

# Adding Factory Floor Automation to Digital Ecosystems; tools, technology and transformation.

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**Abstract**—This paper presents research from the Process Definition Tools implementation at Loughborough University, which is an automated manufacturing testbed that has been integrated into a Service Orientated Architecture (SOA). The enablement of this SOA in terms of Digital Business Ecosystem (DBE) research presents new applications to SME's that support, require and supply automated manufacturing systems. These new applications and characteristics in the context of Digital Ecosystem tools, technologies and general architectural changes are examined. In particular new opportunities in virtualisation of automation and integration at both lower and higher levels of distributed applications are presented in a transformed view of a DBE.

**Index Terms**— Automation, SOA, Manufacturing, Introduction

## I. INTRODUCTION

Web Services and hardware development have combined to place factory floor level devices within the reach of large scale distributed computing applications. In terms of new SOA development this new dimension in potential services presents new possibilities in Digital Ecosystems. These can be seen to stem from increased application pervasiveness via the SOA enablement of the Factory floor that will introduce new services and service providers into DBE based applications.

Investigating this new DBE enablement this paper examines the new structures that could be formed in DBE's in terms of the new users, service providers and applications. In particular these new DBE features are proposed and placed within a the context of typical DBE architectures. This is done using experience from research projects into SOA enablement of factory floor level devices at Loughborough University.

The paper uses a three layer examination of the impacts of factory floor automation on the DBE. Initially the advances in enabling devices from the perspective of the manufacturer are presented. This examines the technology that is to enable SOA based automation and how it is likely to be deployed. The new functions that this enablement presents to the DBE is examined, with a focus on new application areas likely to effect the future structures of DBE's using factory floor level services.

## II. RELATED WORK

*A.. Motivation behind the Web Services (WS) enablement of PLC's and factory floor elements.*

Manufacturers are seeking more agile, flexible and adaptive approaches to their production systems as well as encompassing customers as a part of the business process [1]. The modern production system model must be able to cope with these changes and comply with small quantities of highly customised design-to-order products, where additional services and value-added benefits like product upgrades and future reconfigurations are as important as the product itself. [2].

The need for a SOA enablement of devices on the factory floor has emerged from research into the improvement of automation of factory process. In particular within advanced western economies the need to have flexible production lines able to specify and react effectively to change is a key factor in enabling the production of high quality value added products that this sector is focused on. Within this research elements such as basic Robotics and manufacturing assembly has been the focus of work looking to introduce greater automation and reconfiguration [20]

The SOCRADES [3], SODA [4] and SIRENA [5] project within the EU have taken significant steps in the initial investigation of SOA enablement and support of factory floor level devices in distributed automation applications. These projects are focused at the enablement of SOA within factory floor elements. As this enablement is starting to be defined and applied in test environments in these and similar projects the impacts on SOA based applications in general can begin to be analysed.

*B. Significance to the Digital Business Ecosystem*

There are more than 228000 manufacturing Small to Medium Enterprises (SMEs) in the EU, at the Lisbon summit in 2003 research efforts were agreed at focusing knowledge based manufacturing [6]. An important part of this was the commitment of funds to support investigation into Digital Business Ecosystems in the EU. A digital business Ecosystem can commonly be seen as mechanism by which SMEs, are provided with applications consisting of distributed services normally out of there reach due to lack of resources or skills.

A popular application area has been within ICT based applications and knowledge sharing such to support supply chain management and specialised processing of data [7,8].

The key technical enabler of these distributed environments has been advances in web services and the provision of SOA based resource sharing. To date many DBE exist at what can be seen as the middleware of the distributed computing model, and often link applications and data.

Motivations behind the growth and evolution of DBE can be seen as centred in two main areas, these can be seen as technical and organisational. In terms of the organisation an main proponent of DBE development particularly in the EU has been governmental organisations. These DBE's are formed with the aim to promote the development of and sharing of skills in specific communities SME's. For example the EU's vision of DBE' forms along socio economic boundaries to promote innovation and development in industries and localities improving European competitiveness [9,10]. This vision is not specifically technical but focused on supporting innovation in the distributed collaboration enabled by the DBE.

In order for DBE's to develop technically the new business models that they promote have attracted software development in both the commercial and open source community. This is often linked to genuine commercial motivation where the provision of software to support the DBE can present vendors like SAP with larger sets of users, developers and potential customers to DBE based products. An approach that has presented companied like SAP with new business models, where a ecosystem could be built as SAP components around SAP products such as NetWeaver [11]. With the ecosystem enabling thousands of independent developers to start writing specialized programs that plug into the NetWeaver framework. The same model can also be seen to apply in the Open Source DBE vision. Where the enablement of a DBE using Open Source software can introduce new developers and users to the software [12].

Therefore the DBE like the development of SOA in factory automation is motivated by social economic goal of increasing skills and competitiveness in regional economies. Furthermore the technical enablement of the DBE like in factory automation promises new business opportunities for software providers. Combined within the DBE this combination of business and technical innovation will have a significant impact in DBE use and development. To date within the field of industrial automation the enablement of factory floor elements the use of DBE type applications is yet to become an established commercial model. However as distributed applications emerge around the next generation of SOA based automation the DBE's is likely to adapt and form around this technology. Integration of this factory floor level data in many DBE's will give the applications greater depth and completeness.

### III. ENABLING DEVICES

#### A. Device Profile for Web Services .

Nowadays globalisation, emergent technologies and customer demands require flexible operation on a global scale as well as agile, flexible and adaptive manufacturing control. In response to these rapid, continuous and unpredictable changes organisations should embrace a flexible, adaptive, collaborative, and responsive paradigm. The key en-

abler is the integration of automation systems with other business entities including marketing, engineering, product design, business process management and personnel. However, the integration of a business enterprise with its shop-floor and with business partners correctly is largely achieved via the use of proprietary complex systems due to disparate technologies being used in manufacturing systems and business enterprise [13]. In addition, lack of standardised technologies and interoperability are main obstacles in effectively integrating the enterprise among business partners, thus hindering integration with DBEs.

Recently, the SOA and WS approach has been proposed by a number of researches as mentioned earlier to enhance networked organisations to support the required dynamic networking of the inter- and intra- business collaborators into the factory floor environment. This would enable this level of knowledge and information to be seamlessly shared and accessed through the use of standardised web technologies. Thus the use of SOA hold the potential to break the integration chains of proprietary and legacy software that is surrounding factory automation systems, and preventing them from joining effective DBEs.

The implementation technology to support the dynamic changes from the business and management level of integrating the shop floor is generally recognised will be achieved via SOA enabled by DPWS (Device Profile For Web Services) [14,15]. DPWS is a light-weight protocol stack that enables the service discovery and message passing to the higher local and remote control level. The protocol can be implemented at control devices (PLC, Embedded devices). The protocol is defined with WS-, SOAP-XML, WSDL, UDDI, and TCP/IP/UDP/HTTP stacks and it is becoming the standard for the industrial network application and has its main implementations in the home electronics / consumer computing area [23]. This DPWS protocol will allow automation devices to be directly integrated with high-level manufacturing systems and business supply chains.

The vision of the application of DPWS will be a design of control systems into the distributed application paradigms, and ubiquitous computing environments to enable flexible, reusable, reconfigurable manufacturing systems based on self-reliant, interconnected smart embedded devices [17].

Using the SOA enablement of factory elements these challenges can be addressed potentially in DBE architectures. At Loughborough we have started this investigation in terms of our PDE Tools project. This will now be discussed.

#### B. PDE Tools

An emerging trend to adopt the Web services approach on the automation device as proposed in [15, 16, and 17] enables the creation of the DBE system. Its concept of WS-DPWS is to include the plant activity into the enterprise to facilitate work synchronization between the high and low level applications. This is an conceptual idea to provide the capability to develop distributed applications in diverse real-time computing environments in many business and

automation disciplines including the automotive industry, building automation industry, to name a few.

As we have mentioned DPWS in section 3.1 and it is being developed as the main tool to implement the next generation of factory automation systems. However to date the research into DPWS is yet to yield any significant implementations. In order to advance into this area, initial investigations at Loughborough into the leverage of SOA within manufacturing process have been completed.

The PDE (Process Definition Editor) tool developed at Loughborough University [18] contributes a significant role in the design of control application and visualisation at run/design time to ease the design and (re) configuration of the manufacturing process. Currently the tool includes the ability to communicate with factory level elements through web based technologies bridged to PLC's. The further development on this tool will be to support its applications using DPWS.

PDE architecture consists of a library of device profiles and a storage service that stores the data from previous executions of the elements. The elements are visualised in the PDE tool and these visualisations are linked to the device profiles and saved automated layouts that consist of multiple elements. At the moment the data into the PDE is taken from the PLC controllers of the automation line, a overview of the PDE testbed can be seen in Figure 1.

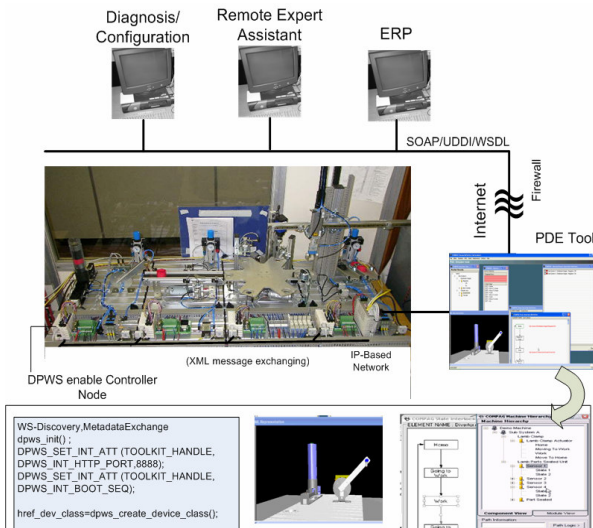


Fig 1: Overview of PDE Test Bed.

DPWS support will present the software with a standardised SOA architecture and will enhance its possible interfaces to higher systems. Currently a SOA can be seen to exist as in that common interfaces to the PLC are exposed making the invocation of the PLC possible as a distributed service. Adoption of the PDE tool to interface directly with devices instead of the PLC controllers will further enhance the model. This could yield new applications in SOA that are already present in PDE tool such as-the process of remote configuration based on distributed web technology. The main challenge of DPWS enabling the devices is the hardware needs, at Loughborough we are developing hardware to support DPWS in the form of RTOS that are supporting DPWS and gSOAP [19] linked to the elements in-

spired by ARM MCU processors [20], as the model presented in figure2.

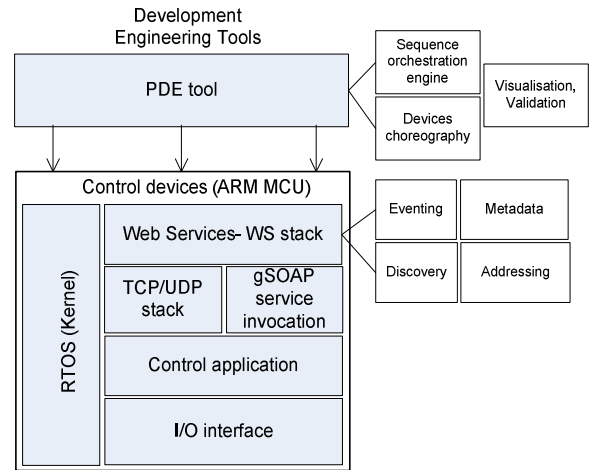


Fig 2 Web services enabling device implementation model

The approach in figure 2 will give greater control over the factory floor devices. However to date the results of our investigation that have been set around new applications developed using the PDE Tool approach, applications that can be seen as a initial insight into the potential of the further SOA enablement of the testbed. In order to aid explanation, the applications can be divided up into three main categories. The first being visualisation and reconfiguration applications, the second higher level enterprise integration and third lower level integration. The make up of each one of these layers will be now discussed focusing on the impacts in terms of new users and applications in this next generation SOA enabled DBE's.

#### IV. NEW APPLICATIONS FOR THE DBE.

The results of the PDE tool investigation is the creation of new sets of applications that can be used over a distributed automation platform. These will now be discussed focusing on the impacts in terms of new users and applications in this next generation SOA enabled DBE's.

##### B. Visualisation and Reconfiguration.

From the PDE Tool work a library of components (PLC, Embedded processor board) is being created as a standard catalogue for machine builders using the Process Definition Editor (PDE) tool developed at LU. Components in the library are defined with their logic state operations. This tool allows a system designer to compose and validate the system using the most appropriate system views (such as State Transition Diagrams, process flow diagrams and a 3-D modelling environment). The tool includes simulation and debug facilities to test and validate the system before and after implementation.

These Libraries are linked to Virtual Reality Modelling Language [21] models of components and enable visualisation of the manufacturing process remotely, or repeat visualisation of saved past processors. Both the recreation of

these runs and also the data saved during this process introduces new capabilities and possible applications to the PDE:

Using standardised Web Services the use of libraries may be enhanced using WS-Resource, although at the moment DPWS is not being developed to support this [22]. The visualisation process could also be enhanced with the WS being configured to collate and broadcast diagnostic and process information to assist support personnel. In fact new support DBE's could be formed around significant manufacturing equipment lines.

As groups of equipment specialists and maintenance engineers who could use this to monitor, analyze, and document the information to schedule maintenance work or examine machine failure modes for proactive and reactive maintenance, accountants who may examine machine throughput/ uptime etc to predict profit, or machine builders/ technology providers providing DBE based remote expert assistance.

### *C. Higher Level Integration.*

The adoption of the next generation of applications that the SOA enablement of factory elements offers is dependant on efficient links to higher level business systems. The architecture to enable these links is subject to work in projects such as SOCRADES and has to be tailored for the specific requirements of the factory floor elements. These functions need to take into account both the requirements of the higher level application such as the ERP system whilst protecting the security and safety of the control of the lower level device.

PDE supports the Device Protocol advertising that is a part of the DPWS discovery function using WS-Discovery. Web services discovery message over the network. to accept this device into the system. The device description service is used as the Meta-data file of the device defined in the DPWS protocol stack. This file describes the function/ application services the device provides, including the part name, serial number, programme version and etc. This mechanism is handled with the resource management programme tool (PDE).

Work in the PDE tool project has highlighted that the demands of the higher level system need to be catered for in a different way to usual enterprise computing models. For example the typical model of business integration is in the are of supply chain management or automated eCommerce. Here the Larger suppliers require that the SMEs integrate with their ERP type system in order for them to become a trading partner [24]. Here the SME gives certain control of data query and even input into their enterprise type system to the larger partner. Logically the model when expanded to factory floor elements will be repeated. With the business's being able to interrogate data on production machinery and even influence production metrics.

However this control when dealing with lower level machinery has not only business critical issues such as the input of wrong data as is contended with in the ERP model, but also the data on live machinery has safety aspects to take into account. For example questions need to be raised about how partner control of live production lines and ma-

chinery can be achieved without risk to the equipment and employees using it.

Within the PDE project the virtualisation of the process is achieved so the partners can influence production on a conceptual level. This can be based on simulated live run data or past data of production runs, and could be linked to higher level business process language such as BPEL. It is likely that the higher level systems will need to integrate with this to enable the control over the lower level machinery. It is therefore likely that this virtualisation will act as a bridge to either aid understanding from the higher level of a production process, or for requests of changes from a higher level to be represented to an appropriate decision point at the local factory for implementation. Whilst this may mirror current distributed SOA policy and security systems in distributed enterprise research, it is likely this challenge will require there frameworks to adapt to support the new requirement of the manufacturers.

Therefore the PLC is wrapped as a service and the actions of the elements modelled virtually in the PDE system. Overall supply chain management in DBE will benefit from the advanced pervasiveness of the applications that can use data derived from elements on the factory floor. The DBS using SOA enabled elements would be able to report on failures of machinery in real time as with other production statistics. For the DBE this data will influent the way existing and emerging applications function between the higher levels to the lower.

### *D. Lower Level Integration.*

Lower level integration into DBE's is dependant on understandings of lower level process. We are developing algorithms to model the functions at a lower level, this is represented in the behaviour of the virtual elements in PDE and would be tied to real element configuration in the device level SOA implementation. The algorithms that we use to model the lower level choreography should be mapped to the higher level workflows in the DBE on integration.

In addition to the implementation of the new installation device for the reconfigured process, the web services facilitates the device discovery service by broadcasting the Web services discovery message over the network (WS-discovery) to accept this device into the system. The device description service is used as the Meta-data file of the device defined in the DPWS protocol stack. This file describes the function/ application services the device provides, including the part name, serial number, programme version and etc. This mechanism is handled with the resource management programme tool (PDE).

Base on this approach, dynamic changes of the process have been optimized through the loosely coupled hardware and the web services ontology. In future DBE's these ontology's and choreography models will be as significant as workflows are in current WS enabled distributed DBE's. As in order for the DBE to function correctly at a distributed application level some knowledge of the types of ontology's used will be needed to improve interfaces with the factory floor elements.

## V. TRANSFORMING THE DBE.

### A. Impact of the New Applications

This paper has only scratched the surface in suggesting the new applications this integration can present to the future DBE. As the distributed enterprise evolves to support the new information yielded from the factory floor to current DBE models will change and new applications emerge. Research into the PDE project into the visualisation of data from the automated manufacturing process and also integration of lower and higher level devices in the model have suggested significant new areas of development for the DBE.

These three main areas that the paper has highlighted will cover the main area of application development. Within this greater potential for management of lower level devices suggests that new controls at middleware level to bridge the SME and larger customer need to be enabled. This would impact current DBE that support automated supply chain management.

Another area that can be seen as holding huge potential for further development in the DBE is in visualisation of processes and process data. As the information and the knowledge of the manufacturing process can be seen to flow well into applications in this business ecosystem environment. Therefore, in this context, the DBE system is able to be greatly enhanced with Remote expert assistance, Decision support system, Machine design-synthesis and validation. The quick response to the external and internal of business changes can be deployed in the shorter time since the system applications are well defined and integrated with the standard and platform neutral of web services architecture spread through out the business ecosystem.

To date many DBE's are motivated by higher level processes such as in supply chain based DBE's. The new data from automation system will require a greater management and linkage between higher level applications and lower level processors. Examples of new areas of middleware development and support can be seen to have the potential to develop. Particularly around the needs of safety and control in DBE's that link into lower levels.

Therefore, in the optimisation of the DBE system, it is foreseen by this research such that the inclusion of services from the manufacturing process will have direct impact on the overall development of future DBEs. The new application in service oriented architecture has focused on enhancing the agility, flexibility, as well as robustness of the manufacturing process to support the manufacturing's lifecycles. Also the implementation of the DPWS- Web services on control devices paves the way to enable the creation of a neutral platform where devices from different vendors can interoperate via the XML message passing; hence the end-users are not tied to specific vendors. In addition, system flexibility is achieved through plug-and-play discovery (UPnP) and binding mechanisms via the use of stub and proxy code for remote procedure calls with the development of DPWS device stack.

## VI. FUTURE WORK.

The next stage of the project is to transfer the proposed framework to enable service oriented ecosystem through UPnP and Service orchestration. This will involve in implementing the proof-of-concept DPWS on embedded devices with developed suite of engineering tools. Some of the work has been initiated and done in integrating RTOS with the DPWS on the ARM9 device. Meanwhile, the work will be carrying on enhancing the PDE tool for managing complexity of the control application and business application integration in a new DBE system. This work will be done on an industry-standard test rig, supported by Ford Motor Company. The research will be investigated in the performance and reliability of control devices in an event-driven control soft real-time environment.

## VII. EVALUATION / CONCLUSION

This paper has reviewed and proposed key areas of development for a new generation of DBEs for SMEs using the PDE project as a testbed. The key characteristic of a DBE is to find the optimum solution for the enterprise among business alliances for the skills and knowledge sharing. Therefore the spread of the DBE is concerned in the integration of two main areas- technical and organisation to support the growing requirement on agility and responsiveness business approach. The paper has addressed this proposing three application layers of the impact of the factory floor automation system on the DBE. These layers will be advanced with the deployment of Web services technology and DPWS stack at device level.

The PDE methodology has given an insight into applying web services to automation systems. The key factor being the implementation of Web services on control devices aims to enable the creation of a neutral and open platform where devices from different vendors can be mixed in the system.

The benefits of service orientation are clearly conveyed all the way to the device level, facilitating the discovery and composition of applications by reconfiguration at the higher level to redefine the combination of provided service of automation devices in the manufacturing process. In addition, the paper has stressed in dynamic self configuration of smart embedded devices using loosely coupled services provides significant advantages for highly dynamic and ad hoc distributed applications to achieve system flexibility through plug-and-play discovery and binding in support of SOA-Web services.

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