Sensor ontology to support collaborative design of Industrial Product-Service Systems

Elaheh MALEKI
IRCCyN, Ecole Centrale de Nantes
1 rue de la Noë, 44300 Nantes
Elaheh.Maleki@irrcyn.ec-nantes.fr

Farouk BELKADI, Alain BERNARD
IRCCyN, Ecole Centrale de Nantes
1 rue de la Noë, 44300 Nantes
farouk.belkadi@irccyn.ec-nantes.fr,
alain.bernard@irrcyn.ec-nantes.fr

Abstract*—Manufacturers, who are adopting Product-service System (PSS) business model, consider PSS as a system of products, services and Cyber-Physical features consisting sensor, software and ICT infrastructure. This new approach in Industrial PSS (IPSS) design makes collaborative design crucial to profit multidisciplinary facets point of views. This approach has also brought new challenges. Considering the above mentioned characteristics, IPSS design relies on communication and information exchange, more than before. Consequently, interdisciplinary design issues are increasingly becoming problematic. To deal with the collaboration challenges between design actors with different facets, ontologies are used to support the collaborative platform of IPSS design. There are plenty of accepted ontologies for each element of PSS yet, as this paper addresses, there is a need to context-based domain ontologies to support the design of whole integrated PSS. This paper discusses about the modular ontology to support the collaborative design of IPSS. In this paper the sensor domain ontology considering IPSS context is described as an industrial practice.

***Keywords*—Industrial Product-Service System, Modular Ontolog, Smart Monitoring, Sensor Ontology**

I. Introduction

To overcome the challenges of the competitive business environment and to fulfil the sustainability issues, manufacturers have started moderating their business model focusing from product to solution by offering Product-Service System (PSS). Starting to offer PSS, industries are trying to support the new form of customer's expectation, which is incorporation of both physical products and non-physical services integrated in a technology-based system.

Using new tools and methods to meet the challenges in front of the PSS design has been received considerable attention from both academy and industry. The new approaches conduct companies to upgrade their PSS by embedding Cyber-Physical System (CPS) components in the offer to support PSS lifecycle engineering, collaborative design and smart services.

There are remarkable incentives to adopt CPS components in the Industrial Product-Service System. Based on case studies, Herterich et al. [1] mentioned "engineering better equipment by leveraging operational performance data, optimization of equipment operations, empower and optimize field service" as the major benefits of such an adoption.

New approaches in IPSS design lead companies to improve their capabilities in through lifecycle PSS design and as a result to a high dependency on the information capturing capabilities. Consequently, enabling through lifecycle observation, sensors are at the core of new Industrial PSS design.

This paper aims to propose a context-based domain ontology approach to support solution finding during PSS collaborative design. As an industrial practice, sensor ontology in an Industrial PSS design project to support the platform's knowledge repository will be presented. The paper is organized as follows: next section gives a brief overview of the PSS characteristics which is followed by the collaborative design methodology in the section after. Outlining the methodology, next two sections describe the proposed context-based sensor ontology and our conclusions are drawn in the final section.

II. PSS Characteristics

The first general definition of PSS is given by Goedkoop et al. [2] as: "a system of products, services, networks of players and supporting infrastructure that continuously strives to be competitive, satisfy customer needs and have a lower environmental impact than traditional business models."

Vasantha et al. [3] reviewed different definitions of PSS used in different methodologies and concluded that "PSS development should focus on integrating business models, products and services together throughout the lifecycle stages, creating innovative value addition for the system".

Meier et al. [4] characterized Industrial PSS by ''the integrated and mutually determined planning, development, provision and use of product and service shares including its immanent software components in Business-to-Business applications and represents a knowledge-intensive socio-technical system''.

Worded by Boehm et al. [6], "integrating sensors and internet with product and service, opens up a new direction in PSS research". Afterward other researchers in PSS domain proposed the integration of PSS and CPS as the new path in PSS design. For example Mikusz [7] proposed "Software-Product-Service System (ISPS²)" and Scholze et al. [8] proposed "Product Extension Services (PES)".

Regardless of different vocabularies to describe PSS [5] and considering the new approaches in PSS design, there are some mutual entities for PSS in the literature as product, service, software, sensor, and actors' network, which are integrated in the system.

III. PSS COLLABORATIVE DESIGN

PSS design has been passed throughout a transition from the added primary after-sale services to the current internet based lifecycle solution. As a result, competitive capability of companies is not any more on adding offline services to their product but to propose a smart function or solution to fulfill the customer needs like remote monitoring and maintenance, real-time information and feedbacks, performance management and preventive maintenance. Considering Industrial PSS model as a meta-model of product, information, service, sensing, information processes and knowledge sharing systems, makes it necessary to adopt a collaborative approach for PSS design.

To support effective collaborative PSS lifecycle design, manufacturers upgrade their product by adding CPS components [8]. Intelligent manufacturing and monitoring through PSS lifecycle are the well-known examples.To offer the above mentioned integrated system of product, service and sensor, PSS design requires involvement of several actors from various disciplines with different facets. Considering this complexity and multi-disciplinary nature of PSS development, using a collaborative IT tool is critical for both provider and customer during PSS lifecycle. In this context, providing the common language to manage the interfaces between various actors is the most complex primary step.

Referring Schmidt et al. [9] we consider "online platform" as a service which provides "relevant data and information of machines, their production status, and the range of functions the customer has booked. Furthermore, it provides individual reporting, a remote service for producing machines and error notifications". During the last decades, several Computer Supported Collaborative Work (CSCW) frameworks have been developed with the aim of assisting actors in their collaborative design activities [10]. However they fail to consider specific integration constraints of mechanical-electronical-software elements of the PSS development process [11].

IV. MODULAR ONTOLOGY IN PSS DESIGN

During the above mentioned collaborative design we need to deal with the complexity of domain as well as the complexity of expertise working in each domain. To fulfil the stakeholders' communication needs, collaboration support platforms are proposed and to deal with the domain complexity, we propose a modular ontology-based design of IPSS elements to support the platform knowledge repository.

Ontology is defined as "a set of concepts and relationships used to describe a particular domain of knowledge". Having high expressive power, high formality, reusability, logical reasoning are the most important advantages of ontology for context modeling [12]. Nadoveza et al. [12] proposed ontology-based context modeling approach consist of domain-specific context extracted from an upper general ontology.

"Due to the complexity of engineering knowledge, modularity in ontology design is a key performance indicator in developing engineering ontologies. Recently, it is identified that attempts made to develop ontologies for product and service design resulted into a massive ontology, which clearly lacked modularity due to bad ontology design and lack of domain experts' involvement" [13]. The modular ontology development proposes that rather than having a massive ontology to cover a domain, it is necessary to abstract and generalize concepts into separate ontologies in order to allow for better flexibility, modularization and maintainability.

The W3C Group produced modular Semantic Sensor Network Ontology (SSN) available at https://www.w3.org/2005/Incubator/ssn/ssnx/ssn. They made use cases from existing sensor ontologies and standards. First "the concepts and relations" have been developed then measuring and operational capabilities, specifications and restrictions. The modular structure of this ontology lets us to use any unit that is required and integrate and link them by customized classes or relations. "This combination can then be used to describe a hierarchy of sensors relevant to the particular application." [14]

V. PROPOSED SENSOR ONTOLOGY

The architecture of the proposed PSS design support platform in ICP4Life project[1] is based on a central knowledge repository as a kernel component through which different business applications are interconnected to provide technical assistance and collaboration facilities to users. To define and implement the structure of this knowledge repository, domain ontologies will be defined and connected to form the whole PSS semantic model. These context-based domain ontologies will be saved in the knowledge repository to support the collaborative platform. (Figure 1)

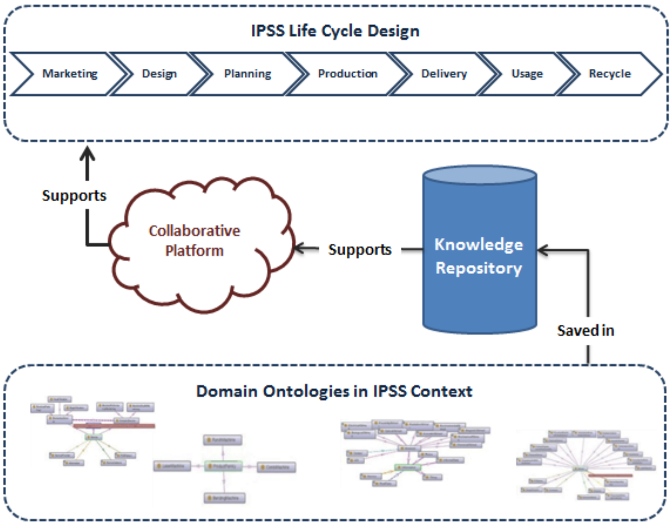

Figure 1. KNOWLEDGE REPOSITORY IN COLLABORATIVE DESIGN

The above mentioned schema shows the multidisciplinary and modular design of IPSS. Considering the IPSS need to integrate sensor in the product-service package, the main domain of ontologies to support the knowledge repository are as follows:

[1] http://www.icp4life.eu/

1. Product component ontology includes the classification of main products categories and their features to support the identification of required standard technical constraints in the design process of the technical solution. The product ontology is used to support adding sensor to the optimal product component.

2. Service ontology includes classification of main service categories by providing a list of standard information and KPIs for each service category. They can be simple or complicated services.

3. Information ontology includes the required information to accomplish the service subjected machine health monitoring, information about machine vibration and temperature of electrical parts should be provided.

4. Sensor ontology includes classification of physical sensors with a technological point of view, according to a set of standard technical indicators to find the optimal sensor for a service. Related to this ontology the sensor specification and working condition ontologies are developed.

5. Connector ontology which includes classification of main connection possibilities and constraints based on the types of the sensors and products. This will help the definition of the integration solution between above mentioned PSS items.

6. PSS Lifecycle ontology is used to classify all possible standard working conditions for each PSS life stage connected to product and service features.

The class sensor takes a central place in the final PSS ontology since one of the most critical task on the PSS design process is the identification of the best sensors for a related integration solution. For this, the definition of a sensor is provided by a set of complementary taxonomies giving different point of view on the same sensor. (Table 1)

Classes	Description	
Complex Service	Machin Health Monitoring	
Elementary Service	Bogie Vibration	Electrical Board Temperature
Service Information	Vibration	Temperature
Product Component	Bogie	Electrical Board
Sensor Technology	Vibration sensor	Thermoresistive Sensors
Design Solution	Onboard	Onboard

TABLE 1. PSS COMPONENTS RELATED TO SENSOR

Analyzing the requirement, the PSS design team identify the services that customer need. According to the complexity of the service, they break it down to some elementary services so that clarifying the information to be captured is possible. Using the product and sensor information, the engineers from mechanical and sensor domain, declare the optimal sensor to add to the suitable product component and the connecting constrains like the position of the sensor on the product is will be defined.

A. *Integration solution*

Integration solution is the most fundamental concept in sensor ontology which supports the integration of optimal elements to provide the solution. (Figure 2)

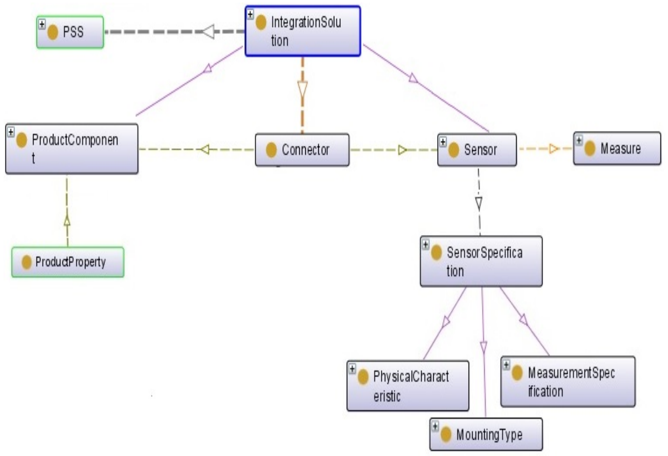

Figure 2. ONTOLOGY-BASED INTEGRATION OF SENSOR AND PRODUCT

The process of providing the optimal integration solution starts with matching the sensors' specifications and product components' specifications. This process is highly dependent on the ontology models. The integration solution ontology in one hand provides the semantic connection between product component, connector and sensor ontology and in the other hand it supports the connection with PSS lifecycle.

To bring the ontology into play, we need to know the whole related components in general. (Figure 3) To provide the final solution, the requirement analysis shows the needed services. To fulfil each requested service we need to capture some related information which will be detected by sensor.

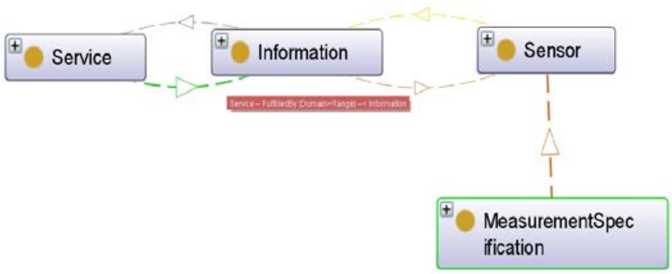

Figure 3. PSS COMPONENTS RELATED TO SENSOR

Next step, using product manufacturer information about the machines and required service by customer, the first general layer of domain ontologies prepared. Sensor technological view and sensor specifications from sensor engineers will be added to this modular ontology. (Figure 4)

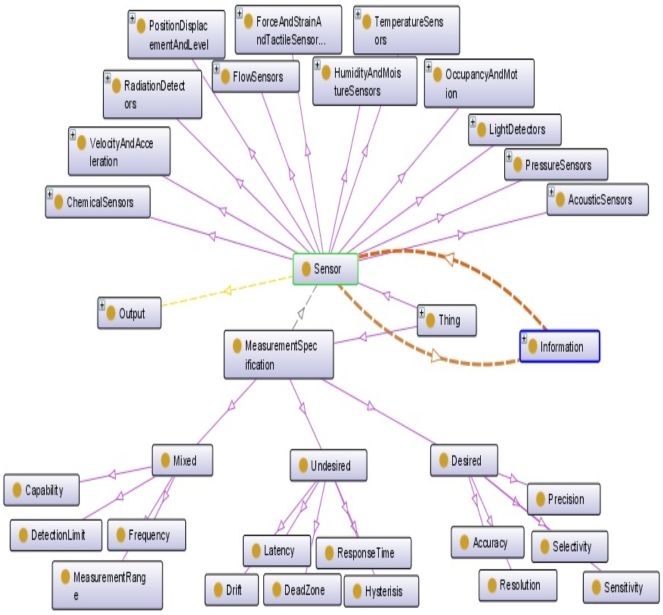

Figure 4. SENSOR ONTOLOGY IN PROTÉGÉ

Using the PSS general ontology, we extract the concepts which have direct effect on sensor ontology. Defining all relationships in detail, the process model helps us to identify the main classes of sensor ontology. According to the modular ontology strategy we have adopted, each of these classes in sensor ontology is detailed in their own ontology. Considering all above, we defined various main classes in sensor ontology as:

1. Service
2. Service Information
3. Sensor Technological point of view
4. Sensor Specifications
5. Measurement Specifications
6. Working conditions
7. Connection Constraints

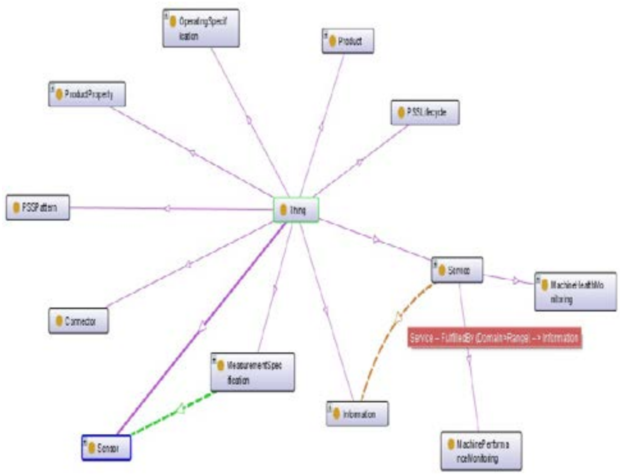

Figure 5. FOCUSED ONTOLOGIES

These ontologies are linked and integrated to support the knowledge repository of the collaborative PSS design. (Figure 5)

B. Service ontology

For this earlier stage, different types of services are identified as part of the service taxonomy. In the supportive platform, this service taxonomy will support the easier identification of necessary service according to the category of client and request but also to identify the list of suitable information according to the related type of service. (Figure 6)

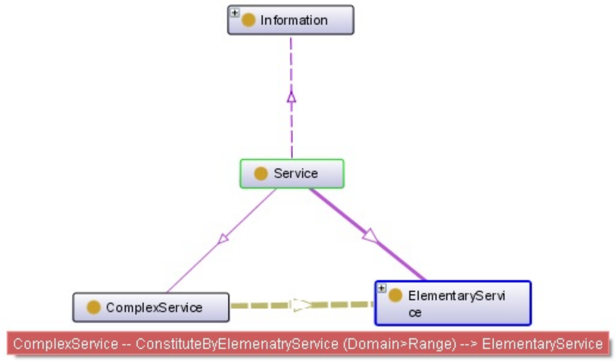

Figure 6. SERVICE TYPES

C. Service information ontology

Service Information, also called “Measurand” and “Stimuli” are defined as “detectable changes in the environment” [15]. According to W3C Semantic Sensor Network Incubator Group, Measure or Stimulus is “An Event in the real world that triggers the sensor”. From the technological point of view, each sensor measures a special event. The classification of information types will help the rapid identification of the identification of main attributes according to the measure domain. This will help engineers to correctly introduce new sensors in the knowledge repository and in consequence, identify easier the best sensors at the conception stage. (Figure 7)

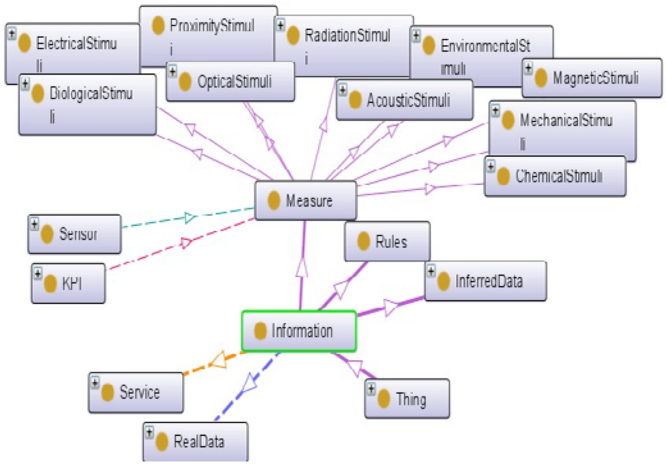

Figure 7. INFORMATION TAXONOMY

D. Sensor ontology

"Sensors are physical objects that perform observations"[15]. The Sensors taxonomy describes the sensor from a technological point of view. This taxonomy shows the different types of sensors. This taxonomy extracted mostly from the commercial portals and some guidelines from sensor handbooks. Integrating both point of views, we proposed the technological point of view of sensor. (Figure 8)

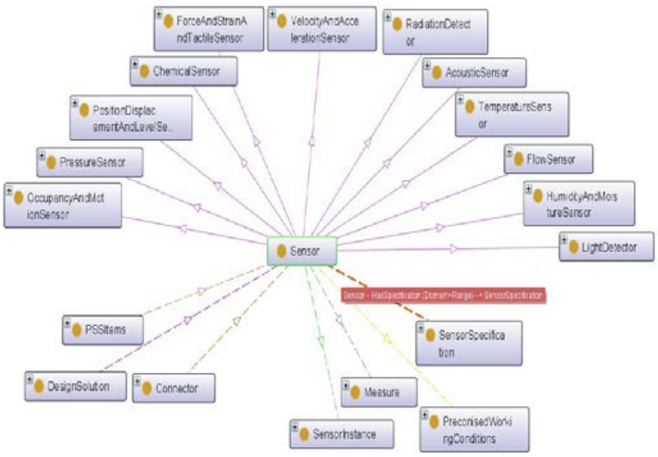

Figure 8. SENSOR TECHNOLOGICAL POINT OF VIEW

It is the principle of solution used to provide the requested measure by the sensor. This will help for example the identification of the main technological constraints to be respected when selecting a sensor. It is also required by the compatibility verifier component to check if the used technologies allowed the use of two different sensors (or more) in the same physical area of the product.

E. Sensor specification ontology

Sensor specification gives the main characteristics of the sensor as preconized by the sensor provider. This will help for example rapid identification of possible connection constraints according to the mounting type. (Figure 9)

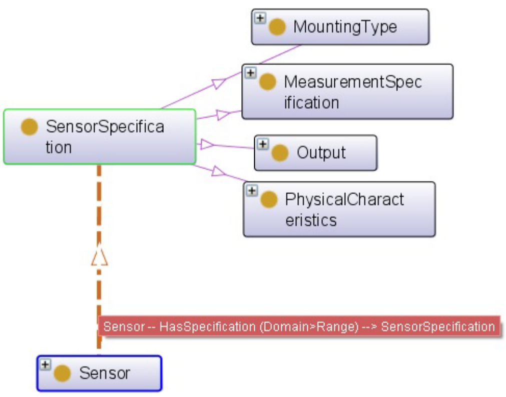

Figure 9. SENSOR SPECIFICATION

"A sensor may have a number of measurement capabilities describing the capability of the sensor in various conditions." [14] Sensor measurement specification describes the sensor operation ranges which can be used in KPI as well as sensor selection. This will help the connection of sensor to the related categories of information for rapid identification of suitable sensors in the proposed PSS. (Figure 10)

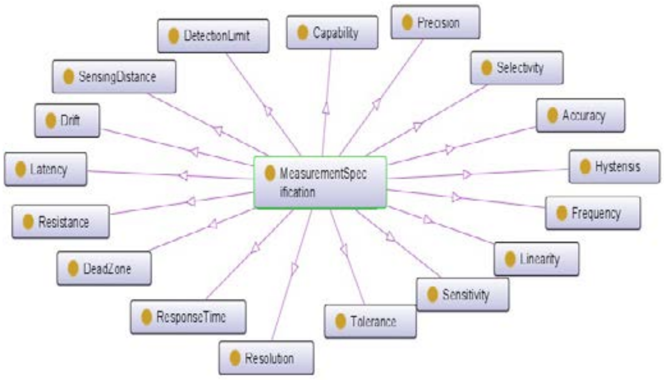

Figure 10. MEASUREMENT SPECIFICATION

Working condition defines the environment where sensor is embedded. (Figure 11) Connecting sensor specifications and working conditions is one of the most important criteria to select the best sensor and optimum solution. This is based on the matching between nominal working conditions and real working conditions of the target product.

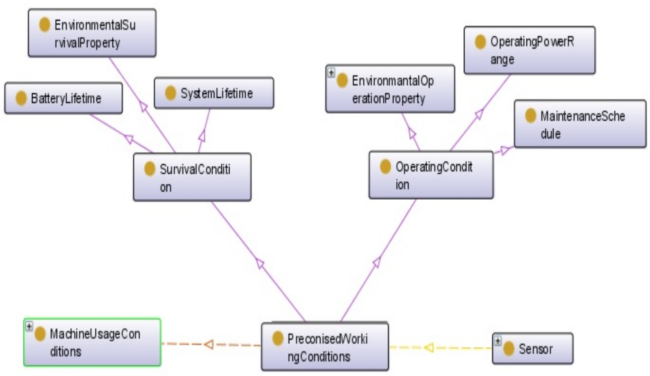

Figure 11. SENSOR WORKING CONDITION SPECIFICATION

To integrate a service with product, connector plays the role of connecting the sensors, the equipment and the product components as the physical system of PSS. Connecting to the mounting type, this will help for example the identification of all constraints to be considered when fixing a sensor to a product component.

VI. CONCLUSIONS

In this paper, domain ontology is proposed to support PSS collaborative design. This ontology is developed using taxonomies for sensor and PSS engineering functions. Reusing domain ontologies is not enough for IPSS modelling. For ontology-based design of IPSS we need to add a tailoring process according to the context. Providing sensor ontology in IPSS context needs a semantic connection with other elements of the system. Similar as general ontology design processes we need to customize the currently exist domain ontology according to the IPSS context need.

This research allows manufacturers to capture and reuse the IPSS design knowledge in modular design. Although our focus is on the sensor ontology, zooming out the view to consider the dependencies between elements is crucial.

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