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Towards the Factory of the Future: A Service-oriented Cross-layer Infrastructure

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Introduction

The business world is highly competitive, and in order to successfully tackle everyday challenges operational managers and executives demand high dependability and wide visibility into the status of their business process networks. The latest is done usually via business key performance indicators (KPIs). However, in order to provide up-to-date information and be able to react in a flexible and optimal way to changing conditions, real-time information must flow via all layers from the shop floor up to the business process level. In that sense enterprises are moving towards service-oriented infrastructures that bring us one step closer to the vision of real-time enterprises. Applications and business processes are modelled on top of and using an institution-wide or even cross-institutional service landscape. For any solution to be easily integrated in this environment, it must feature a service-based approach.

Currently, shop-floor intelligent systems based on distributed embedded devices concentrate the programming of the behaviour and intelligence on a handful of large monolithic computing resources accompanied by large numbers of dumb devices. The intelligence and behaviour are tailored and individually programmed for each application. However, as we are moving towards the 'Internet of Things' [6], where millions of devices will be interconnected, provide and consume information available on the network and co-operate, new capabilities as well as challenges come into play. As these devices need to inter-operate, the service-oriented approach seems a promising solution, i.e. each device offers its functionality as a service, while in parallel it is possible for it to discover and invoke new functionality from other services on demand [8]. By considering the set of intelligent system units as a conglomerate of distributed, autonomous, intelligent, pro-active, fault-tolerant and reusable units, which operate as a set of co-operating entities, a new dynamic infrastructure that is able to provide a better insight to its components to the higher levels and better react to dynamic business changes can be realised.

As business competitiveness increases, manufacturers are under great pressure to comply with market changes and the constant shortening of the product life cycle. Changes on the factory floor are on daily basis. Traditional methods for production planning are no longer applicable to sustain a profitable business, whether a plant needs to be retrofitted or newly planned. The trend shown in Figure 6.1, i.e. markets evolving from traditional mass production to mass customisation and extreme customisation (lot size ≥ 1) may conflict with the simultaneous demand for high productivity of the factory infrastructure, i.e. demand on production-time and/or time-to-market minimisation, demand for improvement of machine utilisation, and demand on reconfigurability and flexibility of the whole production system, considered as a single collaborative environment [9,10,12].

Lot size ≥ 1 in Figure 6.1 represents the new trend called 'extreme customisation' and indicates a high degree of reconfigurability in the complete manufacturing environment, where each customer requires the production of their own product (generally different from the product manufactured before and from that to be manufactured after).

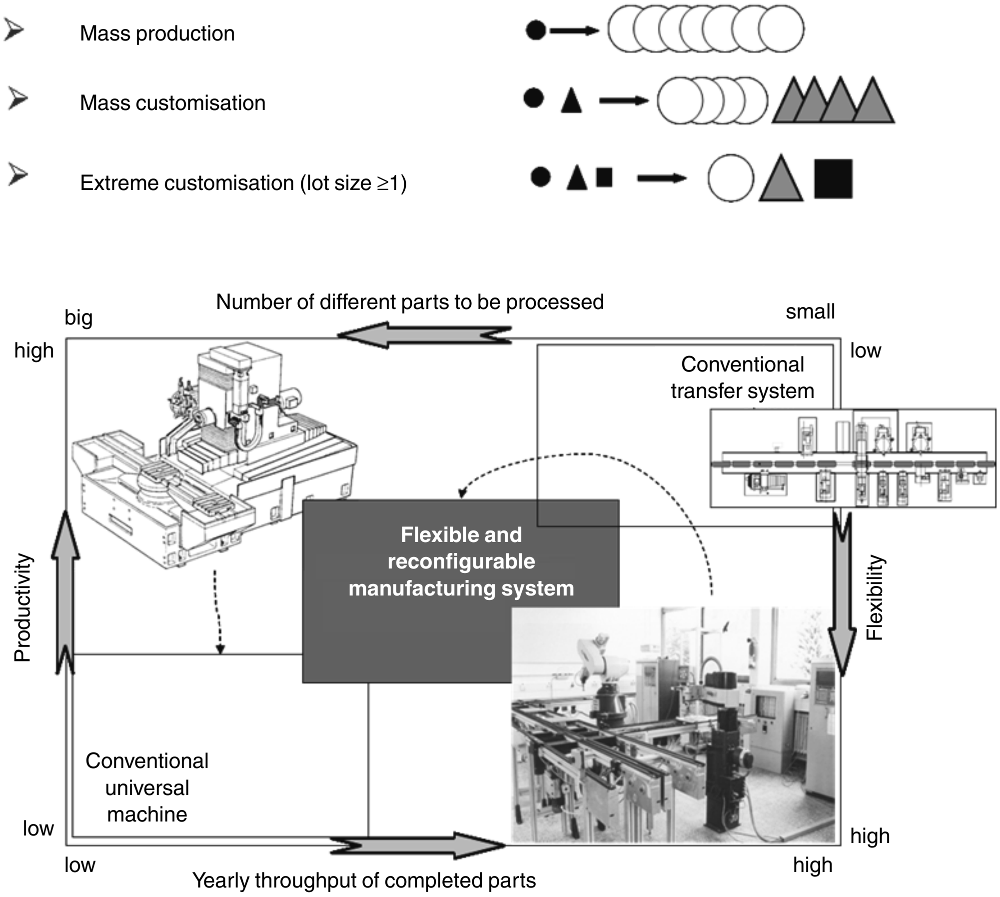

Figure 6.1 Trends in markets and manufacturing systems.

The convergence of solutions and products towards the SoA paradigm adopted for smart embedded devices contributes to the improvement of the reactivity and performance of industrial processes, such as manufacturing, logistics and others. This will lead to information being available 'on demand' and in business-level applications that are able to use them in high-level information for various purposes, such as diagnostics, performance indicators, traceability, etc. These future vertical integration capabilities will also help to reduce the effort required for integration of the affected systems in the sense of the given business scenario.

SoA in the factory: requirements, basic concepts and technologies

The umbrella paradigm underpinning novel collaborative system design is to consider the set of production components as a conglomerate of distributed, autonomous, intelligent, pro-active, fault-tolerant and re-usable automation units, which operate as a set of collaborative/co-operating entities. These entities have the capability of working in a pro-active manner, initiating collaborative actions and dynamically interacting with each other in order to achieve both local and global objectives, down from the physical device control level, up to the higher levels of a business process management system. One consequence of the deep penetration of ICT (information and communication technology) [3,16] is the migration from conventional factory to intelligent manufacturing environments built around the collaborative manufacturing model (CMM) [1,2], the service-oriented architecture (SoA) [17] and the ambient intelligence (AmI) [7,14] paradigms. The result of the confluence of these three main scientific disciplines and the corresponding technologies is now presented as a collaborative system [5]. A collaborative automation unit, building block, offering a service and capable of being asked to offer services, is a mechatronics component with communication capabilities and embedded intelligence. The collaborative unit is able to enter into negotiations with other units in a networked (wired or wireless) environment. This networked environment can be, for example, a modular reconfigurable machine, a reconfigurable production shop floor, etc.

A factory working under this technology–paradigm confluence is composed of workplaces with emphasis on greater user-friendliness, more efficient service support, user-empowerment and support for human interaction. It is a manufacturing environment where workforces are surrounded by a collection of smart distributed components that include mechatronics, control and intelligence (intelligent sensors and data processing units, autonomous, self-tuning and self-repair machines, intuitive multi-modal human machine interfaces, etc.). Under these circumstances, the challenge is to develop production automation and control systems with autonomy and intelligence capabilities for co-operative/collaborative work, agile and fast adaptation to the environment changes, robustness against the occurrence of disturbances, and the easier integration of manufacturing resources and legacy systems.

In essence, the challenge is to create a production automation and control landscape made up of 'convivial technologies' that are easier to live with [4,16]. An aspect that is really important to recall here is that the SoA and the collaborative system are complementary paradigms that result from a multidisciplinary activity, including scientific and technological areas such as knowledge management, production control engineering, information and communication technologies, etc., as depicted on the right-hand side of Figure 6.2. In order to realise SoA and collaborative systems, three main activities have to be performed:

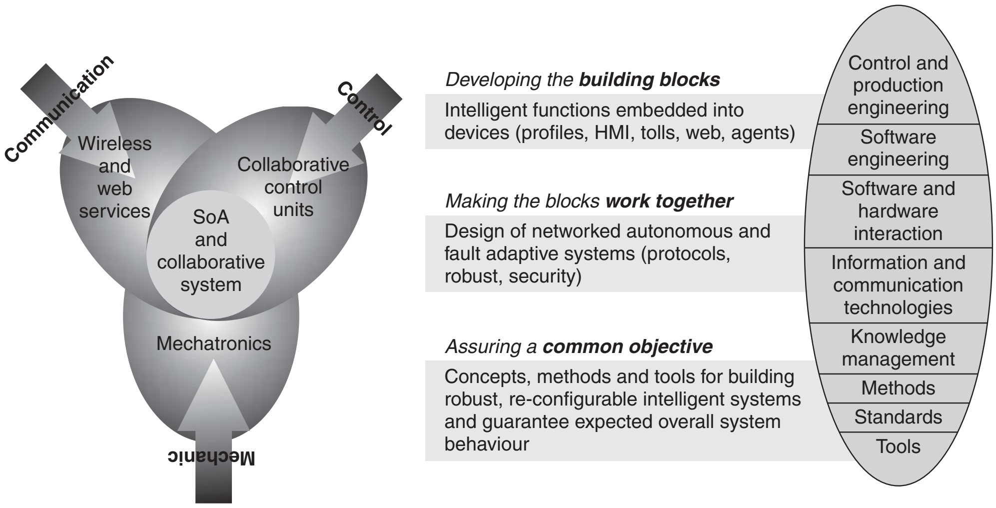

Figure 6.2 Towards a collaborative system.

- the identification of the services and collaborative automation units, for each production scenario in a defined production domain, e.g., electronics assembly, manufacturing, continuous process, etc. A service or a collaborative unit can be a simple intelligent sensor or a part/component of a modular machine, a whole machine and also a complete production system;
- networking/bringing the units together within a SoA or collaborative infrastructure, i.e., putting the units architecturally together; and
- making the units collaborating for reaching common goals, i.e. control objectives, production specifications, markets objectives, etc.

The main technical direction is to create a service-oriented ecosystem (SoA-based ecosystem): networked systems that are composed by smart embedded devices interacting with physical, engineering and organisational environment, pursuing well-defined system goals. Taking the granularity of intelligence to the device level allows intelligent behaviour to be obtained on the shop floor of a factory by composing, aggregating and then orchestrating services offered by configurations of automation devices, engineering systems and ERP. All these systems offer their functions as services (e.g. web services) and are able to introduce incremental fractions of the whole intelligence required for the flexible and agile behaviour of the whole system, within the enterprise/intra- and or inter-enterprise architecture (Figure 6.3).

This approach favours adaptability and rapid (production real-time conditions) reconfigurability, as re-programming of large monolithic systems is replaced by reconfiguring loosely coupled embedded units, across the complete enterprise. From a functional perspective, the main technological challenge is on managing the vastly increased number of intelligent devices and systems and mastering the associated complexity that emerges from the architectural and behavioural specifications of the factory shop floor. In this sense, from a run-time infrastructure viewpoint, the shop floor is now considered as a heterogeneous set of a new breed of very

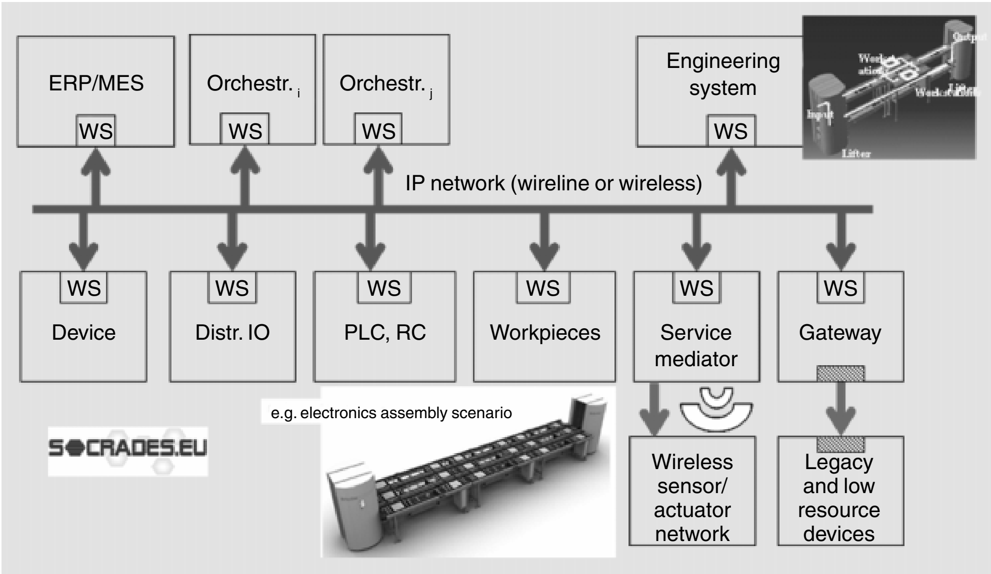

Figure 6.3 Web service based future factory.

flexible real-time embedded devices (wired or wireless) that are fault-tolerant, reconfigurable, safe and secure, and that are exposing their functionality as a set of web services. Auto-configuration management is then addressed through basic plug-in, plug-and-work/run and plug-out mechanisms. This functional perspective must be applied to several types of devices, used in automation systems, automotive electronics, telecommunications equipment, building controls, home automation, telemetry, medical instrumentation, etc.

A cross-layer architecture: from the shop floor to the ERP

To realise the real-time enterprise, we must create a strong coupling of the enterprise concepts domain and the device-level service domain. Nowadays, there is a very limited co-operation among the two layers which in practice translates to weak coupling of the enterprise resource planning (ERP) with the manufacturing execution system (MES) and distributed control system (DCS). One of the key steps is to focus 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 ERP systems – in order to demonstrate seamless integration of device-level functionality into higher-order business application scenarios in manufacturing, logistics, or similar areas.

A promising approach is to create collective system intelligence by a large population of small and networked embedded devices at a high level of granularity, as opposed to the traditional approach of focusing intelligence on a few large and monolithic applications. This increased granularity of intelligence distributed among loosely coupled intelligent physical objects facilitates the adaptability and reconfigurability of the system, allowing it to meet business demands not foreseen at the time of design.

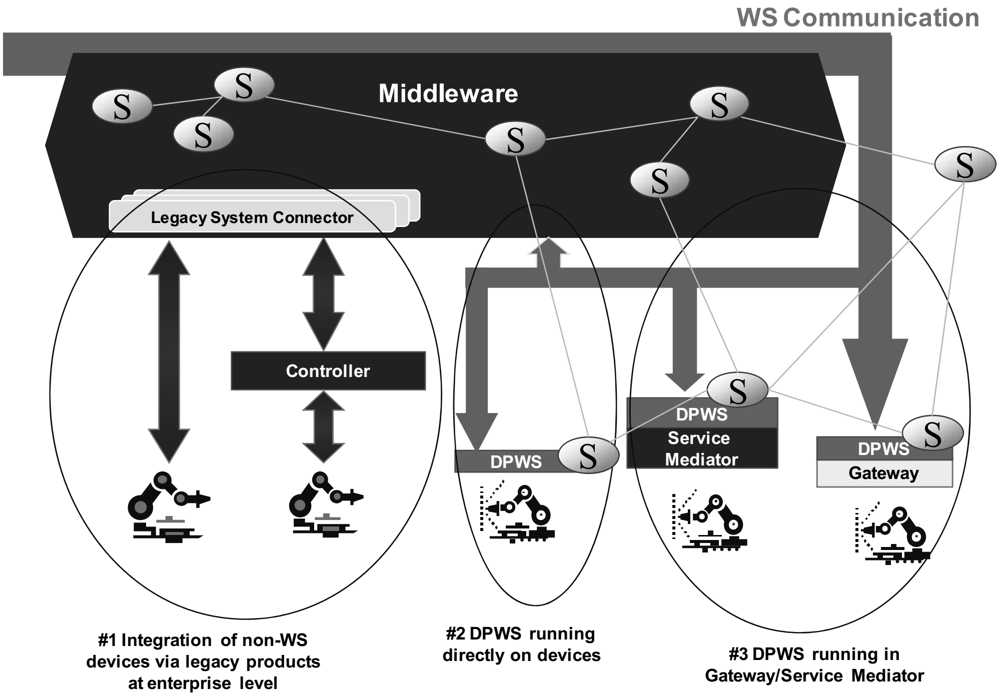

Figure 6.4 Device integration options.

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. The benefits of service orientation are conveyed all the way to the device level, facilitating the discovery and composition of applications by re-configuration rather than re-programming. Dynamic self-configuration of smart embedded devices using loosely coupled services provides significant advantages for highly dynamic and *ad hoc* distributed applications, as opposed to the use of more rigid technologies such as those based on distributed objects.

Integration of devices within a web service infrastructure can be realised generally in three different ways (Figure 6.4).

- We can use existing approaches for connecting to legacy devices, and then wrap at middleware or ERP level part of their functionality and offer it as service(s). In this scheme the middleware connects directly to the legacy system connectors using a predefined (proprietary) protocol.
- The devices runs web services natively, e.g. by implementing DPWS. We expect that in the near future the majority of the devices will be able to offer their functionality as a service, e.g. via a web service. In that sense the integration is painless and straightforward.
- The devices' functionalities are wrapped by another WS enabled device one or more layers above. This is the typical case for a Gateway or a service mediator (e.g. an MES system).

In the ‘Gateway’ method, the non-WS enabled device is hidden by an intelligent proxy called a gateway (also known as a surrogate). Such a component basically understands the device’s proprietary protocol and exposes a DPWS interface. As such it can be addressed as any other service and hides the fact that the device it stands for is not WS-enabled. The mediator concept is somewhat similar. Although the gateway mainly focuses on explicit devices, the service mediator focuses on services independent of the number of devices needed to support the specific service. It aggregates these devices and manages the communication flow between the clients and devices by offering a DPWS end-point.

The architecture proposed [11] (Figure 6.5) clearly shows how the several layers between the business applications and the field devices could be interconnected. This interconnection allows business applications to get a real-time view of the shop floor activities, and be able to even communicate explicitly with devices. This is done via the WS relevant technologies such as DPWS or OPC-UA, which are natively implemented in all devices, allowing them to be part of a service-oriented infrastructure. However, not all devices are expected to host such

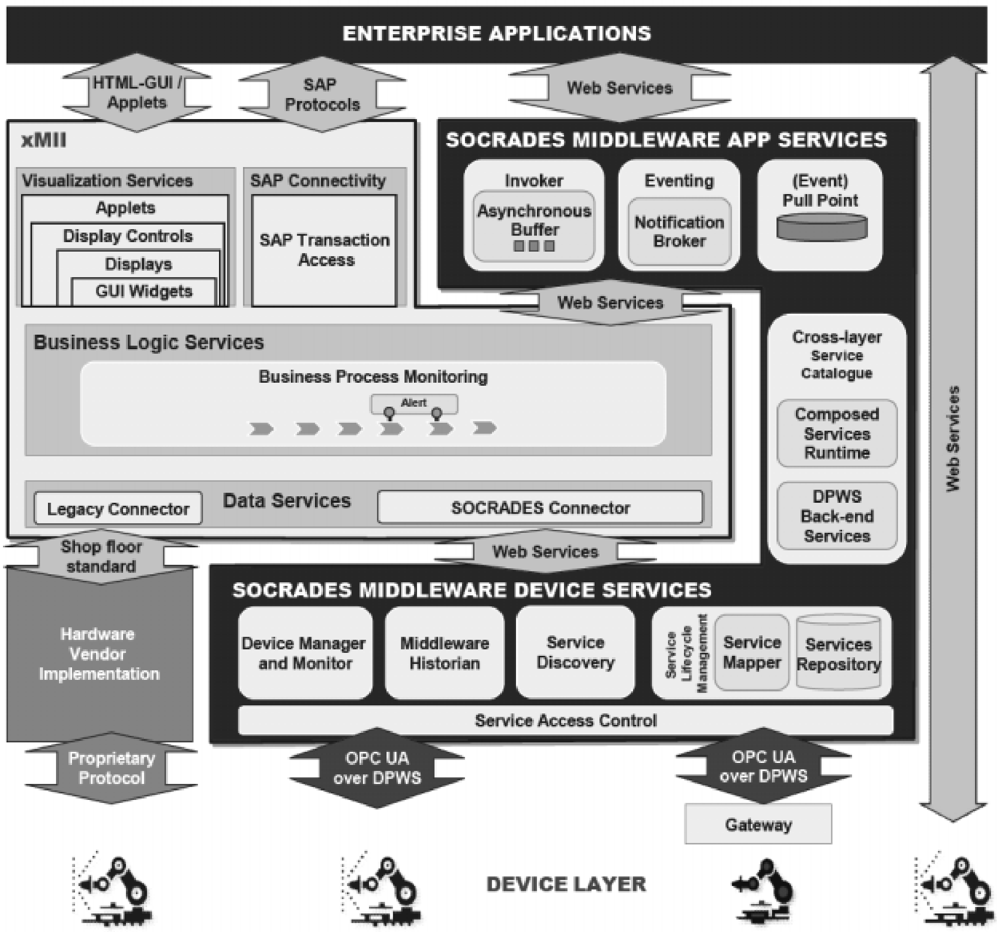

Figure 6.5 A cross-layer integration architecture [11].

WS protocols, therefore the integration architecture accommodates also the integration of legacy and non-web service enabled devices as well via a pluggable and extensible framework. Furthermore, it shows how existing COTS products such as SAP MII can be used and integrated in order to build on top of existing approaches and enhance the legacy infrastructure without drastic changes that could interrupt the line of business.

Although a direct access from the ERP system to the devices is possible, the middleware improves on the management of the shop floor devices through the addition of the following functionalities.

- Brokered access to devices: this is provided through asynchronous invocations and the use of pull point for handling events.
- Service discovery: the service discovery provides the means for ERP systems to discover devices when no access to the shop floor network is available.
- Device supervision: two components provide the main information about all the DPWS devices available in the system: device management and monitor and middleware historian.
- Service lifecycle management: the management of the services running on devices is handled through the use of the service mapper and services repository. These components together make a selection of the software that should run in each device and perform the deployment.
- Cross-layer service catalogue: two components will on the one hand execute descriptions of composed services that use service of all layers and on the other hand will allow DPWS devices to access enterprise-level back-end services through a DPWS client.

A fundamental goal is to enable the integration of device-level services with enterprise systems. This goal will require the definition of new integration concepts taking into account the emerging requirements of business applications and the explosion of available information from the device level. Of particular interest is the availability of real-time event information, which will be used to specify new enterprise integration approaches for applications such as business activity monitoring (BAM), overall equipment effectiveness (OEE), maintenance optimisation, etc.

Discussions and future directions

The device number and heterogeneity on the shop floor will increase. The same will hold true for the services created at enterprise or intermediate levels between the shop floor and back-end systems. As devices are getting more powerful and with advanced networking capabilities, they will offer their functionality as a service. This will lead to numerous services coming from large numbers of devices, whose composition will offer much better and more accurate coupling of the physical and the virtual worlds. Business applications will benefit from this, and since their co-operation with all entities involved will increase, we will move towards a real-time enterprise that will be agile to take up the challenges of the future [13]. We will witness the creation of mashups and complex service compositions that will spawn several layers and that can be discovered and combined on the fly (Figure 6.6). In that sense, devices will be both consumers and providers of services, and will be able to take advantage of co-operation capabilities with

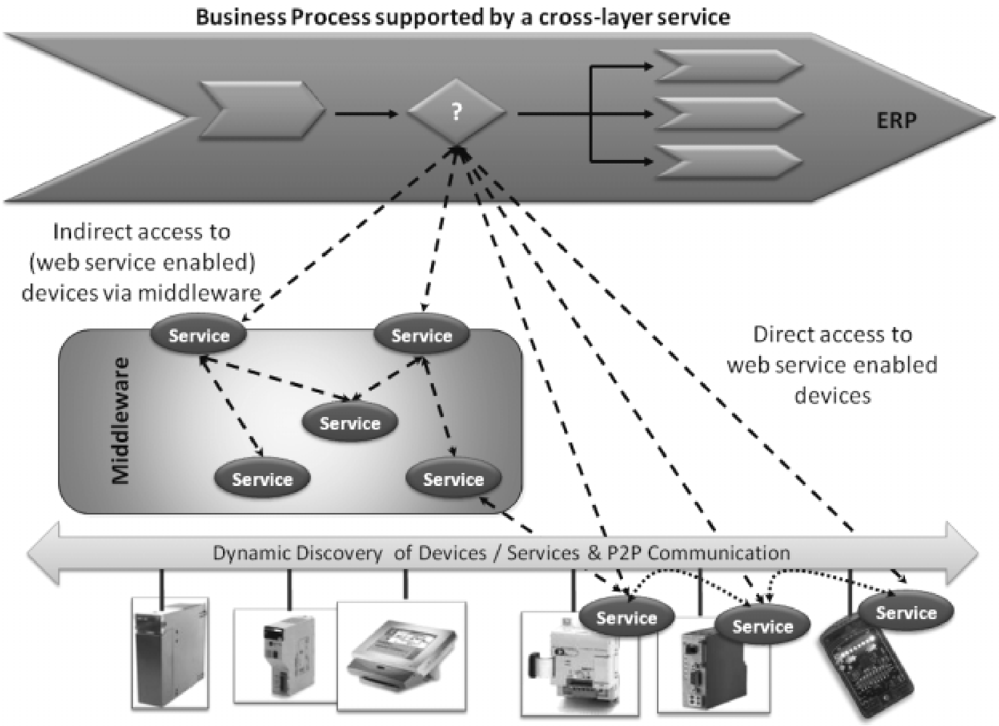

Figure 6.6 Cyber-physical cross-layer service mashups.

services relying on other devices or back-end systems. The last will enable them to become active players in the highly dynamic infrastructure of the future factory. Having such a dynamic infrastructure has a significant effect on the way we design and implement enterprise services and applications. Increasing amount of information coming from the shop floor can enhance existing approaches such as remote diagnosis, maintenance, etc.

Although it is not easy to introduce a new technology in the conservative control and automation markets, it is extremely necessary from the marketing aspects of the SoA and collaborative automation to have identifiable service-oriented automation products with added value, and from the economical perspective to provide economical solutions avoiding additional hardware costs. Fortunately in control technology there is already a trend to integrate different control technologies customised on standard hardware platforms.

A prospective marketing strategy can use this trend to create product scenarios for applications to guide the technical development of platforms under the perspective of service-oriented controlled manufacturing networks.

On one side, service-oriented control for manufacturing is a system technology fundamentally different than the conventional process-oriented control technology. Under the customer's perspective the migration is therefore not a step-by-step process of continuous improvement but a radical change in the manufacturing line design and operation. The development and application of migration techniques, methods and tools matching the newest production automation and control paradigms should be the main challenge for researchers, production control technology developers and also end-users. Control manufacturers have therefore to provide a complete system technology adaptable to a variety of processes and manufacturing structures. On the other side, a roadmap for service-oriented manufacturing automation products must take into account that there is no market need for singular control products. To offer profitable solutions a complete system technology including suitable platforms must be developed in the next 10–15 years time span.

SoA technology: engineering platform

In the first step it is sufficient to define specification of mechanisms to develop SoA-based production control systems in order to obtain new interdisciplinary engineering technologies. In addition, the definition of service interface functions for the processes, to ensure independence from low-level implementation details of communication links and protocols, is necessary for the creation of plug-and-play functional middleware.

At the same time, the definition of human–machine interfaces (HMIs) to integrate appropriately human skills at all functional levels of the SoA-based architecture as well as the definition of human–service interfaces to incorporate human workplaces within the production system should be considered. Subsequently several actions need to follow.

Mature software/hardware development of new interdisciplinary engineering methodologies and tools needs to be realised.

Encapsulation of hardware (mechatronics), control software and intelligence in smart mechatronics components offering ‘services’ in a collaborative SoA-based environment is depicted in Figure 6.7.

The use of such smart mechatronics components will allow automatic reconfiguration of processes by simply plugging new devices (offering services) into the shop floor. As Figure 6.7 shows:

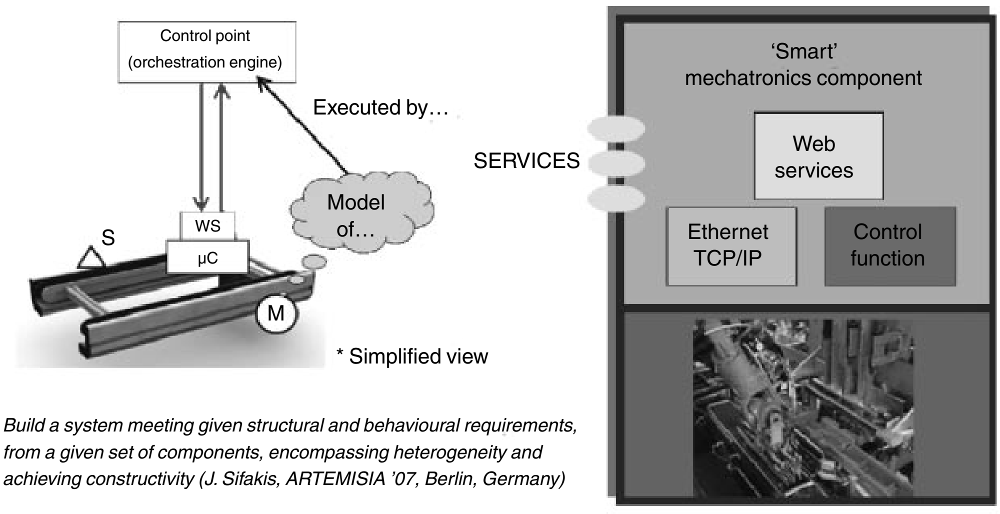

Figure 6.7 Manufacturing equipment offering services.

- mechatronic transport device offers transport functions
- operations are exposed as Web Service (Transfer Interface): TransferIn(int p), TransferOut(int p), TransferStop(), TransferInCompleted(Pallet p), GetStatus(Status s), …
- device offers additionally DPWS standard plug and play functions for description and discovery of the device/transfer service
- the services offered by the eco-system of smart mechatronics components have to be orchestrated and the complete behaviour of the manufacturing system controlled in such a way that the production and automation goals will be reached in a collaborative manner.

Figure 6.8 presents the first results of applying the SoA technology to the componentisation of a flexible assembly cell, as it has been specified, developed and implemented in the EU FP6 STREP Project 'Integrated ambient intelligence and knowledge-based services for complex manufacturing and assembly lines – Inlife'. The assembly cell is transformed in a SoA platform, where each mechatronics component has a defined role as 'service consumer' and/or 'service provider'.

Note 1: There are consumers and or providers of atomic or composed/aggregated services, e.g. a robot provides the atomic service 'place' and a gripper the atomic service 'pick', then a piece/product/pallet can ask for the composed service 'pick & place'. That composed service is provided by the mechatronics configuration robot–gripper. This configuration is generated by the coalition leader, i.e. it is a SoA-component in charge of composing and orchestrating 'services'. In another example, a pallet moving on a transport system is acting as coalition leader (orchestrator) each time that it is calling for the atomic and composed 'transport services' provided by the different transport elements of the system.

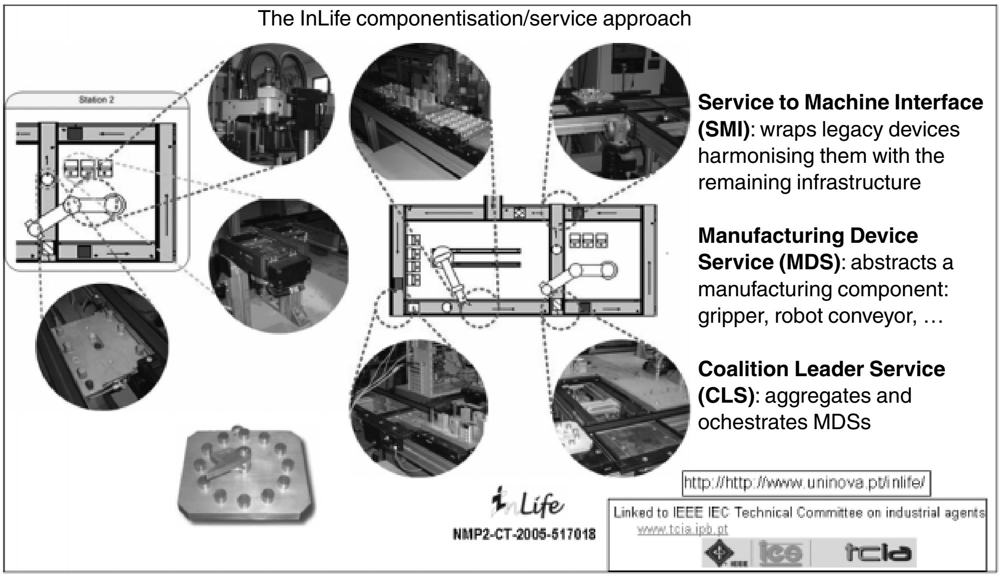

Figure 6.8 The Inlife/SoA approach.

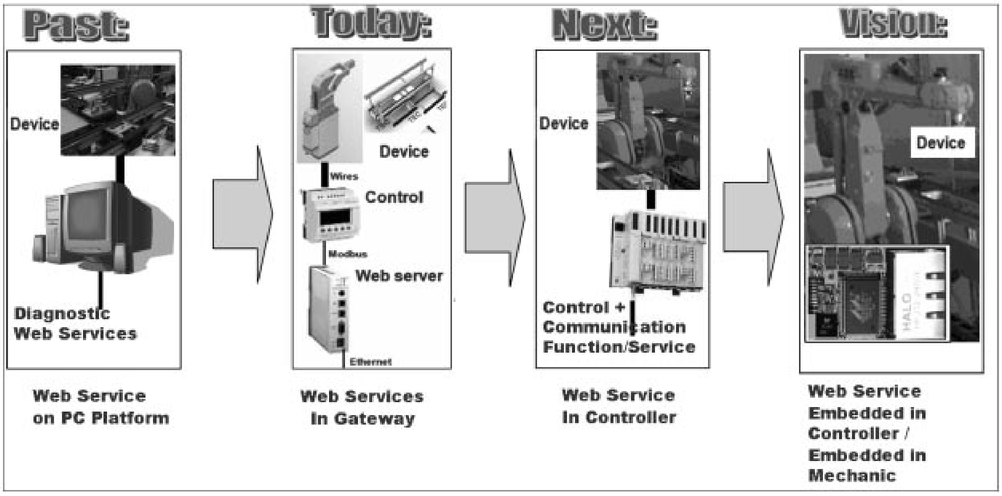

Figure 6.9 The SoA-technological evolving shop floor.

Integration of information, control and communication

It is clear that information, control and communication will have to be more tightly coupled in a service-oriented way and embedded more and more into the manufacturing devices/systems (Figure 6.9). This implies user interfaces for decision support in the planning, implementation and operation phases of SoA-based control systems. SoA-based components must be integrated in the digital factory offering wireless communication and Internet technologies.

The interoperability of control systems and mechatronic components is necessary to allow integration of components from various vendors.

For the realisation of a 'SoA-based automation platform' for easy integration of software modules we need a web service based communication framework enabling the integration of external real-time critical and non real-time critical control components; also the methodologies, algorithms and tools that support the structured specification, analysis, design, testing, project work, configuration, maintenance and recycle of the whole control system.

Note that the interoperability of heterogeneous devices is provided by following a ubiquitous service-oriented approach, which provides opaque interfaces and facilitates discovery and composition of resources.

Interoperability at the semantic level is enabled by employing machine-interpretable semantic mark-up, which is used by intelligent physical agents to reason and infer the skills and services offered by other devices, and collaborate towards common goals. Managing semantic interoperability and auto-configuration is definitely an ambitious task. Starting points are field bus device profiles, which have a common foundation in the IEC 62390 Device Profile Guideline.

SoA-based production systems engineering

The need for specification and implementation of SoA-based production systems that can efficiently tackle domain-specific problems is needed. Several questions arise with respect to machine aggregation, especially the new generation of intelligent machinery and systems, manual work places and material found on a shop floor to production units which are optimal to take over the role of SoA-based control and automation units. To that end we need to develop an engineering and control environment approach to support the implementation of an intelligent distributed architecture with real-time 'shop-floor' distributed control and dynamic scheduling functions. An engineering framework for SoA-based controls in different industrial application domains based on already existing solutions must come as an evolutionary step. The definition of granularity of SoA-based production systems, from an intelligent sensor (that can act as a collaborative unit exposing services and be able to call for services) throughout an intelligent machine (that can act as a collaborative unit exposing services and able to call for services) till the upper levels of an enterprise (that can act as a collaborative unit exposing services and able to call for services) needs to be realised. Capabilities provided by a manufacturing device should be advertised as services, not as objects; a service should be entirely described by its interface, i.e. the format of the messages flowing into and out of the device, the implementation of this interface being totally opaque. Message exchanges should be asynchronous. This enables platform-neutrality, increases flexibility, adaptability to change and scalability, reduces development cost and time as re-use is facilitated, enables new device networking paradigms through peer-to-peer communications, and allows real-time access to the necessary information and knowledge. Methods and tools for the definition of services in industrial production scenarios must be created. Analysis of the production process at the shop floor and designing an environment that lets end-user easily add service-based automation systems to the shop floor is needed. Knowledge and initial tools for successful, safe and efficient migration of intelligent service-based automation and control techniques in a variety of production scenarios must be provided.

SoA integration with legacy systems

Due to the fact that legacy ERP and MES systems are widely used in the industry and these systems set already common standards, there is a need for a service-based integration. The service model is already dominant in ERP systems and business world, and by pushing it down to the MES or device level wrapping the legacy infrastructure, better integration can be achieved. However, this implies evaluating the integration aspects of the new technology in a variety of customer production scenarios. Support of existent intelligent supervisory control functions and components with service-based decision support systems: inventory control, diagnosis, monitoring, maintenance, etc. should be added. Developing hybrid and cross-layer system architectures and investigating the appropriate grade of decentralisation is another issue to tackle.

SoA-based components interoperability

The variation of interfaces and components used in industries leads to the need for standardisation and interoperability, especially for the acceptance of SoA. Several challenges arise here. Providing knowledge, methods and tools to facilitate the interoperability of different SoA systems to finally reach a plug-and-play functionality is the first step. Providing reference ontologies for service-based production systems in different industrial scenarios, as well as comparison between particular ontologies, and development of methods and tools to facilitate successful communication between SoA systems with disparate ontologies would further increase collaboration. Facilitation of interoperability of SoA-based automation and control systems produced/generated by different vendors would minimise isolated islands at the shop floor. Furthermore, communication standards for ontologies, standardised functional units/ modules especially for the field of production systems need to be developed.

Marketing confidence and trust in SoA-based control and automation systems

Internet technologies will dominate the shop floor; however, most factory managers associate them with the Internet itself and do not trust or fear this exposure. We need to market the new concepts in the right way and context, and in parallel work towards increasing the trust and confidence in them.

The majority of controls today are process-oriented systems where the PLCs are dominating the market. They are offered and used in a large variety of performance and characteristics. Other important process-oriented controllers are NC and CNC, regulators and drives. The direct implementation of service-based collaborative automation technology to these types of controllers would lead to an exploding catalogue of components. Even with this high number of individual products, most of the applications would not be realisable because of the lack of a general service-based control system to represent physical units which are not controlled in conventional technology. Also the interoperability required for SoA-based manufacturing systems is expensive to achieve for these very different hardware concepts and the necessary standards are difficult to integrate.

Therefore, the marketing for SoA-based collaborative controls must include the perspective of a new type of control where the different physical functionality of a manufacturing module can be realised on a set of common platforms with unique architecture. A SoA-based control product program must consist of a series of controllers, which are configurable to control a broad range of different physical processes and can combine the traditional functions of industrial controllers with new concepts like HMI, quality monitoring and control and extensive data processing. The product differentiation for SoA-based controls is by performance under the perspective of a generalised profile instead of different physical control categories.

In that sense we need to generate a catalogue that will provide an overview on the European and worldwide status of SoA-based applications. Providing a structure and data on existing SoA-based technologies and systems, both in industry and applied research, will help monitoring. Industrial-oriented research with strong collaboration between academia and industry will facilitate better technology transfers and tackling of real-world problems as SoA-based automation methods and problems should be based on existent industrial experiences. Providing knowledge and initial tools for successful, safe and efficient migration of intelligent SoA-based automation and control techniques, applying the new taxonomies for SoA-based production in a variety of European production scenarios would also increase confidence. Furthermore, we should accommodate the building of demonstrator environments where the European industry will be able to build and demonstrate final products, and where control of manufacturing sequences by means of negotiation and autonomous decision incorporated as an inherent co-ordination function in manufacturing entities like machines and manual workplaces can be realised. These new functions of SoA-based production components replace the logical programming of manufacturing sequences and supervisory functions. Finally, we need to develop new methods of software testing and benchmarking, and investigate possibilities to predict the emergent characteristics of SoA-based automation.

Conclusions

Enterprise applications support business activities in companies, so that they can manage complexity and be more effective. The service-oriented architecture (SoA) concepts empower modern enterprises and provide them with flexibility and agility. These concepts nowadays expand towards the shop floor activities, down to the device level. By implementing web services on the devices natively, we are able to push down at item level SoA concepts. The use of device-level and cross-layer SoA contributes to the creation of an open, flexible and agile environment, by extending the scope of the collaborative architecture approach addressed before through the application of a unique communication infrastructure, down from the lowest levels of the device hierarchy up into the manufacturing enterprise's higher-level business process management systems. For the technology developers, the specification, design and implementation of the components of the SoA infrastructure is a big challenge and a multi-disciplinary task, and for the customers of that technology (the factory) it is now possible to foresee, among others, a comprehensive set of values, as shown in Figure 6.10.

It is clear that we are heading towards an infrastructure where heterogeneity will be dominant and not all devices will have the capability of hosting DPWS and providing their functionality as a service to others. In fact, the last might not only be infeasible due to technological constraints, but it also might not make sense from the business point of view. Therefore any approach proposed for the future manufacturing domain has to make sure that all types of devices can be directly and indirectly integrated in a global communication infrastructure. To that sense, there is the need for a cross-layer collaborative infrastructure that is open for extensions to unknown devices and/or aggregation of devices, able to use uniform protocols for vertical and horizontal, peer-to-peer asynchronous communication, and able to use wired and wireless communication media.

Towards a complete decentralised and cross-layer integrated SoA-based factory

Addressing customer values (I): applications with SoA and WS to the factory

- Decentralised, non-hierarchical, flat application
- No gateway, no specific interface
- Uniform communication protocols
- Vertical and horizontal communication
- Peer to peer asynchronous communication
- High-level, self-describing, real-time protocols
- Service-based integration of the shop floors into the intra- and inter-enterprise architecture

Addressing customer values (II): reconfigurability/flexibility in the factory

- Dynamically add new devices, functions, machines
- Duplicate machines or manufacturing lines (by 'copy and paste' in the design tool)
- Automatically build the application by assembling mechatronics devices
- Full plug-and-play/run at the application level
- Detect and manage manufactured pieces of equipment

Figure 6.10 Customer values if a factory is SoA-based working.

Providing web services on the shop floor is effectively bringing the business logic closer to it. The near real-time use of data created on the shop floor serve as parameters to make timely decisions on the next operation of the processes with or without human intervention. As such visibility in the whole enterprise is increasing, now events happening are quickly propagated to the relevant services and applications that affect them. However, when the number of devices and services increases on the shop floor, it is often difficult to have an overview on them. Scalability needs to be checked; especially due to the fact that we usually deal with embedded, and hence resource constrained, devices. Semantics pose another significant challenge, as the understanding of the data delivered by web service enabled devices needs to be automated and universal. Additionally, these services have to be governed and regulated to reflect the process flow of an operation – which calls for more research in this area.

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