Case example – choices for implementation

The architecture introduced in chapter 3 has been used in different ongoing research projects where our centre is involved in. The overall idea in our participation in such projects is to develop an IT infrastructure to support the Factory of the Future based on the analysis and reuse of the information and knowledge contained in the manufacturing processes and CPS and their production units counterparts known as CPPS (Cyber Physical Production Systems). In general the idea that our clients require us to support is to perform a series of analysis over the CPS/CPPS gathered data from a given manufacturing line. Let us say that though a Graphical User Interface (GUI) a user interacts with a cloud based storage/analysis service, which is fed by sensor, CPS and CPPS data produced by the control elements in each machine in the manufacturing line. Using the existent data bus, the data is stored in a local database and the contained data is translated to HDFS to be stored in an elastic cloud service in Hbase, MongoDB and NoSQL. The reason for the existence of the local database is no other that a design requirement of the client who is already capturing data in an existing PLM. The reason of the three aforesaid databases that have to be supported in the big data database is due to three existent consumers of information that will be also feeding data from non in-machine sources like for example ERP, Business intelligence suites, etc. In the case of the CPS stored data, the selected database is a NoSQL flavor. The stored data is consumed by IT tools that are part of the solution. At minimum, we propose three tools, the first tool is in charge of the statistical analysis and it is implemented using Scikit-learn and Mahout ([5],[9]).

The second is a context analyzer, which makes use of OWL-DL ontologies and has FACT++ as the reasoner service [16]. It also includes a RETE rules [2] processor implemented using Drools[15]. The objective of this tool is to be able to infer intrinsic knowledge, whereas the first module is aimed towards extrinsic knowledge gathering and reuse. The third and last tool is a visual analytics engine implemented in JavaScript [10] and its main goal is to represent the data and knowledge in a structured but at the same time compact and easy to read manner. The implementation is nondependent on the operating system or any third party plugins and it is highly interactive by design.

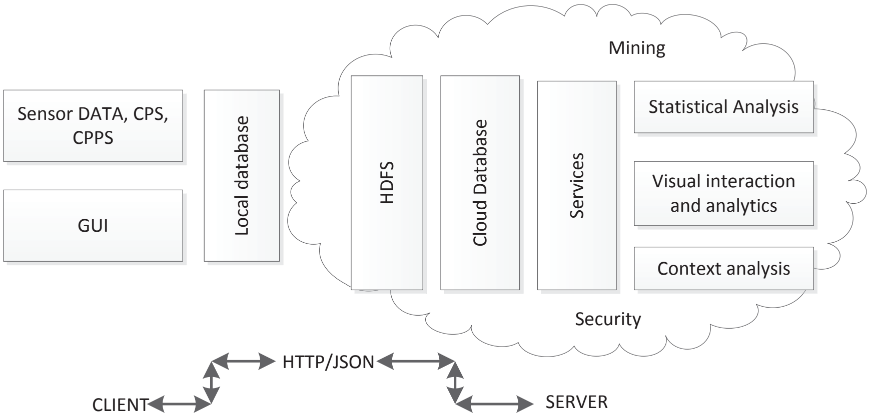

Figure 4. An example implementation of our architecture's modules

A series of implementation decisions are reported in table 1, referring to possible embodiment of such decisions.

Table 1. A sample embodiment and implementation remarks

Architecture module	Choice of embodiment	Implementation remarks
CPS/CPPS	Own development	The CPS are being developed and are commercially available, different companies offer the technology
Databus	Profinet, Profibus	Both data buses should supported
Standardization	AutomationML	Any standardization is proposed using AutomationML would be a great idea since its OPC-UA compatibility
Communication	OPC,OPC-UA	At present time OPC is broadly implemented already, however a recommendation to move towards OPC-UA mandates compatibility with such.
In/Out	Hadoop HDFS 3	The reason of this choice is the easiness of implementation and the readiness of pre-existent code in java for the translation between local data storage and cloud storage.
Reasoner	Fact++ over standard ontologies	The use of ontologies in this framwerok will be explained further in a future work.
Production Rules	Drools	The choice of this RETE engine is a practicality, however considerations to move this feature towards python based scenario using PyKe are being considered for the speeding up of the process.
Visual Analytics	D3.Js, WebGL, Bokeh	This choice was steered by the design requirement of no plug ins required
Operator management	Own development	This is an authoring tool developed using Java and python

5. Conclusions and future work

In this paper we have presented an initial perspective on how to support Industrie 4.0 with intelligent systems. The advantage relays on the better use of the data and information generated within the manufacturing processes for re-utilization, tendency analysis and prognosis. Our conceptualization is based in the experiences gathered during the participation in different ongoing research projects. In this paper we have focused in the conceptual model, architecture and necessary elements we believe are required for real world implementation, but since our work is extracted from an ongoing effort, we are in a continuous development stage that will hopefully end up with a fully working system implemented in the companies in the consortium as test scenarios.

Acknowledgements

We would like to thank ETXE-TAR for their strong support in promoting real applications of Industrie 4.0 solutions.

References

1. Blanchet, M. Rinn, T., von Thaden, G. de Thieulloy, G. "*Industry 4.0: The New Industrial Revolution. How Europe will succeed*.", Roland Berger Strategy Consultants GmbH. March 2014. http://tinyurl.com/otq4azn
2. Forgy. Charles L.. "*Rete: a fast algorithm for the many pattern/many object pattern match problem.*", In Expert systems, Peter G. Raeth (Ed.). IEEE Computer Society Press, Los Alamitos, CA, USA 324-341. 1991
3. Drath, R.; Horch, A., "*Industrie 4.0: Hit or Hype?.*" [Industry Forum]. Industrial Electronics Magazine, IEEE, vol.8, no.2, pp.56-58, June 2014.
4. European Commission "*Advanced computing*" Available in http://tinyurl.com/okpfpp4, last visited 15/12/2014
5. Fensel, D Hendler, J;Lieberman, H and Wahlster, W. "*Introduction to the Semantic Web, in Spinning the Semantic Web. Bringing the World Wide Web to Its Full Potential*." ed. by D. Fensel, J. Hendler, H. Lieberman, W. Wahlster (MIT Press, , 2003), pp. 1–25
6. Fernbach, Andreas Granzer, Wolfgang, Kastner, Wolfgang, and Furtak, Paul. Mapping ETS4 "*Project Structure to OPC UA using ETS4 XML Export.*", In KNX Scientific Conference, November 2012.
7. Final report of the Industrie 4.0 Working Group. "ACATECH*: Recommendations for implementing the strategic initiative INDUSTRIE 4.0.*", July 2014.
8. Lee, Jay; Lapira, Edzel, Bagheri, Behrad, and Kao, Hung-an "*Recent Advances and Trends in Predictive Manufacturing Systems in Big Data Environment.*" Manufacturing Letters 1(1):38-41, 2013
9. Pedregosa, Fabian; Varoquaux, Gaël; Gramfort, Alexandre Michel, Vincent; et al. "*Scikit-learn: Machine Learning in Python.*". Journal of Machine Learning Research 12: 2825–2830, 2011
10. Posada, Jorge; Carlos, Toro; Barandiaran, Iñigo, and Oyarzun David, et al, "*Visual Computing as a Key Enabling Technology for Industrie 4.0 and Industrial Internet*" IEEE CG&A Journal, Published by the IEEE Computer Society 0272-1716/15 , 2015
11. ReApp project, available online at : http://www.reapp-projekt.de/
12. Sanin, Cesar, Toro, Carlos, Haoxi, Zhang, Sanchez, Eider, Szczerbicki, Edward, et al. "*Decisional DNA: A multi-technology shareable knowledge structure for decisional experience.*", Neurocomput. 88 (July 2012), 42-53., 2012
13. Shafiq, S. I.; Sanin, Cesar; Szczerbicki, Edward; and Toro, Carlos, "*Decisional DNA Based Framework for Representing Virtual Engineering Objects.*" in Intelligent Information and Database Systems. vol. 8397, N. Nguyen, B. Attachoo, B. Trawiński, and K. Somboonviwat, Eds., ed: Springer International Publishing, , pp. 422-431. 2014

14. Semprom Project available online at: http://www.semprom.de/
15. Szczerbicki Edward; Graña, Manuel, Posada, Jorge; Toro, Carlos. "*Current Research Advances and Implementations in Smart Knowledge-Based Systems.*",Cybernetics and Systems 44 (2-3), pp. 95-97, 2013.
16. Toro, Carlos. Vaquero. Javier., Graña, Manuel., Sanín, Cesar., Szczerbicki, Edward, Posada, Jorge.: "*Building Domain Ontologies from Engineering Standards.*" Cybernetics and Systems 43(2): 114-126, 2012
17. Wahlster, Wolfgang, "*SemProM: Foundations of Semantic Product Memories for the Internet of Things.*" ISSN 1611-2482 Cognitive Technologies, ISBN 978-3-642-37376-3 ISBN 978-3-642-37377-0 (eBook), DOI 10.1007/978-3-642-37377-0, Springer Heidelberg New York Dordrecht London, 2013
18. Wahlster, Wolfgang, "*Industrie 4.0: Active Semantic Product Memories for Smart Factories.*", IDA 30th Year Celebration SeminarLinköping, 24.09.2013, Available online at : https://www.youtube.com/watch?v=u2n9voWR1ZA
19. ZIM IDA project 2015 , available online at : http://www.iosb.fraunhofer.de/servlet/is/18792/