Application of Soft Computing Techniques for Factory Floor Automation to Digital Ecosystems

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Abstract: *This Research paper presents from the Process Definition Tools implementation, 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 Small to Medium Enterprises (SMEs) 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 virtualization of automation and integration at both lower and higher levels of distributed applications are presented in a transformed view of a DBE.*

Key Words: *Automated Manufacturing, SOA, DBE, SME,Ecosystem*

I. INTRODUCTION

Web Services and hardware development have combinedto place factory floor level devices within the reach of largescale distributed computing applications. In terms of newSOA development this new dimension in potential servicespresents new possibilities in Digital Ecosystems. These canbe seen to stem from increased application pervasivenessvia the SOA enablement of the Factory floor that will introducenew services and service providers into DBE basedapplications.

Investigating this new DBE enablement this paper examinesthe new structures that could be formed in DBE's interms of the new users, service providers and applications.In particular these new DBE features are proposed andplaced within a the context of typical DBE architectures.This is done using experience from research projects intoSOA enablement of factory floor level devices. The paper uses a three layer examination of the impactsof factory floor automation on the DBE. Initially the advancesin enabling devices from the perspective of themanufacturer are presented. This examines the technologythat is to enable SOA based automation and how it is likelyto be deployed. The new functions that this enablement presentsto the DBE is examined, with a focus on new applicationareas likely to effect the future structures of DBE's usingfactory floor level services.

II. RELATED WORK

A.. Motivation behind the Web Services (WS) enablementof PLC's(Programmable Logic Controllers) and factory floor elements.

Manufacturers are seeking more agile, flexible and adaptiveapproaches to their production systems as well as encom p assingcustomers 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 ofhighly customised design-to-order products, where additionalservices and value-added benefits like product upgradesand future reconfigurations are as important as theproduct itself. [2].

The need for a SOA enablement of devices on the factoryfloor has emerged from research into the improvementof automation of factory process. In particular within advancedwestern economies the need to have flexible production lines able to specify and react effectively to change is akey factor in enabling the production of high quality valueadded products that this sector is focused on. Within thisresearch elements such as basic Robotics and manufacturingassembly has been the focus of work looking to introducegreater automation and reconfiguration [20].

The SOCRADES [3], SODA [4] and SIRENA [5] projectwithin the EU have taken significant steps in the initialinvestigation of SOA enablement and support of factoryfloor level devices in distributed automation applications.

These projects are focused at the enablement of SOA withinfactory floor elements. As this enablement is starting to bedefined and applied in test environments in these and similarprojects the impacts on SOA based applications in generalcan begin to be analysed.

B. Significance to the Digital Business Ecosystem

There are more than 228000 manufacturing Small toMedium Enterprises (SMEs) in the EU, at the Lisbon summitin 2003 research efforts were agreed at focusing knowledgebased manufacturing [6]. An important part of this was

the commitment of funds to support investigation into DigitalBusiness Ecosystems in the EU. A digital business Ecosystemcan commonly be seen as mechanism by whichSMEs, are provided with applications consisting of distributedservices normally out of there reach due to lack of resourcesor skills.

A popular application area has been within ICT basedapplications and knowledge sharing such to support supplychain management and specialised processing of data [7,8].The key technical enabler of these distributed environmentshas been advances in web services and the provision ofSOA based resource sharing. To date many DBE exist atwhat can be seen as the middleware of the distributed computingmodel, and often link applications and data.

Motivations behind the growth and evolution of DBEcan be seen as centered in two main areas, these can be seenas technical and organisational. In terms of the organization an main proponent of DBE development particularly in theEU has been governmental organisations. These DBE's areformed with the aim to promote the development of andsharing of skills in specific communities SME's. For examplethe EU's vision of DBE' forms along socio economic boundaries to promote innovation and development in industriesand localities improving European competitiveness[9,10]. This vision is not specifically technical but focusedon supporting innovation in the distributed collaborationenabled by the DBE.

In order for DBE's to develop technically the new

business models that they promote have attracted softwaredevelopment in both the commercial and open source community.This is often linked to genuine commercial motivationwhere the provision of software to support the DBE canpresent vendors like SAP with larger sets of users, developersand potential customers to DBE based products. An approach

that has presented companied like SAP with newbusiness models, where a ecosystem could be built as SAPcomponents around SAP products such as Net Weaver [11].With the ecosystem enabling thousands of independent developersto start writing specialized programs that plug intothe Net Weaver framework. The same model can also beseen to apply in the Open Source DBE vision. Where theenablement of a DBE using Open Source software can introducenew developers and users to the software [12].

Therefore the DBE like the development of SOA infactory automation is motivated by social economic goal ofincreasing skills and competitiveness in regional economies.Furthermore the technical enablement of the DBE like infactory automation promises new business opportunities forsoftware providers. Combined within the DBE this combinationof business and technical innovation will have a significantimpact in DBE use and development.

To datewithin the field of industrial automation the enablement offactory floor elements the use of DBE type applications isyet to become an established commercial model. Howeveras distributed applications emerge around the next generationof SOA based automation the DBE's is likely to adaptand form around this technology. Integration of this factoryfloor level data in many DBE's will give the applicationsgreater depth and completeness.

III. ENABLING DEVICES

A. Device Profile for Web Services.

Nowadays globalisation, emergent technologies and customerdemands require flexible operation on a global scaleas well as agile, flexible and adaptive manufacturing control.In response to these rapid, continuous and unpredictablechanges organisations should embrace a flexible, adaptive,collaborative, and responsive paradigm.

The key enableris the integration of automation systems with otherbusiness entities including marketing, engineering, productdesign, business process management and personnel. However,the integration of a business enterprise with its shop floorand with business partners correctly is largelyachieved via the use of proprietary complex systems due todisparate technologies being used in manufacturing systemsand business enterprise [13]. In addition, lack of standardized technologies and interoperability are main obstacles ineffectively integrating the enterprise among business partners,thus hindering integration with DBEs.

Recently, the SOA and WS approach has been proposedby a number of researches as mentioned earlier to enhancenetworked organisations to support the required dynamicnetworking of the inter- and intra- business collaboratorsinto the factory floor environment.

This would enable thislevel of knowledge and information to be seamlessly sharedand accessed through the use of standardised web technologies.Thus the use of SOA hold the potential to break theintegration chains of proprietary and legacy software that issurrounding factory automation systems, and preventingthem from joining effective DBEs.

The implementation technology to support the dynamicchanges from the business and management level of integratingthe shop floor is generally recognised will beachieved via SOA enabled by DPWS (Device Profile ForWeb Services) [14,15]. DPWS is a light-weight protocolstack that enables the service discovery and message passingto the higher local and remote control level.

The protocolcan be implemented at control devices (PLC, Embeddeddevices). The protocol is defined with WS-, SOAP-XML,WSDL, UDDI, and TCP/IP/UDP/HTTP stacks and it is becomingthe standard for the industrial network applicationand has its main implementations in the home electronics /consumer computing area [23]. This DPWS protocol willallow automation devices to be directly integrated with

high-level manufacturing systems and business supplychains.

The vision of the application of DPWS will be a designof control systems into the distributed application paradigms,and ubiquitous computing environments to enableflexible, reusable, reconfigurable manufacturing systems

based on self-reliant, interconnected smart embedded devices[17].

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

B. PDE Tools

An emerging trend to adopt the Web services approachon the automation device as proposed in [15, 16, and 17]enables the creation of the DBE system. Its concept of WSDPWSis to include the plant activity into the enterprise tofacilitate work synchronization between the high and lowlevel applications.

This is an conceptual idea to provide thecapability to develop distributed applications in diversereal-time computing environments in many business andautomation disciplines including the automotive industry,building automation industry, to name a few.

As we have mentioned DPWS in section 3.1 and it is beingdeveloped as the main tool to implement the next generationof factory automation systems.

However to date theresearch into DPWS is yet to yield any significant implementations.In order to advance into this area, initial investigationsat Loughborough into the leverage of SOA withinmanufacturing process have been completed.

The PDE (Process Definition Editor) tool developed atLoughborough University [18] contributes a significant rolein the design of control application and visualisation atrun/design time to ease the design and (re) configuration ofthe manufacturing process. Currently the tool includes theability to communicate with factory level elements throughweb based technologies bridged to PLC's. The further developmenton this tool will be to support its applicationsusing DPWS.

PDE architecture consists of a library of device profilesand a storage service that stores the data from previous executionsof the elements.

The elements are visualised in thePDE tool and these visualisations are linked to the deviceprofiles and saved automated layouts that consist of multipleelements. At the moment the data into the PDE is takenfrom the PLC controllers of the automation line, a overviewof the PDE testbed can be seen in Figure 1.

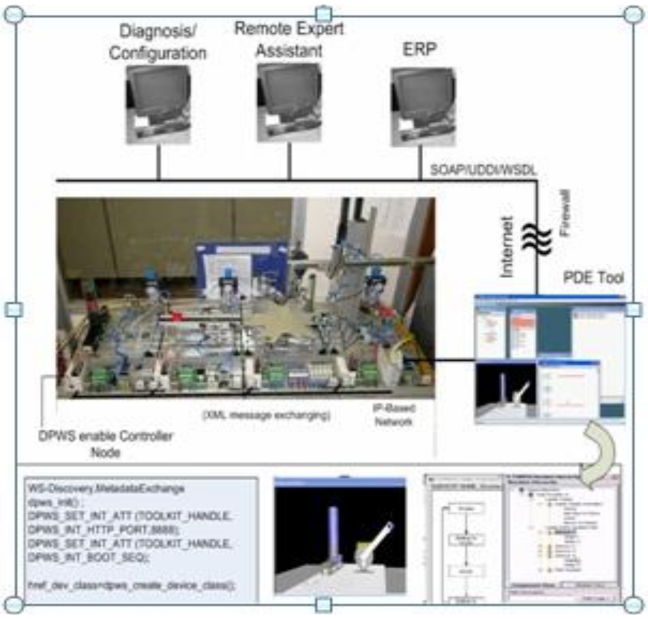

Fig 1: Overview of PDE Test Bed.

DPWS support will present the software with a standardized SOA architecture and will enhance its possible interfacesto higher systems. Currently a SOA can be seen to existas in that common interfaces to the PLC are exposedmaking the invocation of the PLC possible as a distributedservice.

Adoption of the PDE tool to interface directly withdevices instead of the PLC controllers will further enhancethe model. This could yield new applications in SOA thatare already present in PDE tool such as-the process of remoteconfiguration based on distributed web technology.The main challenge of DPWS enabling the devices is thehardware needs, at Loughborough we are developing hardwareto support DPWS in the form of RTOS that are supportingDPWS and gSOAP [19] linked to the elements inspiredby ARM MCU processors [20], as the model presentedin figure2.

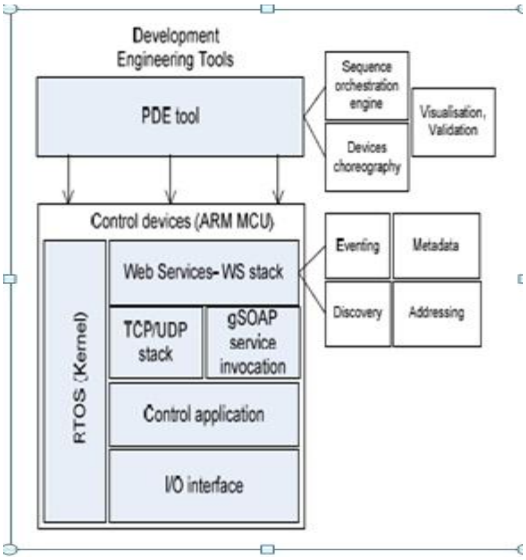

Fig 2 Web services enabling device implementation model

The approach in figure 2 will give greater control overthe factory floor devices. However to date the results of ourinvestigation that have been set around new applicationsdeveloped using the PDE Tool approach, applications thatcan be seen as a initial insight into the potential of the furtherSOA enablement of the testbed.

In order to aid explanation,the applications can be divided up into three maincategories. The first being visualisation and reconfigurationapplications, the second higher level enterprise integrationand third lower level integration.

The makeup of each oneof these layers will be now discussed focusing on the impactsin terms of new users and applications in this nextgeneration SOA enabled DBE's.

IV. NEW APPLICATIONS FOR THE DBE.

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

A. *Visualisation and Reconfiguration.*

From the PDE Tool work a library of components (PLC,Embedded processor board) is being created as a standardcatalogue for machine builders using the Process DefinitionEditor (PDE) tool developed at LU. Components in the libraryare defined with their logic state operations.

This toolallows a system designer to compose and validate the systemusing the most appropriate system views (such as StateTransition Diagrams, process flow diagrams and a 3-Dmodeling environment). The tool includes simulation anddebug facilities to test and validate the system before andafter implementation.

These Libraries are linked to Virtual Reality ModelingLanguage [21] models of components and enable visualization of the manufacturing process remotely, or repeat visualization of saved past processors. Both the recreation ofthese runs and also the data saved during this process introducesnew capabilities and possible applications to thePDE:

Using standardised Web Services the use of librariesmay be enhanced using WS-Resource, although at the momentDPWS is not being developed to support this [22].The visualisation process could also be enhanced with theWS being configured to collate and broadcast diagnosticand process information to assist support personnel. In factnew support DBE's could be formed around significantmanufacturing equipment lines.

As groups of equipment specialists and maintenance engineerswho could use this to monitor, analyze, and documentthe information to schedule maintenance work or examinemachine failure modes for proactive and reactive maintenance, accountants who may examine machinethroughput/ uptime etc to predict profit, or machine builders/technology providers providing DBE based remote expertassistance.

B. Higher Level Integration.

The adoption of the next generation of applications thatthe SOA enablement of factory elements offers is dependenton efficient links to higher level business systems. The architectureto enable these links is subject to work in projectssuch as SOCRADES and has to be tailored for the specificrequirements of the factory floor elements. These functionsneed to take into account both the requirements of thehigher level application such as the ERP system whilst protectingthe security and safety of the control of the lowerlevel device.

PDE supports the Device Protocol advertising that is apart of the DPWS discovery function using WS-Discovery.Web services discovery message over the network. to acceptthis device into the system. The device description serviceis used as the Meta-data file of the device defined inthe DPWS protocol stack. This file describes the function/application services the device provides, including the partname, serial number, programme version and etc. Thismechanism is handled with the resource management programmetool (PDE).

Work in the PDE tool project has highlighted that thedemands of the higher level system need to be catered for ina different way to usual enterprise computing models. Forexample the typical model of business integration is in theare of supply chain management or automated eCommerce.Here the Larger suppliers require that the SMEs integratewith their ERP type system in order for them to become atrading partner [24]. Here the SME gives certain control ofdata query and even input into their enterprise type systemto the larger partner. Logically the model when expanded tofactory floor elements will be repeated. With the business'sbeing able to interrogate data on production machinery and
even influence production metrics.

However this control when dealing with lower level machineryhas not only business critical issues such as the inputof wrong data as is contended within the ERP model,but also the data on live machinery has safety aspects totake into account. For example questions need to be raisedabout how partner control of live production lines and machinerycan be achieved without risk to the equipment andemployees using it.

Within the PDE project the virtualisation of the processis achieved so the partners can influence production on aconceptual level. This can be based on simulated live rundata or past data of production runs, and could be linked tohigher level business process language such as BPEL. It islikely that the higher level systems will need to integratewith 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 aproduction process, or for requests of changes from a higherlevel to be represented to an appropriate decision point atthe local factory for implementation. Whilst this may mirrorcurrent distributed SOA policy and security systems in distributedenterprise research, it is likely this challenge willrequire there frameworks to adapt to support the new requirementof the manufacturers.
Therefore the PLC is wrapped as a service and the actionsof

the elements modeled virtually in the PDE system.Overall supply chain management in DBE will benefit fromthe advanced pervasiveness of the applications that can usedata derived from elements on the factory floor. The DBSusing SOA enabled elements would be able to report onfailures of machinery in real time as with other productionstatistics. For the DBE this data will influent the way existingand emerging applications function between the higherlevels to the lower.

C. Lower Level Integration.

Lower level integration into DBE's is dependent on understandingsof lower level process. We are developing algorithmsto model the functions at a lower level, this is representedin the behavior of the virtual elements in PDE andwould be tied to real element configuration in the devicelevel SOA implementation. The algorithms that we use tomodel the lower level choreography should be mapped tothe higher level workflows in the DBE on integration.

In addition to the implementation of the new installationdevice for the reconfigured process, the web servicesfacilitates the device discovery service by broadcasting theWeb services discovery message over the network (WSdiscovery)to accept this device into the system. The devicedescription service is used as the Meta-data file of the devicedefined in the DPWS protocol stack. This file describesthe function/ application services the device provides,including the part name, serial number, programmeversion and etc. This mechanism is handled with the resourcemanagement programme tool (PDE).

Base on this approach, dynamic changes of the processhave been optimized through the loosely coupled hardwareand the web services ontology. In future DBE's these ontology'sand choreography models will be as significant asworkflows are in current WS enabled distributed DBE's. Asin order for the DBE to function correctly at a distributedapplication level some knowledge of the types of ontology'sused 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 suggestingthe new applications this integration can present to the futureDBE. As the distributed enterprise evolves to supportthe new information yielded from the factory floor to currentDBE models will change and new applications emerge.Research into the PDE project into the visualisation of datafrom the automated manufacturing process and also integrationof lower and higher level devices in the model havesuggested significant new areas of development for theDBE.

These three main areas that the paper has highlightedwill cover the main area of application development. Withinthis greater potential for management of lower level devices

suggests that new controls at middleware level to bridge theSME and larger customer need to be enabled. This wouldimpact current DBE that support automated supply chainmanagement.

Another area that can be seen as holding huge potentialfor further development in the DBE is in visualisation ofprocesses and process data. As the information and theknowledge of the manufacturing process can be seen to flowwell into applications in this business ecosystem environment.Therefore, in this context, the DBE system is able tobe greatly enhanced with Remote expert assistance, Decisionsupport system, Machine design-synthesis and validation.The quick response to the external and internal ofbusiness changes can be deployed in the shorter time sincethe system applications are well defined and integrated with

the standard and platform neutral of web services architecturespread throughout the business ecosystem.

To date many DBE's are motivated by higher level processessuch as in supply chain based DBE's. The new datafrom automation system will require a greater managementand linkage between higher level applications and lowerlevel processors. Examples of new areas of middleware developmentand support can be seen to have the potential todevelop. Particularly around the needs of safety and controlin DBE's that link into lower levels.

Therefore, in the optimisation of the DBE system, it isforeseen by this research such that the inclusion of servicesfrom the manufacturing process will have direct impact onthe overall development of future DBEs. The new applicationin service oriented architecture has focused on enhancingthe agility, flexibility, as well as robustness of the manufacturingprocess to support the manufacturing's lifecycles.Also the implementation of the DPWS- Web services oncontrol devices paves the way to enable the creation of aneutral platform where devices from different vendors caninteroperate via the XML message passing; hence the end-usersare 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 andproxy code for remote procedure calls with the developmentof DPWS device stack.

VI. FUTURE WORK.

The next stage of the project is to transfer the proposedframework to enable service oriented ecosystem throughUPnP and Service orchestration. This will involve in implementingthe proof-of-concept DPWS on embedded deviceswith developed suite of engineering tools. Some of thework has been initiated and done in integrating RTOS withthe DPWS on the ARM9 device. Meanwhile, the work willbe carrying on enhancing the PDE tool for managing complexityof the control application and business applicationintegration in a new DBE system. This work will be doneon an industry-standard test rig, supported by Ford MotorCompany. The research will be investigated in the performanceand reliability of control devices in an event-drivencontrol soft real-time environment.

VII. CONCLUSION

This paer has reviewed and proposed key areas of developmentfor a new generation of DBEs for SMEs usingthe PDE project as a testbed.

The key characteristic of aDBE is to find the optimum solution for the enterpriseamong business alliances for the skills and knowledge sharing.

Therefore the spread of the DBE is concerned in theintegration of two main areas- technical and organisation tosupport the growing requirement on agility and responsivenessbusiness approach.

The paper has addressed this proposingthree application layers of the impact of the factoryfloor automation system on the DBE.

These layers will beadvanced with the deployment of Web services technologyand DPWS stack at device level.

The PDE methodology has given an insight into applyingweb services to automation systems.

The key factor beingthe implementation of Web services on control devicesaims to enable the creation of a neutral and open platformwhere devices from different vendors can be mixed in thesystem.

The benefits of service orientation are clearly conveyedall the way to the device level, facilitating the discovery andcomposition of applications by reconfiguration at the higherlevel to redefine the combination of provided service ofautomation devices in the manufacturing process.

In addition,the paper has stressed in dynamic self configuration ofsmart embedded devices using loosely coupled servicesprovides significant advantages for highly dynamic and adhoc distributed applications to achieve system flexibilitythrough plug-and-play discovery and binding in support ofSOA-Web services.

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