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Tools for Human-Product Collaborative Development of Intelligent Product Service Systems

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Abstract. Intelligent products, having cyber physical features, are best candidates for building Intelligent Product Service Systems (IPSS), in which integrated products and services provide a higher level of intelligence. Such IPSS may actively provide feedback on their use, which in turn may support the development of new IPSS. The objective is to develop a set of tools to establish a Collaborative Network, where both human actors and products themselves can collaborate and contribute to the development of such IPSS. The tools support involvement of various stakeholders within the Collaborative Networks. Several tools, such as a tool to select sensors and intelligent features at the products, a tool to model context under which IPSS is used, as well as tools to provide feedback on the IPSS use are defined. The paper presents as well the application of the proposed concept in machine industry.

Keywords: Intelligent Products, Collaborative Development, Product Service System, Cyber Physical Features, Collaborative Network

1 Introduction

Modern products include more and more cyber physical features as a basis for their intelligence. Cyber physical features allow to build various intelligent services encompassing such products to build for example Intelligent Product Service Systems (IPSS). IPSS provide a new quality of offers to customers as the products and services are integrated and built with a higher level of intelligence. Such systems can communicate and provide information within Collaborative Networks. Many Cyber Physical Products in manufacturing industry, such as vehicles, home appliances etc., are already used or can be used to build such IPSS. Modern machines are probably one of the most promising products to build IPSS.

Such IPSS are innovative results of the fourth industrial revolution [1-2], as a collective term covering a number of modern technologies in manufacturing, automation and data exchange. The forth industrial revolution is 'a collective term for technologies and concepts of value chain organization' consisting of loosely coupled Cyber-Physical Systems (CPS) in an Internet of Things and Internet of Services [3-6], it includes all resources needed for developing IPSS.

IPSS is an evolutionary step to smart manufacturing. Loosely coupled cyber-physical systems realize comprehensive cross-level and cross-domain collaboration and analyzation possibilities. Furthermore, in manufacturing environments such services improve the volatile and dynamic. This continuously rising ramification generates also a demand on Collaborative Development approaches to manage those future highly complex IPSS and to exploit new potentials.

IPSS, having the ability to communicate within Collaborative Networks, may actively contribute to the development of new IPSS or re-design of the existing ones. The objective of the research shown in this paper is to develop Collaborative Networks, comprising both humans and IPSS, whose aim is to (re-)develop IPSS. Within such networks, besides different stakeholders normally involved in the development of IPSS (product designer, process designers and shop-floor experts, service providers, various suppliers, as well as business customers, consumers etc.), IPSS can play an active role. They may pro-actively provide information about the product use and by this support the development of intelligent products and/or services. Such an approach requires new organization and definition of processes for IPSS development. However, collaborative environments and tools to support such Collaborative Networks in which human stakeholders and IPSS collaboratively “work” together on the development of IPSS are currently missing, based on the literature review carried out for this research.

The paper presents the vision of the human-product Collaborative Network and Environment, which shall support the operation of such Network and focuses upon three tools.. The paper also discusses the application of the approach in machine industry where development of IPSS is specifically complex. The paper focuses on the environment and tools while organizational aspects will be implicitly addressed

2 Overview of State of the Art

Cyber Physical Systems/Products: CPS are systems that include seamlessly integrated and closely interacting hardware (physical) and software (cyber) components sensing and to controlling (in real-time) the state of them and their environment. A high degree of complexity of such systems at a numerous spatial and temporal scale generate highly networked communications for integrating with their computational and physical components. As such CPS refer to information and communication systems (computing, communicating, actuating, sensing, etc.) seamless integrated in physical objects, interconnected through a unified network technology including the (Industrial) Internet (of Things/Services), providing several innovative applications based on digitized data and virtualized models, services and information. Therefore, CPS can also be referred to as emerging ubiquitous computing embedded cyber-physical applications that is bridging the physical and virtual worlds and share all kind of collaborative networks [7-11].

Product/Service-System (PSS): PSS has evolved in different geographic locations and has different motivations, e.g., one of the most spread concept is closely coupled sustainability and the reduction of environmental impact [12]. There are many research communities that deal with similar concepts, e.g. services sciences [13].

Product-service bundles enable to extend the product's life-cycle. The concept of extended products [14] provides a suitable model to conjunct products, product related services and the needs of users. The meta-product plays a decisive role in this process. The more a manufacturing enterprise is getting closer to a highest level of servitisation, the more the meta-product has knowledge about a service embedded in itself and the more it is becoming "service-aware", thus smarter. Products based on CPS are especially appropriate for building PSS, because they allow to combine the intelligence of the cyber physical products themselves with the intelligence of services built using sensors and intelligent features of the product, which in turn build higher level of system intelligence, namely Intelligent PSS (IPSS).

Collaborative Development Environment: Collaborative Networks and Environments for complex service-enhanced products are subject of intensive research activities [15], [16]. One of the most important topics in research relevant for IPSS is related to generic software frameworks allowing developers to integrate services for products to create specific improved/extended industry solutions. Still promising approaches in this area are the "Common Object Request Broker Architecture (CORBA)", the Grid computing infrastructure (e.g. Globus, Legion and SNIPE) and the Common Component Architecture (CCA). This work has now led to the concept of Service Oriented Architecture, Cloud Computing etc. Some commercial collaborative systems are coming from CAD/CAM/PLM vendors which are more specific for the manufacturing industry and others are more tailored towards more general forms of collaboration (Webex, GoToMeeting, MS Messenger). Similarly, much research work has been done to develop virtual distributed environments resulting in advances in the area of collaborative virtual environment. Still a lot of work is needed to realize in real engineering settings collaborative workspaces covering the whole view of a product life cycle and intensive collaborative engagement of all the stakeholders that could lead to services, ecological products and related processes in production.

Many leading industries related to CAD are now offering in some form features for collaboration into their CAD / PLM products/services. The fundamental motivation for this evolution is to enable CAD / PLM products and services using remote teams to come together for their own product to work collaboratively to improve productivity (reduce costs and time consumption in product design and development while increasing quality). This indicates that major CAD/PLM vendors currently providing some forms of collaboration capabilities focused on collaboration related to their products so that one of the key limitations of their systems is the collaborative restriction on detailed CAD design but less on PSS. Although these systems tend to support some form of distant collaboration, they lack the ability to integrate various contributions from both humans and products that can expand the IPSS life cycle analysis involving multi-functional teams.

Context Sensitivity: With recent advances in context-aware computing, an increasing demand for formal context modelling and reasoning techniques arises. To enable the development of context-aware applications in first step a well-designed Context Model (CM) is necessary. As context merges different sources of knowledge and associates knowledge to a user to guarantee a consistent understanding, context modelling is extensively studied within research of Knowledge Management.

Research related to context can be categorized in two areas: (1st) proactive context-based delivery of knowledge, and (2nd) capturing and utilization of contextual knowledge. CMs enable the understanding of user's activities in relation to situational conditions for applications. Traditional techniques for context modelling include object oriented and key-value models, as well as ontological methods [17]. Ontologies as base for the modelling of context is the most suitable approach for realizing context sensitive IPSS; context reasoning and context provisioning are some of the main topics for context extraction: how to inference high-level context information from low-level raw context data [18], [19]. Using context awareness in IPSS has not yet researched in a sufficient magnitude. In the case of IPSS the notion of context is related to capabilities of the equipment, process preferences of products and process features of devices and also environmental conditions. In this case the modelling of context shows a further challenge, as IPSS solutions are highly dynamic and working in environments which are distributed and often in a continuous change.

3 Vision of an IPSS Collaborative Environment

As the development of IPSS around products with CPS features requires involvement of all stakeholders from the whole value chain, there is a need for building innovative Collaborative Networks where collaboration paths can be extremely complex. The main idea of the research presented in this paper is to build Collaborative Networks, where besides human stakeholders, IPSS can be actively involved and where IPSS are able to actively provide information on use in real-time and conditions under which the products and services are used. By this, they actively support building new IPSS or extending/re-development existing ones.

Such human-product Collaborative Networks require an ICT Environment to support effective and collaborative development of IPSS as shown in Fig.1. The Environment includes a range of engineering tools covering various life cycle phases of the IPSS development process starting from idea generation and conceptual phase up to the deployment and re-design phases based on the feedback obtained from customers and consumers [20]. The tools that may be included are e.g. simulation tool to simulate/predict the behavior on new IPSS and by this investigate different design options, Product Data Management/Product Lifecycle Management (PDM/PLM) tools for IPSS (i.e. IPSSDM/IPSSLM) which may in real time monitor the configuration of IPSS and allow for real-time reconfigurations of IPSS [21], tools for idea generation, tools for engineering of data mining algorithms for various services etc These tools allow for collaborative work of various human stakeholders in the network such as product designer, manufacturing process designer and shop floor leaders, service designer and providers, marketing experts, component designer from various suppliers (both hardware and software components), management from all stakeholders, as well as business customers, consumers etc. The main innovative characteristics of these tools are that they allow for active participation of the IPSS themselves. In many of these tools, IPSS actively provide data needed for the engineering tasks covered by the tools. The key rational behind the environment is that the IPSS may provide the inputs needed for the engineering tasks based on the requests from human actors involved in the development of IPSS. Furthermore, IPSS may pro-actively provide inputs whenever they observe that the engineering is dealing with tasks for which the IPSS products may provide additional data/knowledge.

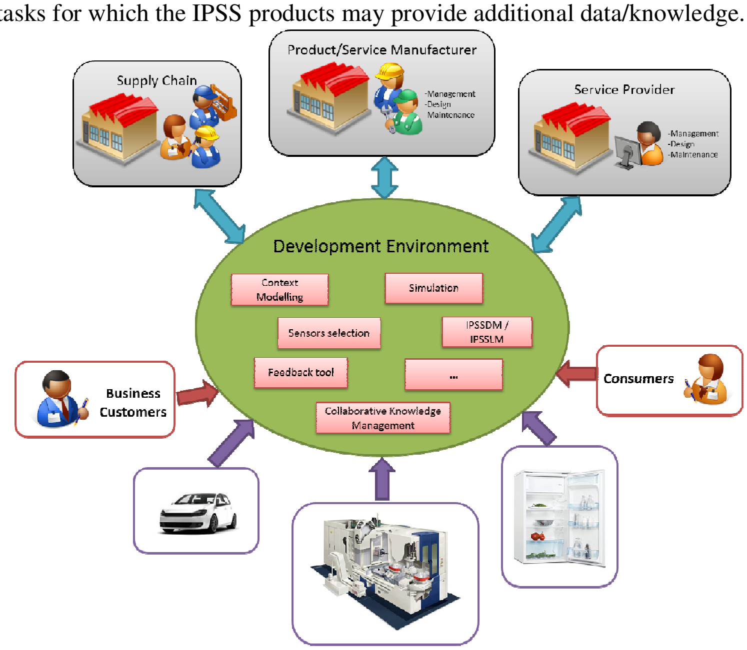

Fig. 1. Development Environment for IPSS Human-Product Collaborative Network

4 Tools to Support Human-Product Collaborative Development

As indicated at Fig 1, the Development Environment may include diverse engineering tools. In the text to follow three tools typical for human-product collaboration in the Network, are briefly described. The key approach to integrate information flowing from various sources (IPSS products, human actors, different systems in supply chain, etc.) is semantical enrichment of all data using the agreed ontology for IPSS. This allows to effectively correlate data/knowledge from various sources. The visual analytics approach is planned to be applied for delivery of such integrated knowledge to various actors in the environment.

4.1. Tool to Select Sensors and Intelligent Features

The objective of this engineering tool is to support the design/development of IPSS by allowing a selection of sensors and diverse intelligent features, or propose to the designer which sensorial and smart feature/technology could be used in the product to allow for building of IPSS and which information on the designed product one could obtain from such smart systems/sensors. The sensors and intelligent features integrated in IPSS are sources of information which can be effectively (re-)used to build various services and/or new intelligent features. The tool offers to the designing team the list of sensors /features which are currently available at the product and which may be used for building diverse services. The selection may involve several stakeholders: product and service designer but also sensors suppliers etc. The tool uses a structured methodology for sensorial solutions for production industry based on a so-called Ambience Intelligence solutions reference model integrated in products with cyber-physical features [22].

IPSS may provide in real time information on sensors and available smart features used in various configurations of the products and services and by this supports the designer to select the most appropriate ones to build new IPSS or extend the existing IPSS with the new services. It also may provide sets of data obtained by these sensors allowing to design new services and features.

The tool and method support the designing team in designing/selecting of sensors and other kinds of measurement systems and extended monitoring and services for decision support, may also support to improve eco efficiency during life cycle operation and product manufacturing, as well as to provide useful knowledge to enhance the design of processes and products in an ecological point of view. One critical RTD issue is for example, how to select the mentioned measurement systems or sensors with potential information on ecological impact relevant for (further) design of a product and which potentially support an optimum for eco-impact in life cycle operation and manufacturing of a product. The tool proposes to the designer which sensorial system/technology could be used in the product under design and which information on ecological impact of the designed product one could obtain from such sensorial systems.

4.2 Tool to Model Context of IPSS Use

IPSS offer to users' diverse opportunities to use products and services aiming to adjust both product and services to the specific customers' needs and specific conditions under which a user is using IPSS. In other words, the use of IPSS is context sensitive, i.e. the IPSS adjust its offer to the specific current context of the user. On the other hand, sensors integrated in IPSS provide information usable to extract context under which the products and services are currently used and by this allow for making IPSS context sensitive. Context sensitivity requires a definition of context model (CM). One of the tools in the IPSS Development Environment enables the user to model the context of the user and use of IPSS.

In most cases, the user uses this tool in a combination with the Sensors Selection tool, starting by selecting the sensors/signals (signals related to the Products) and using the Context Modelling tool to add signals to identify the user behavior and needs and user environment. In order to be able to extract the context of IPSS use, CM has to be created using the context modelling tool. The full description of context of an IPPS use is not provided by a CM, but the indexing of context to support the identification of the current context. Essentially, CM defines three models: generic, sector-specific and company specific CM. All three CMs exist to model the knowledge by the use of context (including information of user, product, resource, activity, goal, etc.).

As shown in Figure Fig.2., the tool is a web based application for defining context models (ontologies). The free software solution Protégé is applied. The tool allows to define/select concepts which will be included in CM as well as their mutual relations. The tool allows for an effective maintenance of CM .

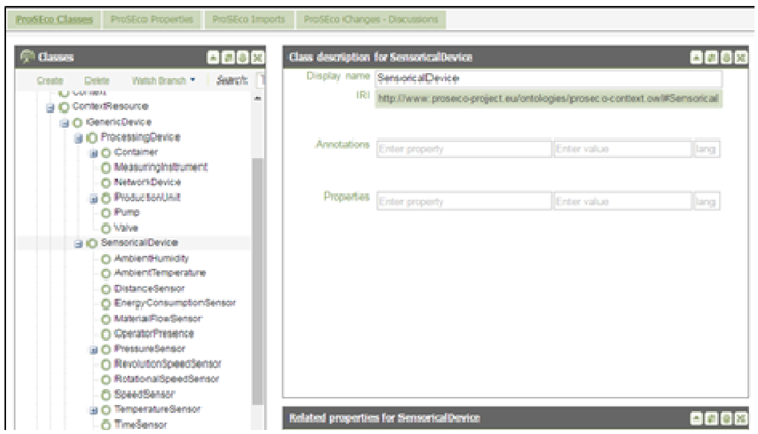

Fig.2. Context Modelling Tool

Once the model is defined and deployed in IPSS environment, it can be updated based on the feedback on IPSS use. IPSS provide, based on sensorial system, information on CM use: e.g., by detecting how the user accepts the product and/or services under different context, one may conclude whether the context models is appropriate or has to be updated. Therefore, IPSS may actively provide inputs on CM use and by this contribute to definition of new CMs (for new IPSS) or to update of the already deployed models

4.3 Feedback Tool

The tool includes three basic functionalities: (1) feedback from business customers, (2) feedback from consumers, (3) feedback provided by the IPSS themselves.

1. The customers of many IPSS are business organizations: e.g. machine industry normally sells their IPSS to various manufactures with whom they build various business partnerships. From such customers the companies get either direct feedback (e.g. on problems with the products, etc.) or get feedback about various joint activities. In the proposed tool, the feedback from business customers is captured via social software which serves as a platform for cooperation of the manufacturers, service providers and their business customers. As IPSS have to exhibit very high flexibility and require multidisciplinary expertise, experience in

using and building services. Collecting feedback is a very difficult task, when using classical PDM/PLM solutions. Social software such as wikis etc. allows for very flexible capturing and presentation of knowledge/experience of different actors and provision of feedback from the business customers. Social software, however, often suffers from missing structures limiting reuse of these experiences and feedback. These solutions allow non-IT experts to provide their experience/feedback in any form it fits them. For example, problems in manufacturing of parts or assembly can be documented by the shop floor in a form which best suits specific manufacturing line/machine (each group can define its own 'form'). The feedback from customers on the IPSS use can be also provided in any form which suits specific customer and/or service experts.

2. Social media networks allow the gathering off feedback in very "free" form. Feedback is thereby often indirectly expressed by opinions/experiences of consumers. The tool analyses such feedback from social media networks, such as LinkedIn, Facebook, Twitter, Pinterest, Instagram, etc., by applying various data mining algorithms, and provides it in the form re-usable by the actors.
3. As explained above, IPSS can directly provide feedback on their use as well as other information which can be used for (re-) development of IPSS. For example, IPSS may provide feedback serving for continuous ecological impact improvement (including monitoring of ecological impact patterns using sensors based information). Feedback could also be used for "eco-optimal condition based maintenance" of products (including e.g. setting observers to predict possible negative ecological impact patterns etc.), or design recommendations based on "eco-knowledge" as feedback for continuous "eco-improvement" of the products itself, in a form of so-called feedback or monitoring services integrated in IPSS. In order to have an accurate measure and monitoring mechanism to gather feedback from IPSS e.g., on the environmental impact, the tool for the selection of sensors, as explained above, supports the definition of appropriate sensors on the products. Special attention is e.g., paid to monitoring the resources (energy and water) consumption during the use stages. This ensures a critical component performance to optimize IPSS operation and improving sustainability by extending product life.

One of the most critical questions is how the monitoring services identify feedback patterns within use and provide design recommendations in appropriate form that can be effectively used in the future design. The tool applies a method (under development) for modelling such feedback patterns, which is continuously improved based on self-learning approach using measurement data and data obtained from the selected sensors. As self-learning approach genetic algorithms, Reinforcement Learning methods (adequate to support adaptation based on experience) or Supervised Learning techniques (require a set of training samples to start with) are under consideration [23]. In this way, the selected sensors are embedded within the product during the use in order to collect the required data and feed them back to the Development Environment. In addition, the tool includes the mechanisms to capture the behavior of the users to provide a feedback loop to the Environment to provide the Network with the ability to conceive and understand the needs of the market to provide solutions to these unexpressed new requirements and evolving needs. The data mining algorithms are under consideration to capture the behaviors of the users and by this provide feedback to the Development Environment in a form which can be effectively used by various actors in the Collaborative Network. It is assumed that IPSS may provide such feedback proactively: whenever the Network starts to deal with the services and products which are same or 'similar' the IPSS may 'offer' the available data/knowledge to the Network.

5 Potential Applications

Machine industry is the most typical sector in a need for new methods and tools for development of innovative IPSS, as machines are the most typical products with cyber physical features and this industrial sector is rapidly turning from solely manufacturing to servitisation. The manufacturing companies in the machine sector, producing machines and equipment for various sector, to be delivered to the global market require new solutions for effective collaboration and knowledge exchange among various stakeholders within IPSS Collaboration Networks. For such companies the design of IPSS is even a more complex process than for mass product manufacturers. Manufacturing companies are today facing a new paradigm, called "Mass Customization". This new paradigm intends to move from classical production to production of highly customized products in large numbers. Companies can interact with customers, following different approaches, to determine the features of a product/service that they really need or firms can produce a standardized product that will be customizable by consumers. One of the most distinctive features to achieve mass customization is to provide customizer the ability to involve customer in the design of products and services. However, to meet requirements of mass customization, the manufacturers of machines for production of mass customized products need feedback from their business customers to whom they sell their equipment as well as from the final-product users/consumers. For example, the German company producing machines for shoe industry, involved in the research on IPSS development environment, needs to combine feedback from their business partners (shoe manufacturers) and feedback from the shoe buyers in order to improve their machines and various services around machines and allow for mass customization of shoes, which is one of the key requirement in today's global shoe market [24].

This company aims at both products performance/usability improvements as well as a reduction of the lifecycle CO2 footprint of new/enhanced machines-services within IPSS. They intend also to use the services (e.g., remote diagnostics and predictive maintenance) to automatically collect the overall equipment efficiency of their machines, used at their customers. Goal is thereby enhancement of the design of the machines and services. On the other hand, in order to improve the design of the machines and reduce CO2 footprint in manufacturing of machines, they feedback along the whole machine life-cycle (from design to machine usage). Their machines have cyber physical features and a number of services collect high volume of data on the machines usage, which allow to establish direct feedback from the IPSS to the Development Environment.

Besides data which is collected by automatic measuring overall equipment efficiency (hardware and software), especially the knowledge of people involved in these processes is of key importance. For example, the knowledge of service teams as well as business customers (shoe manufacturers), which are distributed all over the world (mostly Far East, South America etc.) is of key interest. In order to allow the people involved in these value chain, taking into account diverse aspects, such as cultural differences, education level of operators and highly variable machine usage conditions, they need a support system allowing for easy documentation of actors experience. Therefore, they intend to build a unique system where machines and services are delivering automatically feedback over the tools described in Section 4 and knowledge/experience from both machine designers, process designers, shop-floor experts and customers from different world regions. The feedback is collected and structured to be re-used for optimization of IPSS design. However, as explained above, in order to cope of mass customization requirements in shoe market, and upgrade their machines and services to achieve flexibility required by such approach (but in the same time reducing prices of machines, assuring their reliability), the company needs to obtain feedback from ‘shoe consumer’. This will allow for better identification of mid-term customization requirements of consumers in different parts of the world. To achieve the upcoming trend for consumer driven customization, they intend to build shops (both physical and internet based) where the consumers may design/customize their own shoes and by this implicitly and automatically provide knowledge on their needs. Therefore, feedback from own manufacturing, business customers and shoe consumers will be collected in real time and provided to machine and service designers within the new Development Environment. On mid-term, it is expected that also the final products (shoes) will include sensors and cyber physical features which may be used to gather feedback to the Environment.

The company is currently testing several services built within the new IPSS Development Environment and using the tools described in Section 3 and 4, and investigate the feedback from the machines in order to establish continuous improvement of IPSS and especially address environmental aspects. The senor data as a feedback from machines is automatically flowing in the environment and used to identify potentials for improvements. The feedback from the business customers is obtained over wiki and semantically enriched to be correlated with the products knowledge. Based on the current testing by this company, as well as by several other companies involved in the research, it is expected that the environment and tools will allow for a reduction of time and efforts needed for development/update of IPSS by 25-35%, and allow for an increase in number of innovative personalized services by more than 40%. It is expected that the proposed solution will contribute to reduction of time to market of IPSS for products with cyber physical features by at least 10%.

6 Conclusions

The paper introduces the new concept of Intelligent PSS (IPSS), i.e., PSS developed around products with cyber physical features. The research presented in this paper is one of the first attempts to establish the Development Environment and set of tools for human – product cooperation on the development of IPSS. The three tools presented are typical examples of novel engineering functionalities needed for the development of IPSS, which allow for effective collaboration among various stakeholders in the IPSS values chains and IPSS themselves. Such tools, together with a set of other tools for engineering of IPSS, may facilitate building of new forms of Collaborative Networks within which humans and products may effectively collaborate on (re-)development of IPSS.

The Development Environment and the tools are currently under development and they are tested by several companies both in machine industry (as presented in Section 5) and by several mass product manufacturers (automotive and home appliance industries). The current version of the Environment and of the tools is limited to active provision of data/knowledge by IPSS. This means that the Collaborative Environment and the tools "inform" IPSS distributed over the world that a new IPSS is under development and IPSS then may provide appropriate knowledge. Future research it will be investigated how IPSS may more proactively take part in the development process: e.g., they may initiate re-development of certain services or components. For example, based on the identification of the needs of the customers, new services to improve the use of the product may be proposed etc.

The benefits of the proposed concept and tools are expected in terms of more effective building of intelligent product-services which better fit to the users' needs.

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