A Technology Roadmap on SOA for smart Embedded devices: towards Intelligent systems in manufacturing

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Abstract – **Intelligent systems, composed by devices with embedded computing capability, sensors and actuators interacting with the environment, will enhance and support manufacturing in the future. SOCRADES (Service-oriented cross-layer infrastructure for distributed smart embedded devices) is a European research project that focuses on the development of a platform for next-generation industrial intelligent systems, exploiting SOA paradigm. Within SOCRADES a Technology Roadmap is being developed. Its aim is to provide inputs for the orientation of technological research to achieve the long term objectives required for the enhanced and pervasive exploitation of intelligent systems for manufacturing support. We present the Expected Features of Technology Areas (EFTAs) identified within SOCRADES Technology Roadmap. Then we show how the outcome of SOCRADES Technology Roadmap addresses important needs such as those pointed out by the Strategic Research Agenda developed by ARTEMIS (European Technology Platform for Embedded systems).**

Keywords - **Roadmap, SOA-based manufacturing, Embedded devices, wireless, intelligent system**

I. INTRODUCTION

In the next future intelligent systems, i.e. systems where intelligence is distributed among numerous devices provided with computing capability, are more and more spreading especially in industrial domains. Moreover thanks to the provision of sensors, actuators, wireless communication capability and SOA paradigm for supporting seamless interaction, devices will become autonomous agents with personal intelligent perception, reasoning, learning, and acting.

Since the adoption of intelligent systems in manufacturing will have a positive impact on manufacturing performance especially in terms of systems design and management, research in this field is needed in order to provide a reliable framework for the implementation.

The use of the service-oriented architecture (SOA) paradigm, implemented through Web Services technologies, at the ad hoc device network level enables the adoption of a unifying technology for all levels of the enterprise, from sensors and actuators to enterprise business processes.

Hence SOA represents the fundamental paradigm on which a new "SOA-based manufacturing" can be developed. With this name we refer not only to the application of Service Oriented Architecture to manufacturing environment, but also to the adoption of embedded system and wireless communication as enabling technologies, addressing Intelligent systems. SOA-based manufacturing has a dramatic impact on manufacturing strategy, management and execution, by supporting relevant and revolutionary abilities of manufacturing system such as interoperability, reusability, scalability, etc.

SOCRADES (Service-Oriented Cross-layer Infrastructure for Distributed smart Embedded devices) [1] is a European research project addressing SOA-based manufacturing paradigm. Its primary objective is to develop a design, execution and management platform for next-generation industrial automation systems, exploiting Service Oriented Architecture paradigm both at the device and at the application level. SOCRADES will create new methodologies, technologies and tools for the modeling, design, implementation and operation of networked systems made up of smart embedded devices. Both wired and wireless networking technologies will be considered for the network implementation analysis.

Within SOCRADES a Technology Roadmap is being developed. The aim of the Technology Roadmap is to provide inputs and to aid in the orientation of technological research to achieve the long term objectives required for the enhanced and pervasive exploitation of this kind of intelligent systems.

The first release of the SOCRADES Technology Roadmap has just been completed. In the present paper we will present the methodology, structure and results and we will link them to three relevant Industrial research priorities identified by ARTEMIS [2], a well-known European Technology Platform focused on Embedded Systems.

II. ARTEMIS STRATEGIC RESEARCH AGENDA

ARTEMIS [2] identified three Industrial Research Priorities [3] in order to enhance cost and time to market reduction.

1) Reference designs and architectures (RDA), whose objective is the creation of a generic platform and a suite of abstract components with which new developments can be engineered with minimal effort. [4]

2) Seamless connectivity and middleware (SCM), this seamless connectivity is a vital element in the model of future Embedded Systems. It includes the middleware, operating systems, and other functions required to link the physical world, as seen by the networked nodes, to the higher layer applications. [5]

3) Design methods and tools (DMT), essential for rapid design and prototyping, without which it is unrealistic to attempt development of such complex systems. The objectives are: design efficiency, systematic design, productivity and quality. [6]

These Industrial research priorities will represent our benchmark for the analysis of the results coming out from the roadmapping exercise.

III. ROADMAPPING METHODOLOGY

The first step followed in SOCARDES was to identify some Technology Areas (TA) relevant in terms of impacts towards SOA-based manufacturing and towards the enhancement of intelligent systems. Hence the project scope has been divided into four TAs:

1) *Ad-hoc networking services platform – Service-oriented Architectures,*
2) *Wireless sensor/actuator networking infrastructure,*
3) *Service-centric infrastructure – Enterprise integration*
4) *System Engineering & Management.*

After the identification of these four Technology Areas, the first aim of the Roadmap was to identify, for each TA, some Expected Features (EFTA: Expected Features of Technology Area). EFTAs are relevant technology characteristics that are expected to become available in the future thanks to R&D efforts.

Firs of all a state of art analysis was carried out. Some of the most relevant roadmaps recently published that are focused on the SOCRADES project topics [7-15] were analyzed and reviewed. On the strength of this analysis and of the derived knowledge, we started the process of identification of the EFTAs within SOCRADES scope. In particular this was carried out considering also some other sources of information, like workshops, questionnaires and a Delphi study.

Finally, in order to stress the relevance of the EFTAs come out from SOCRADES roadmapping activities we analyzed how they are linked to the Industrial research priorities identified by the ARTEMIS Strategic Research Agenda.

IV. EXPECTED FEATURES OF TECHNOLOGY AREAS

In this section the Expected Features identified for each Technology Area are briefly described. Moreover for each EFTA we indicate if there is a direct connection with one of the Industrial research priority identified by ARTEMIS, by mentioning the related acronym (respectively: RDA for Reference designs and architectures, SCM for Seamless connectivity and middleware and DMT for Design methods and tools).

A. Ad-hoc networking services platforms – Service-oriented Architectures (SOA)

A service-oriented architecture (SOA) is a set of architectural building blocks that establish autonomous and interoperable systems. Autonomous systems are identified as independent and provided with self-contained functionality. Interoperable systems refer to the ability of interacting with other different systems, generally through an interface that exposes the service together with policies and constraints for its use. The EFTAs for the Ad-hoc networking services platform – SOA Technology Area are the following:

- Orchestration: the practice of sequencing and synchronizing the execution of services, which encapsulate business or manufacturing processes. An orchestration engine implements the application logic necessary to orchestrate atomic services, and provides a high-level Web Service interface for the composed process. (*RDA*)

- Decision Support System (DSS): Orchestration by itself cannot solve every problem arising during the system's operation (implementing all functions in the same level could neutralize the flexibility of the system), a DSS is needed to address complexity and reconfigurability. Some issues will be handled locally through orchestration, others will request DSS. (*RDA*)

- **Context-aware services:** the capacity of services being aware of their environment (devices, factors, etc.) and reacting by adapting their functionality. (*SCM*)

- Lean data generation and processing: in order to obtain efficiency, methods and tools are needed for data structuring and handling inside each machine, i.e. how to expose specific data as particular service attributes. (*RDA*)

- **Standardization of basic functionalities provided by services:** communication technologies are pretty much standardized but this is not the same for standardization of basic functionalities provided by services. A separation between the standardization of the communication technologies and the standardization of basic functionalities provided by services is needed. This specific standardization is expected to evolve in various domains and cross-domain. (*SCM*)

- Common Language: a common language is expected to be widely diffused. The protocol should be at least XML-based and support OWL mark-up in order to enhance it with explicit semantics. Having a common basis for seamless operation of standard functions such as discovery, description, addressing, invocation etc. will be required. (*SCM*)

- **Choreography:** a complementary concept to service orchestration is choreography. The orchestration level is concerned with the workflow-oriented execution and sequencing of atomic processes. Choreography, instead, considers the rules that define the messages and interaction sequences that must occur in order to execute a given process through a particular service interface. Choreography evolution will be related to complexity due to the increasing dimension of systems. (*RDA*)

- **Chronology-aware Service Composition:** time is not yet represented in the description of service, while making service composition; so duration of the composed service could not be known. Methodology to infer composed times (capacity) of execution of two (or more as an expected evolution) services with time properties is expected to become relevant. (*SCM*)
- **Knowledge processing and reasoning:** to address the issue of usage of ontologies that contradict each other. So the issue is ontologies reconciliation for agent systems, especially at run-time. Till now, reconciliation of ontologies is very complex to be achieved and may require a considerable amount of computational resources. (*RDA*)
- **Large and complex:** increasing size involves increasing number of services and number of interactions. With a greater number of nodes the increased complexity implies issues in managing the system. (*RDA*)
- **Run-time behavior of a SOA:** concurrency model is the core component of a real-time program. Whilst the concurrency model of high-integrity systems is now well understood and has found representation in subsets of languages, more expressive subsets are needed. (*RDA*)
- **Localization of functionalities:** in a highly distributed system it is fundamental to have tools for efficient service localization. A way to reach this EFTA should be to use Clustering technique. (*SCM*)
- **Intellectual Protection:** this is an important issue for interoperable and knowledge-sharing systems. Thanks to SOA, IP should be protected since only the service is seen, not how the service is furnished, however improvement are expected. (*RDA*)
- **Dynamic Deployment of Services:** in order to better support dynamic reconfiguration and to reach orchestration and choreography. (*RDA*)

B. Wireless Sensor/Actuator Networking Infrastructure (WSAN)

Wireless technologies are already widely used in industrial domain. Their diffusion should grow in the future in order to enhance autonomy, mobility and reconfigurability of manufacturing systems. Development of wireless communication technologies are still required especially in terms of reliability for application in closed-loop control and of interoperability with the heterogeneous wireless technologies deployed in the same area. The EFTAs for the WSAN Infrastructure are now described:

- **Quality of Service:** This is a macro-EFTA which includes: (i) Real-time service: e.g. to perform production control. In order to guarantee this requirement research should be carried out both in terms of stability of the communication and of energy consumption. (ii) Determinism: reliable delivery of data packets with a guaranteed (mainly maximum) delay. Wireless medium is subject to inference by machines or other wireless networks; hence it is difficult to guarantee determinism especially for hard real-time applications. (iii) Reliability of sensors: in particular concerning the integration of support for dependability and real-time. High-level dependability mechanisms must complement low-level mechanisms such that distributed applications running on the sensor network as a whole exhibits reliable behavior even if parts of the network fail. (iv) Efficient communication: energy use is linked to frequency of communication and use for each communication. Efficient communication can improve energy saving, helping also in reaching energy autarky. (*RDA*)
- **De-centralization:** that is shifting intelligence and processing tasks towards the field level devices. Decentralization adds robustness, flexibility and scalability to the system; of course, this trend should be not followed as a dogma for all devices. (*RDA*)
- **Energy autarky (self-sufficient devices):** in a WSAN a way of powering the single devices in a decentralized manner has to be found. This might involve batteries, energy harvesting, energy transmission, optimization of energy usage and power management. (*RDA*)
- **Self-X Features:** For reasons of easier engineering, easier maintenance, etc. features like self-organization, self-optimization, self-healing, self-configuration, self-stabilization, self-describing etc. are of highest importance. In their maximum extent this would mean a WSAN which does not need any engineering, maintenance, configuration, or human care at all. (*SCM*)
- **Enhanced Service oriented Features:** due to the limited amount of resources, SOA features nowadays can only be implemented on the gateway. As soon as the energy challenge is solved, it will also be possible to apply common IT technologies. (*RDA*)
- **Efficient Data Processing:** This is a macro-EFTA which includes: (i) Push-based information transmission: information is transmitted when ready (push logic), not when required (pull logic) (ii) Fusion/aggregation of data processed within the network: information have to be propagated within the network by using rules of aggregation/fusion to avoid to overload some nodes of the network and to provide useful information instead of raw data. (iii) Context-aware MAC and Routing: a system that extracts, interprets and uses context information and adapts its functionalities to the current context will be required in the future. (*RDA*)
- **Sensor calibration:** calibration in WSAN is more frequent than in wired networks. It is important to understand when to do calibration. The problem is not only due to WSAN, itself but to the increase of number of sensors enabled by the WSAN. (*RDA*)
- **Localization:** provision of localization information in distributed networks can be both a service offered by the network to the applications (object tracking, etc.) and a technique for improvement of the network itself. (*SCM*)
- **Data storage and search:** collecting data it is crucial to minimize communication cost for the application tasks. Hence, efficient storage and querying of sensor data are both critical and challenging issues in WSAN. (*RDA*)

- **Scalability:** number of nodes should vary depending on the need of the application. Existing approaches are still far away from the optimal desired scalability. (*RDA*)

- Robustness: devices in a WSAN should be resistant to the potentially harsh environmental conditions and should integrate seamlessly in the environment. Since the application trend requires more sensors and the operational environment gets more hostile, the importance of research on this EFTA increases. (*RDA*)

- Mobility: in a WSAN devices can be moving relative to each other. Mobility depends on the application and can vary depending on the proprieties of the mobility scenario. (*RDA*)

- Security (cross-layer): WSAN have to be secured in many ways to ensure their reliable operation. Besides the security in WSAN, the focus will be in cross-layer security. (*RDA*)

- Interoperability (heterogeneity): the emergence of WSAN standards should facilitate the deployment of large industrial WSAN at plant and field levels. Nonetheless it is still a very demanding research topic (*SCM*)

- WSAN technologies for closed-loop control: in the future it is expected that WSAN technologies should be able to address closed-loop control needs through higher robustness, prioritization schemes, etc. The central components like PLC will become more and more unnecessary for controlling production processes. (*RDA*)

- WSAN deployment tools: With the advent of interoperable WSAN technologies, new standard installation, deployment and maintenance tools will be available. Also, specific planning tools should be made available to cope with complex installations and provide pre-deployment simulation capabilities. (*DMT*)

C. Service-centric infrastructure - Enterprise Integration (EI)

This TA is related to the integration between application-level functionality and device-level functionality through a common, unifying technological approach, based on the service-oriented architecture (SOA) paradigm. Then the focus is on the integration of aggregated device-level services with higher level Web Services and business processes situated at the level of business applications - in particular Enterprise Resource Planning (ERP) systems. Business application systems increasingly benefit from the adoption of service oriented architectures (SOAs) allowing to flexibly compose components of heterogeneous software systems across traditional system boundaries and swiftly adapt business processes to changing requirements. The EFTAs of EI are described here:

- Flexible Production with Enterprise Support: a characteristic of the future manufacturing plant will be its connectedness to all its vital components: workers, machines, and products. Cross-Enterprise approaches considering the end-to-end process from the supplier via the plant to the customer need to be developed. Especially the vertical dimension where automation, manufacturing execution, and enterprise systems will be seamlessly integrated into each other is of key importance. Material flow along the value chain and information flow along the product life cycle are considered significant future features to be supported. (*SCM*)

- **Device to Business Integration (D2B Integration):** device manufacturers have been dramatically increasing the amount of embedded software in their products. Hence they are able to handle a wide range of computing and communication tasks, but also to provide their functionality as a service. Therefore device can participate in real-world business applications by providing information coming from their domain and also consuming services available at enterprise level. (*SCM*)

- **Cross-layer Adaptive Modeling:** software development is becoming more complex, model-driven engineering technologies offer a promising approach to address the inability of third-generation languages to alleviate the complexity of platforms and express domain concepts effectively. Development of approaches that effectively handle service modeling and management of intelligent distributed business processes in highly populated device infrastructures is needed. Business logic traditionally resided at high-level systems (e.g. ERP) but in the future it will be distributed in several layers (e.g. ERP, middleware, network, device level). (*DMT*)

- **Security / Service Policy Compliance:** business applications are moving from stand-alone systems to enterprise service-oriented architectures (enterprise SOA). The openness and heterogeneity of such systems is requiring a security approach different from that of traditional systems and architectures. (*RDA)*

- **Industrialization of software development:** this is needed in order to rapidly configure, adapt and assemble self describing components to produce systems. Moreover it will be applicable in different domains that share common core functionality. (*RDA*)

D. System engineering & management (SEM)

A number of system modeling and logic design environments are emerging with the potential to not only automatically generate control logic software but to allow the support of multiple aspects of the complete systems engineering life cycle. Such tools promise to enable higher level design, improved reuse of control logic applications and the possibility to visualize applications in a virtual environment. They also have the potential of supporting distributed control system configurations. The EFTAs of SEM are now described:

- Efficient/effective (re-)configuration: the ability to configure systems (machines, lines, etc.) built from SOA-enabled modules both statically and dynamically in a standardized manner, e.g., with predictable system performance. Flexible use of systems components coupled with a high-level system configuration capability. (*DMT*)

- High level process definition: the ability to describe the overall behavior of systems composed of many distributed devices in a high level process description language, which directly relates to the specific process the user is concerned with. (*DMT*)

- **Collaborative, integrated, distributed business-driven engineering:** systems capable of being configured and managed in a global business context (e.g. support for globally distributed engineering teams). The added pervasiveness of SOA-enabled manufacturing devices and the effective coupling of embedded systems to business drivers are keys to greater agility. (*DMT*)

- **Open, lifecycle support:** engineering systems capable of being used at all phases of the machine lifecycle, all provided in a consistent manner and in a vendor independent way. In future, as the lifecycle of systems continually gets shorter the provision of lifecycle support rather than a collection of separate support tools are necessary. SOA presents a standards based and neutral platform on which these lifecycle systems can be both built and linked. (*DMT*)

- **Service-oriented engineering:** engineering support provided primarily through the provision of services rather than on-site engineering activities. SOA will aid in the standards based development of this type of remote support by linking various systems both physically and in conceptual terms. (*SCM*)

- **SOA Marketplace:** SOA could be used to expose services to the systems. SOA enables IP (Intellectual Protection). IP enables marketplace for tools to be developed (maintenance, diagnosis, etc.), creating new business models. This marketplace model will present the users of services and systems in the domain to new pricing models that may be more suitable to companies such as Small to Medium Enterprises. (*RDA*)

- **SOA-enabled Digital Factory:** Planning and modeling, improving cooperation between the enterprises, and internally. This is a macro-EFTA which includes: (i) Seamless integrated digital engineering: the ability to mix the engineering of digital and real system components. (ii) Fully digital mock-up of machines: mechanical structure simulation, process simulation, prediction and validation of final pieces' optimal results in design-time, smart configuration. (iii) PLM (Product Lifecycle Management): tools to design, analyze and manage products from the stage of initial conception to the retirement stage. (*DMT*)

- **Synthetic environments integration:** synthetic environments integrate the last developments in the area of virtual reality which allow representing environments close the reality to the practical extension of the synthetic environments in the manufacturing domain. (*DMT*)

V. CONCLUSIONS AND FUTURE DEVELOPMENT

Intelligent systems will increase their importance in manufacturing domain but still need for research and development efforts in order to face the issues presented in this paper. Roadmapping activity represents an effective tool for orientating R&D efforts towards high-level guidelines. In highly competitive environments, such as manufacturing domain, roadmaps are even vital to exploit new technologies' opportunities in order to increase performances and competiveness.

SOCRADES Technology Roadmap identified some Expected Features within the four Technology Areas involved in the project. EFTAs represent the goals that should be aimed by R&D efforts.

TABLE I
SUMMARY OF EFTA FOR TECHNOLOGY AREA AND FOR INDUSTRIAL RESEARCH PRIORITY

	RDA	SCM	DMT	Total
SOA	9	5	0	14
WSAN	12	3	1	16
EI	2	2	1	5
SEM	1	1	6	8
Total	24	11	8	43

For each EFTA identified we made explicit the link with an Industrial research priority (defined by ARTEMIS). A summary of these links between SOCARDES Technology Roadmap and ARTEMIS Industrial research topics is presented in Table I. These links support SOCADRES Technology Roadmap results and encourage research's continuation on SOCRADES scope even going beyond SOCRADES goals themselves. As expressed by this Table, SOA and WSAN Technology Areas contain EFTA related mostly to Reference designs and architectures and to Seamless connectivity and middleware; this is acceptable for the nature of these specific Technology Ares (architecture/middleware and network), however attention to design methods and tools could be intensified also in these TAs in order to obtain an enhanced support and integration of these tools in the overall framework.

Further developments will be performed in order to validate and complete SOCRADES Technology Roadmap. One important development is EFTA prioritization, involving both time and content priorities. Once priorities are defined, the identification of trajectories will be possible; both EFTAs and trajectories together will represent SOCRADES advice to policy-makers for a proper R&D efforts' orientation towards Intelligent Systems in manufacturing.

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