Trends and roadmaps on SOA-based embedded networks for industrial automation systems: a review

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Abstract: In order to plan a strategy based on technological research in the industrial domain, roadmaps represent one of the most relevant tools. SOCRADES is a European-funded project, whose 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. Within SOCRADES, a Technology Roadmap is being developed. Even if in SOCRADES scope, there are several technology roadmaps available, made by policymakers, Industry, University and Research Institutes, the outcome documents are slightly heterogeneous in terms of objectives and perspectives. In order to have a clearer view of the present awareness on future trends and research, there is a need for a review of available roadmaps. This review is presented in this paper. Moreover, this review is used as a starting point for SOCRADES Technology Roadmap building process.

Keywords: Technology Roadmap, SOA-based manufacturing, Smart Embedded devices, wireless, intelligent system.

1. INTRODUCTION

As already evidenced by some authors [Jovane et al.], the development of competitiveness in manufacturing industry is essential for European prosperity; moreover, manufacturing innovations are needed in order to improve European manufacturing processes. However, technological research and development is usually critical for the success of the innovation process.

In order to plan a strategy based on technological research in the industrial domain, roadmaps represent one of the most relevant tools [Galvin, Kostoff et al.]. Unfortunately, this kind of roadmapping activity represents a very tough task. On the one hand, it is usually difficult to identify future technological trends and to define a roadmap that proposes how research effort in specific fields should be allocated in order to obtain relevant results. On the other hand, in the industrial environment, multi-disciplinary knowledge and technologies are needed. Hence, nowadays industrial technological research, needed for the innovation process, must be multi-disciplinary [Jamison et al.]. These two aspects imply that the definition of a technology roadmap in the industrial domain, where both a technological perspective and an application point of view have to be taken into account, is a real challenge.

Due to the difficulties described above, a lot of effort has been made by policymakers, Industry, University and Research Institutes all together for creating technology roadmaps. However, the outcome documents are slightly heterogeneous in terms of objectives and perspectives; hence, in order to have a clearer view of the present awareness on future trends, there is a need for a review and rearrangement of available roadmaps.

2. CONTEXT

This paper presents the results of a review of relevant roadmaps already published and available at present. This activity represents one step of the overall Roadmapping process that is being carried out in SOCRADES (Service-Oriented Cross-layer Infrastructure for Distributed smart Embedded devices) [SOCRADES].

SOCRADES is a European research and advanced development project whose primary objective is to develop a design, execution and management platform for next-generation industrial automation systems, exploiting the Service Oriented Architecture paradigm both at the device and at the application level. The SOCRADES integrated project will create new methodologies, technologies and tools for the modelling, design, implementation and operation of (wired or wireless) networked systems made up of smart embedded devices.

Within SOCRADES, as one of the most important output of the project itself, a Technology Roadmap is being developed and will be publicly available. The aim of the Technology Roadmap is to go beyond the results of the project and to suggest possible directions for continuing research in SOCRADES scope. Hence, the output will provide policymakers and stakeholders (from Industry, University and Research Institutes), with SOCRADES perspective on how research should be directed in order to face the future challenges in the industrial domain.

2. METHODOLOGY for SOCRADES ROADMAP

The methodology used for SOCRADES Roadmap is represented in Fig. 1.

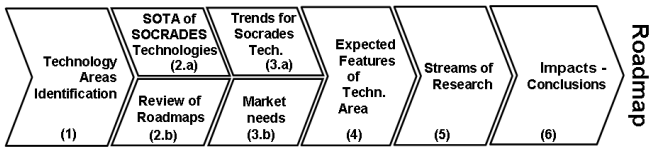

Fig. 1. Roadmap building steps

1) Technology Areas Identification, i.e. SOCRADES Roadmap Scope. In order to identify and map future trends of technologies the first step has been to identify relevant Technology Areas (TAs). Namely they are:

i. Ad-hoc networking services platform – Service-oriented Architectures;
ii. Wireless sensor/actuator networking infrastructure;
iii. Service-centric infrastructure - Enterprise Integration;
iv. System engineering & management.

2) State of The Art Analysis.

a. The aim is to have a clear picture of the current state of the art of the 4 Technology Areas, as starting point of the roadmapping activity.
b. After analysing the state of the art of technologies, it is important to review existing roadmaps related to SOCRADES scope, in order to understand both their structure and the connections between their content and SOCRADES technology areas. Moreover, this analysis can provide a clearer view of the present awareness on future trends within SOCRADES scope, providing inputs for roadmapping activity. This article describes and provides results mainly about this step.

3) Market analysis

a. Trends and expected market for SOCRADES Technologies. The aim of this step is to investigate how markets of the main TAs related to SOCRADES will increase in the future, determining virtuous cycle between research and applications.
b. Market needs and trends in SOCRADES Area. This step highlights the most important industrial needs and trends that will pull for technological advances in SOCRADES scope. The aim is to show why roadmap on these technologies is important from an industrial (and not only technological) perspective. In this section some Industrial Challenges are identified as relevant for the future.

4) Expected Features of Technology Area (EFTA)., i.e. relevant technology characteristics related to each specific Technology Area that are expected to become available in the future. Such EFTAs are identified according to a mix of different approaches: data-based approach, workshop-based approach, survey-based approach.

5) Streams of research. This step should focus on suggesting some "streams of research" that can be considered the most relevant and effective ones in order to reach the EFTAs.

6) Impacts – conclusions. This step sums up the results of the roadmap, by describing how the streams of research identified will bring to the realization of EFTAs that are relevant for the industrial needs (Industrial Challenges identified in step 3.b).

3. REVIEW OF ROADMAPS

Focusing on step 2.b, a review of relevant publicly available roadmaps was carried out in order to provide a synthesis of the present awareness of trends and challenges expected in SOCRADES TAs for the next years, by policymakers and stakeholders from Industry, University and Research Institutes. As a matter of facts, there are several roadmaps concerning the Technology Areas identified in SOCRADES however these roadmaps present differences in terms of objectives and scope. Hence there is a need for some rearrangement and review in order to obtain an overall clear picture. Moreover, this activity was conducted in order to derive some relevant inputs for SOCRADES Roadmapping activity.

3.1 Positioning of the roadmaps

Before analysing the roadmaps, a matrix was defined in order to have a tool for comparing and positioning the different roadmaps, by representing differences and communalities among them. This exercise is useful for better understanding the present state-of-art of Roadmaps available on SOCRADES Technologies.

A matrix has been defined by the authors in order to analyse roadmaps. This matrix is composed of two drivers: *Orientation* and *Strategic Level*.

- *Orientation*: this driver represents the type of objective aimed by each roadmap. In fact, a roadmap can be focused on technology or on application. A roadmap is considered Application oriented when its aim is to derive new research approaches and tools to solve relevant issues related to the specific application to which it is concerned (Manufacturing industry, process industry, Home automation, Health care, etc.). This kind of roadmaps is somehow pulled by the market, since its aim is to find possible technological improvements for fulfilling applications needs. After having selected a single application, all the main relevant technologies that can support its development are considered and investigated. As an example, the Manufuture Roadmap can be considered Application Oriented since its aim is to screen various technological trends and foresight technological evolution that can be adopted for supporting manufacturing in the future. On the other side, a roadmap can be considered Technology oriented when its aim is to outline future research needed in one or multiple referred technology areas. Hence, the emphasis is on how technologies can enable future applications, instead of deriving from future expected applications which specific technologies are needed. In other words, this kind of roadmaps can be considered technology-push since their aim is to improve specific technologies with which future applications could be fulfilled, even if these applications

are not yet much defined or needed during the editing of the roadmap. Roadmaps of this type usually set an agenda for future research on certain technology areas with multiple (possible) applications impacts (Research on embedded systems can have impact on manufacturing, health care, etc.). As an example, Artemis Roadmap can be considered Technology Oriented since starting from a specific technological area (i.e. embedded systems) it outlines various R&D challenges, envisioning a broad spectrum of applications.
It should be noticed that this driver is not meant to be a sound differentiation since some roadmaps could be considered a mix of the two approaches. However, a prevalent orientation of each roadmap can be evaluated and represented helping in understating the differences in purposes.

- *Strategic Level:* this driver depends on the time-frame and on the expected impact level of the roadmap. The more strategic is a roadmap the more long-term and impactful is intended to be. On the other hand, the more strategic is a roadmap the less the challenges arisen can be solved quickly. Usually, High strategic-level roadmaps present future challenges and streams of research that are identified and described not deeply in detail since issues and possible solution are not yet enough clear. As a matter of facts these roadmaps provide *visions* more than *views* of challenges and possible technological solutions. Instead, Low strategic-level roadmaps typically present a list of detailed research challenges needed to solve specific problems that can be well identified and described. Hence, this kind of roadmaps is usually more achievable in middle-short term.

With the help of these two drivers the roadmaps have been analysed and compared in order to obtain a clear (even if not complete) picture of the present state of the art of roadmaps that are published.

3.2 Analysed roadmaps

In this section, some of the most important roadmaps published recently (within the four Technology Areas of SOCRADES) have been reviewed and analysed, clarifying differences in objectives and scopes, by taking into consideration the classification framework previously described. In each roadmap some (technological or industrial) challenges have been identified. For each roadmap the challenges that can somehow involve SOCRADES scope have been identified and counted. They provide inputs for the overall roadmapping process. Moreover, they were counted in order to obtain a first attempt of quantification of which roadmaps will be more relevant for SOCRADES purposes (even if it is clear that a quantification analysis is not enough for fully catching the impact that a roadmap can have on SOCARDES aims). The following roadmaps have been analysed:

- ARTEMIS Strategic Research Agenda [ARTEMIS];
- Manufuture Strategic Research Agenda [Manufuture];
- ITEA Technology Roadmap for Software–Intensive Systems [ITEA];
- Embedded WiSeNts Research Roadmap [Marron et al.];
- ARTIST (Advanced Real-Time Systems) Year2 Roadmaps [ARTIST];
- I*PROMS Summary of Cluster Strategies for Addressing Manufacturing Challenges [I*PROMS];
- Embedded Systems Roadmap 2002: Vision on technology for the future of PROGRESS [Eggermont];
- Enterprise Interoperability Research Roadmap [Enterprise Interoperability];
- HIPEAC (High-Performance Embedded Architecture and Compilation Roadmap) [De Bosschere].

Artemis

The European ARTEMIS (Advanced research and technology in embedded intelligence and systems) Technology Platform was established in June 2004. Its aim was to bring together key players, such as industry, small and medium-sized enterprises, universities, research centres and European public authorities, in the field of Embedded Systems. One of its core tasks was to define a common Strategic Research Agenda (SRA) which acts as a reference for the Embedded Computing domain.

The application contexts considered in ARTEMIS SRA is very broad. ARTEMIS SRA considers:

- Industrial Systems: large, complex and safety critical systems in automotive, aerospace, manufacturing;
- Nomadic Environments: enabling devices to communicate in changing and mobile environments;
- Private Spaces: includes homes, cars and offices for improved enjoyment, comfort, well-being and safety;
- Public Infrastructure: major infrastructures that embrace large scale deployment of systems and services.

The ARTEMIS strategy is to establish common technology to support the development of high value-added Embedded Systems across the wide range of application sectors described above. This common technology has been divided into three categories:

- Reference designs and architectures: standard architectural approaches for a given range of applications to address complexity and build synergies between market sectors. In ARTEMIS SRA view, a well-conceived platform will allow the addition of application-specific modules, thereby increasing the reach of the reference design into more advanced and diverse application domains.
- Seamless connectivity and middleware: that enables seamless connectivity and wide-scale interoperability; 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.
- Systems design methods & tools: for rapid design and development. The objectives are: design efficiency, systematic design, productivity and quality.

In each of these main areas, ARTEMIS SRA indentifies some topics that should be addressed in order to achieve the impacts envisioned in the industrial applications described

above. Among these topics identified in ARTEMIS SRA the authors selected those which fit best in SOCRADES scope. Comprehensively, 15 topics in the three categories (5 in Reference designs and architectures, 4 in Seamless connectivity and middleware, and 6 in Systems design methods & tools) are selected

ARTEMIS SRA is an high-level, strategic roadmap for embedded systems. In the classification framework described above, ARTEMIS SRA can be positioned in high strategic-level and technology-oriented area of the matrix. This roadmap provides many inputs for SOCRADES roadmapping activity.

Manufuture

The Manufuture European Technology Platform was launched in December 2004. The Manufuture Technology Platform aims to provide an analysis and methodology leading to a transformation of European manufacturing industry into a knowledge-based sector capable of competing successfully in the globalised marketplace. Manufuture SRA addresses underlying approaches applicable across a broad spectrum of industries, instead of addressing technology- or sector-specific action plans. Manufuture SRA identifies challenges and future needs on three main topics: products moving to product/services (extended products), innovating production and innovating research. Innovating production, the second main topic of Manufuture SRA, presents four interesting attributes for describing future manufacturing that are relevant in SOCRADES scope. According to Manufuture SRA, innovating manufacturing will be:

- Adaptive manufacturing: responding automatically to changes in the operating environment, integrating innovative processes, overcoming process limitations, and handling the transfer of manufacturing know-how.
- Digital manufacturing: involving the adoption of planning tools, software and ICT, creating a scalable virtual representation of the entire factory (buildings, resources, machines, etc.).
- Networked and integrated manufacturing: cross-company and cross-country operation. Processes will be integrated into dynamic, co-operative manufacturing and value-adding networks, replacing conventional linear sequencing of processes.
- Knowledge-based manufacturing: seamless integration of scientific, technical, and organisational knowledge from all fields of production. Hence, not only making use of knowledge to optimise specific production resources and processes, but also capturing that knowledge and transferring it to other areas where it can be employed.

Manufuture SRA provides 6 characteristics of the mainstreams for future development that are relevant for SOCRADES scope. Moreover within the three main topics (extended products, innovating production and innovating research) several features are relevant for SOCRADES scope, especially within the innovating production scope.

Manufuture SRA is an high-level, strategic roadmap for manufacturing. Moreover it can be considered application-oriented since it starts from market/industrial needs to derive which technological research should be carried out. This roadmap provides important concepts and foresights that are relevant for SOCRADES perspectives.

ITEA

ITEA 2 is an EUREKA Technology cluster [EUREKA] for information technology. ITEA 2 helps bring together partners from large companies, small and medium sized enterprises (SMEs), research institutes and universities in strategic projects for pre-competitive R&D. The ITEA Technology Roadmap for Software-Intensive Systems, develops the shared vision of the technological direction for the programme itself, on the broad topic of Software-intensive Systems and Services (SiS). ITEA Roadmap's focus is on Technology and R&D supporting product development and market targeting. ITEA Technology Roadmap identifies five broad Application Domains:

- Home: activities required in private environment in order to exchange information inside and outside the home and perform the corresponding tasks.
- Cyber enterprise: activities required by people or machines in order to achieve a common goal and/or perform a task together, independent of the organizational and/or geographical location of these people or machines.
- Nomadic: activities required by nomadic actors away from their home or workplace and on the move to exchange information and perform corresponding tasks.
- Intermediation services & infrastructures: activities that required to support the different actors who need to access and manage networks and network services.
- Services & software creation: activities required to help the different actors engaged in designing, implementing, verifying, maintaining and modifying software-intensive products, systems or services.

Moreover, in ITEA Technology Roadmap four Technology clusters are identified:

- Content: whatever is exchanged within the environment of the system or between systems.
- Infrastructures & Basic Services: networking and computer structure consisting of transport mechanisms, protocols, and basic services.
- Human-System Interaction: the interaction between human beings and the appliances and systems that support the services.
- Engineering: embedding software into systems increases their complexity and the complexity of the engineering process. This cluster explores the complexity of engineering processes and deals with the creation of end-to-end services.

In each of these Technology Clusters, ITEA Technology Roadmap indentifies some challenges that should be addressed in the future. Among these topics identified, we selected those which best fit in SOCRADES scope. We selected comprehensively 27 challenges in the four categories (8 in Content, 10 in Infrastructures & Basic Services, and 1 in Human-System Interaction and 8 Engineering).

ITEA Technology Roadmap shows some challenges that can be considered high-strategic level (since they are looking at

the long-term) and others that are more low-strategic level. It is considered technology-oriented since its focus is the information technology with heterogeneous application considered and envisioned.

WiSeNts

The Embedded WiSeNts project was created in September 2004 under IST/FP6 to create a series of studies on the state of the art of Cooperating Objects and to derive a research roadmap. With Cooperating Object, Embedded WiSeNts means entities consisting of sensors, controllers (information processors), or actuators that communicate with each other and are able to achieve, more or less autonomously, a common goal. This research roadmap considers a wide applications' range: Control and Automation, Home and Office, Logistics, Transportation, Environmental Monitoring for Emergency Services, Healthcare, Security and Surveillance, Tourism, Education and Training. Some challenges are identified by Embedded WiSeNts; among them 17 are considered relevant by the authors for SOCRADES scope. The callenges have been grouped into 5 different categories (in brackets the number of challenges considered relevant by the authors for SOCRADES scope): Hardware (3), Algorithms (5), Non-functional Properties (6), Systems (2), Others (1).

Embedded WiSeNts Research Roadmap is mainly focused on Wireless Sensors Networks and generally Cooperating Objects. This is why it is considered Technology-oriented. Moreover, it shows both visions on long-term and short-term challenges; hence it includes both high-strategic and low-strategic level aspects.

ARTIST Year2 Roadmaps

ARTIST is the Network of Excellence on Embedded Systems Design. The strategic objective of the ARTIST Network of Excellence is to strengthen European research in Embedded Systems Design, and promote the emergence of this new multi-disciplinary area. ARTIST Roadmap, published in May 2004, presents four main areas: Hard Real-Time Development Environments, Component-based Design and Integration Platforms, Adaptive Real-Time Systems for Quality of Service Management, Execution Platform. This roadmap presents a survey of selected topics important, based on which, directions for further work are outlined. In this roadmap, 7 challenges identified within the four areas described above, are considered relevant by the authors for SOCARDES scope. ARTIST (Advanced Real-Time Systems) Roadmap can be considered technology-oriented and low-strategic level since its focus is the technological aspects of real-time systems (independently from the application) and since it presents a very detailed view of all the challenges that should be faced in the next years rather than presenting a more generic and long-term view of the trends.

I*PROMS Summary of Cluster Strategies for Addressing Manufacturing Challenges

The Network of Excellence for Innovative Production Machines and Systems (I*PROMS) is funded under the EU Sixth Framework Programme. It focuses research on intelligent and adaptive production machines and systems to realise its vision of the knowledge-based 'Autonomous Factory' for delivering increased competitiveness for manufacturing in 2020. The roadmap, published in November 2007, presents a summary of strategies to be followed in order to realise the "Autonomous Factory" vision of I*PROMS. The roadmap is structured in four integrated clusters spanning the whole field of production equipment and technologies. The four clusters are: Advanced Production Machines (APM), Production Automation and Control (PAC), Innovative Design Technology (IDT), Production Organisation and Management (POM). Within these clusters challenges are identified by I*PROMS; among them 6 are considered much relevant for SOCRADES scope. Especially they are included in the Production Automation and Control (PAC) cluster. I*PROMS Summary of Cluster Strategies for Addressing Manufacturing Challenges is an application-oriented roadmap since it screens some technological challenges needed for specific applications. Since this roadmaps identifies both some long-term and short-terms steps of future research it can be considered both high-strategic and low-strategic level.

Embedded Systems Roadmap: Vision on technology for the future of PROGRESS

PROGRESS, PROGram for Research on Embedded Systems & Software, is a programme carried out by Netherlands Organisation of Scientific Research, Technology Foundation STW and the Dutch Ministry of Economic Affairs. The roadmap's objective is obtaining a clear picture of the essential technology developments for embedded systems and finding the related technology gaps. The scope is restricted to technologies for embedded systems incorporated into information processing, possibly networked, embedding systems. In particular, interaction and information processing are seen as the two most important technology areas for embedded systems. In Embedded Systems Roadmap, some important trends and features have been identified; among them 6 trends are relevant for SOCRADES scope. Embedded Systems Roadmap is considered technology-oriented since its focus is to derive future research needed for embedded systems independently from the application. Moreover, it is mainly low-strategic level since it looks more on the short-term, presenting a detailed list of the present challenges with a clear view of the issues unsolved rather than a description of future trends expected in the long-term.

Enterprise Interoperability Research Roadmap

In autumn 2005, the European Commission launched the definition of a research roadmap in the domain of Enterprise Interoperability. The main objective of the Enterprise Interoperability Research Roadmap is to identify the main areas of research in the domain of Enterprise Interoperability. This Roadmap targets breakthrough research for stimulating and catalysing business innovation. In this Roadmap four relevant Grand Challenges concerning Interoperability have been identified. The following ones are considered relevant within SOCRADES scope:

- Interoperability Service Utility: denote the overall system that provides enterprise interoperability as a utility-like capability. The utility metaphor is to indicate that enterprises should be able to expect and afford basic, interoperable IT as a critical infrastructure for operation, just as water, electricity.
- Future Internet and Enterprise Systems: new Web technologies for Enterprise Interoperability. It seeks to apply concepts and technologies flowing from developments in Web technology to address the problems of Enterprise Interoperability.

Enterprise Interoperability Research Roadmap is considered application-oriented since it focuses on various, heterogeneous technologies that can help for reaching interoperability (specific application). Since it looks both at long-term and short-term, it covers both high-strategic and low-strategic level.

HIPEAC

HiPEAC, the High-Performance Embedded Architecture and Compilation Network of Excellence, was funded by the 6th European Framework Programme (FP6). The HiPEAC roadmap is a research roadmap on high-performance embedded architecture and compilation. In total 55 key challenges organized in 10 themes are listed in this roadmap. Within these themes, several challenges, that are relevant for SOCRADES perspectives, are identified. Challenges particularly relevant within SOCRADES scope are especially in the following themes: single core architecture, multi-core architecture, interconnection networks, run-time systems. Totally, 11 challenges are considered by the authors as relevant for SOCRADES scope. HiPEAC Roadmap is considered technology-oriented since it focus on specific technologies giving future research suggestion, without focusing on specific applications. Moreover, it is considered low-strategic level since it presents a short-term view of the future technological developments needed.

4. CONCLUSIONS

The analysis carried out in this paper shows that there are several roadmaps that deal with SOCRADES scope. Even if these documents are heterogeneous in terms of objectives and perspectives, several inputs are used as starting point for SOCRADES roadmapping activity.

SOCRADES Technology Roadmap exploits the results came out of the analysed roadmaps, going beyond them. SOCRADES Technology Roadmap considers both technology and application perspectives due to the objectives of the projects itself (i.e. to develop a platform for next-generation industrial automation systems). Moreover SOCRADES Technology Roadmap considers both the long-term and short-term perspectives giving insights on the *visions* on the future research needed and also *views* on more detailed and closer steps that are needed to be done.

From the analysis carried out in the previous section, considering the two drivers introduced in section 3.2, the graphic shown in Fig. 2 can be derived. As shown, SOCRADES Technology Roadmap has a central position, assessing both technology and application topics and dealing with high-strategic and low-strategic level issues.

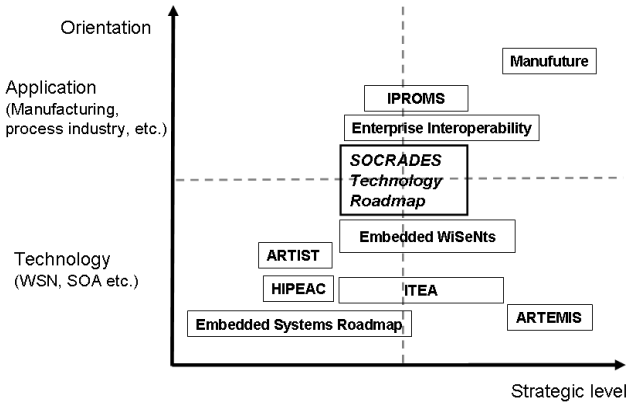

Fig. 2. Positioning of Roadmaps

Further research activities should be conducted for extending the review of available roadmaps and for proceeding with SOCRADES roadmapping activity.

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