Software Agents for Automated Knowledge Generation in IPS²

R. Gegusch, K. Gestrich, G. Seliger
Department for Machine Tools and Factory Management, Technische Universität Berlin, Germany

Abstract

For a competitive (re)design, planning and usage of Industrial Product-Service System (IPS²), knowledge about the usage patterns of the customer, the IPS² system behavior and the remaining lifetime of products is needed. The data from the operation phase is the source to discover this knowledge. With the help of software agent technology product- and process data can be made locally available - data which are spatially and temporally distributed along the life cycles of IPS² in different media and formats. In a next step it will be processed with the help of data mining algorithms in an appropriate form to knowledge, as required by the application. The Virtual Life Cycle Unit (VLCU) is a concept for such an information system. It is an information technology network, which appears to humans or machines as a single unit to support the supply chain and communication processes in the complete IPS² life cycle.

In this paper the technology, data acquiring and communication concepts of the VLCU in the IPS² life phases is being discussed and presented.

Keywords

Industrial Product Service Systems, Virtual Life Cycle Unit, Knowledge Generation, Software Agents, Ontology

1 INTRODUCTION

In business-to-business and also business-to-customer markets there is a tendency towards combined offers of products and services, which are sold in one package to fulfill customer needs. These combinations of products and services are called product-service systems (PSS) or industrial product-service systems (IPS^2) in case of industrial application [1]. The use models of Industrial Product-Service Systems (IPS²) are based on the idea of selling functionality, availability or results instead of selling machines.

For a competitive design, planning and usage of IPS², knowledge needs to be generated about the usage patterns of the customer, the IPS² system behavior and the remaining lifetime of products in the IPS². The data from the operation phase is the source to discover this knowledge. With the help of information technology product- and process data can be made locally available, data which are spatially and temporally distributed along the life cycles of IPS² in different media and formats, and processed in an appropriate form - as required by the application. The Virtual Life Cycle Unit (VLCU) is a concept for such an information system. It is an information technology network, which appears to humans or machines as a single unit to support the supply chain and communication processes in the complete Industrial Product-Service System (IPS²) life cycle.

2 IPS² LIFE PHASES AND REQUIRED KNOWLEDGE

The idea of selling functionality instead of products is the core idea of Industrial Product-Service Systems (IPS²) [2]. To be competitive on the market the provider and manufacturer of IPS² have a strong interest in using a minimum of production resources, which means maximum utilization and usage of products and components. Therefore manufacturers of capital goods (e.g. machine tools) expand their business activity beyond selling physical products. Industrial customers make their day-to-day business by selling this kind of products (e.g. manufacture components) which means that they are interested in functionality over a time frame to achieve a result [3]. Therefore, with new business models manufactures of capital goods offer functionality, availability or results instead of selling products to meet the customer needs. Selling functionality means that the customer gets the physical products designed to its requirements. The customer is responsible for maintenance and the risk of breakdowns or in the case of selling availability or results, the risk for breakdowns, malfunctions and the execution of maintenance processes goes over to the provider.

To maximize the lifetime of components and to replace them at the time before it breaks – not too early, but to ensure the functionality not too late - a lifetime prognostic is required. It facilitates a minimum costs for spare parts due to enable the maximum use of resources and prevent an unseen production breakdown. Of course this implies that the exchange can be made within the time to the predicted breakdown. From the point of the planning, this might be not always economical. It might be cheaper to replace a part during an inspection, than sending a technician two days later again to replace the worn part. Lifetime prognostic allows a condition based scheduling for services. Finally the lifetime prognostic also enables the reuse of components. Combined with a condition diagnostic it is possible to decide if a used component can have a second life phase in another application. This saves further resources and so and leads to a more competitive IPS².

Assuming that the IPS² provider knows about the usage patterns of his customer, the design and planning would be made perfectly matching to the customer needs or the provider would give advises to his customer how to produce more economic. In the initial phase of the IPS² business relation, the customer tries to communicate his demands to the provider. He tries to design an IPS² which fits best to these requirements. However, most times the sold product or in our case IPS² has many chances to be enhanced. This is because the designer relies on ideal assumptions that differ from the real product behavior and use. Identifying these gaps would create the ability for a more efficient design and planning of the IPS².

To ensure the functionality, to enhance the design of the IPS² and to adopt the services the provider needs knowledge about the IPS² system behavior. The system behavior is knowledge about inferences between product and services, as well as services or products among each other.

If identified new system behaviors, e.g. for the early malfunction of machines under certain conditions, the question is for which IPS² in business this is effective. Usually every IPS² is a unique system, but certain conditions lead to a system behavior, which bases on design, usage etc. To identify similar IPS² classification are useful. Classification identifies groups or similarities.

In addition as mentioned before lifetime prognostics is required to prevent loosing of production functionality due to unplanned breakdowns and so to schedule services, like wear part exchange to optimize the service scheduling or to save resources.

This is called knowledge, as it leads to a competitive provision or design of IPS². Actually there are many definitions for the term knowledge, but the definition of [4] has become more and more popular within the last years. This defines knowledge as the appropriate linking of information. Knowledge results from the processing of data and information, acquired in certain situations. So data and information are the raw material for knowledge. The value of knowledge will be shown, when it is referenced to an application and the ability for acting is facilitated. The acting itself needs an intention and if acting correctly and original or inventive, the competitiveness is given, see Figure 1.

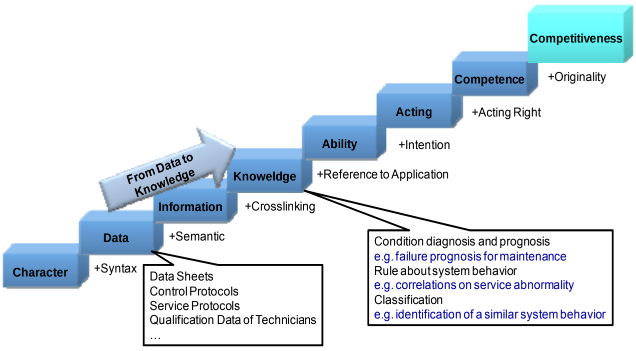

Figure 1: Knowledge in the context with as the foundation for competitiveness [4]

This means that automated generated knowledge set the foundation for a competitive business with IPS². Therefore the VLCU and its knowledge generation is an enabler for the competitive redesign, planning or delivery in the IPS² business model.

3 DATA SOURCES FOR KNOWLEDGE GENERATION

Due to the modern IT based engineering, business communication and documentation, most data along the life cycle of an IPS² are already digital available and via internet worldwide accessible, e.g. machine datasheets, service protocols or personal database. The challenge lies in the access, acquiring, communication and finally the processing to knowledge to support the decision-maker along the IPS² life-cycle.

The available data sources are in different formats and media. The VLCU access these data sources by the use of software agents. Agents are software modules acting independent, based on given rules. Those agents build the communication and processing platform for the knowledge generating information technology concept of the VLCU. Necessarily not every single source has to have an own agent, one agent could also handle different local sources. Each agent is responsible for a location of data sources. Finally this concept allows a database, file or company-based access.

The content of the data sources and their relations are described by an ontology, to select the relevant data for the knowledge generation process. In the context of computer and information sciences, an ontology defines a set of representational primitives with which to model a domain of knowledge or discourse. The term is taken from philosophy, where ontology is a systematic account of Existence. For Artificial Intelligence systems, what 'exists' is that which can be represented. [5]

4 EXAMPLE SCENARIO

As an example scenario there shall be electric wire discharge machines in micro-production, with the problem that the wire is sometimes not transported correctly and get tangled up along the transport wheels. The question for the designer is what causes this problem. Knowledge about under what conditions this happens facilitates an effective analysis of this problem and enables to develop the right therapy. This inference knowledge can be found by comparing the data of the usage of all machines of this kind. Influencing factors to this problem can be technicians, service procedures, special kind of used spare parts, production equipment, the process itself or production conditions. This means, that the VLCU needs to call data from the control protocols from the wire erode machines, the IPS² customer production, service protocols from service partners, datasheets or quality test reports about used production equipment and involved technicians personal and qualification data. Those are distributed digital available within the databases or computers of the partners in the IPS² supply chain. The technical access for the VLCU to these data is being done by using software agent technology.

5 SOFTWARE AGENTS FOR DATA ACQUIRING AND COMMUNICATING WITHIN THE VLCU NETWORK

In the VLCU Network the JADE (Java Agent DEvelopment Framework) [6] Software Agent system is used for acquiring and communicating the information that contains knowledge. The software agents work within a network in a flat hierarchal concept. A special designed agent - the so called DataAdministrator Agent - acts as the controlling unit for the VLCU Network; it sends out the requests for data delivery to the agents at the data sources and collects all communicated data into its connected database - the so called VLCU data warehouse. A data warehouse is a standardized, consistent, clean and integrated form of data sourced from various operational systems in use in the organization, structured in a way to specifically address analytic requirements [7]. This database is the source for the data processing step; the knowledge generating.

JADE is a software Framework fully implemented in Java language and based on the FIPA (The Foundation for Intelligent, Physical Agents) specifications for software agents and their message based communication [8]. The implementation in Java language makes it independent of the operating system where it is executed. The message based communication allows an asynchrony operation which ensures a robust system as well as that the agents cannot interfere with each other.

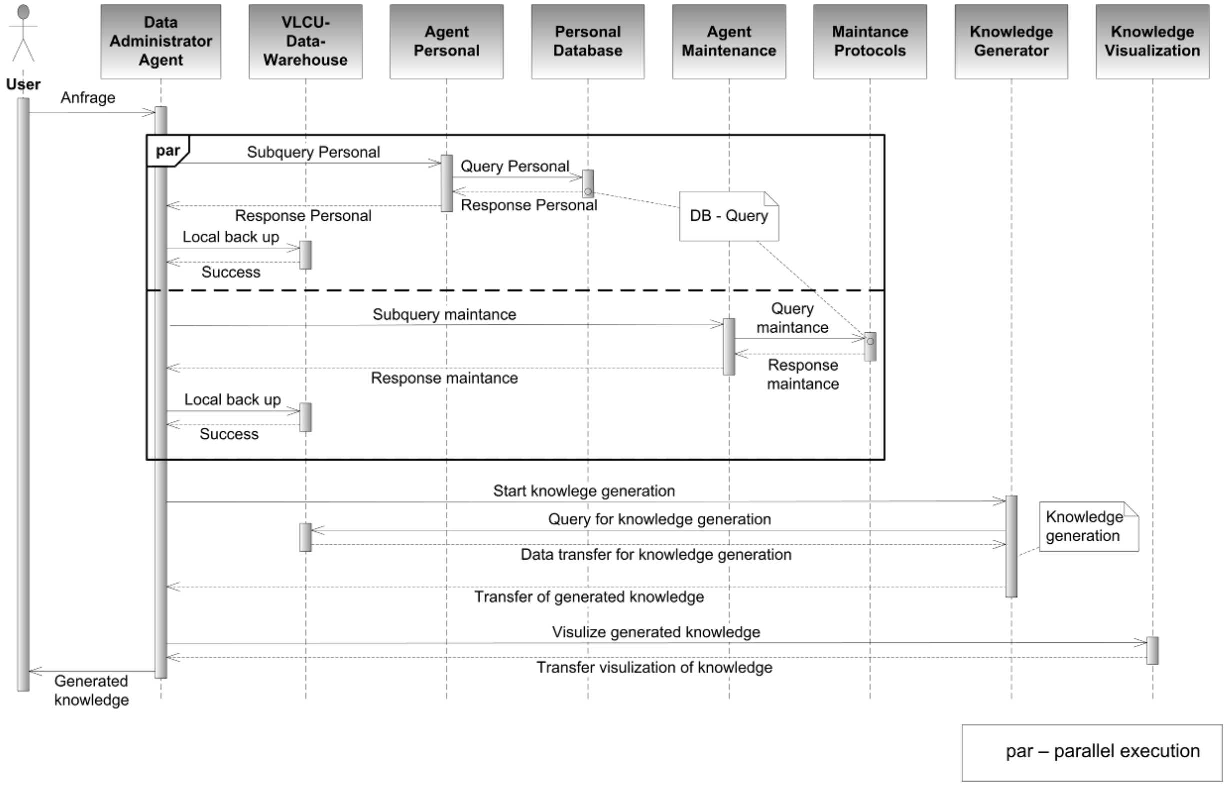

Figure 2: Communication Sequence Diagram of the Agents for the knowledge generation in the VLCU network

At the top of the JADE Agent hierarchy there are platforms that are composed of container, holding the individual agents. Each platform has one main container that holds two administrative agents – the Agent Management System (AMS) and the Directory Facilitator (DF).

The AMS agent could be called the white page of the network - it has the function to insure that each agent has a unique name and address within the platform. The DF agent can be referred to as yellow pages - it manages the available services from the registered agents within the platform. This means it tracks which service is provided by which agent and lists which agent has booked which type of services. So it informs all agents booked for a type of services when a new service of that type is available. The information flow is based on the pushing principle. A new agent sends which services it offers to the DF agent. In turn it informs all the agents that have booked that type of service about the newly available service. These two agents are the basis for a dynamically changing network, where agents can sign on and off. The IPS² network is growing dynamically with new service provider that only need to register with their own JADE agent to integrate into the VLCU network. A new agent in the network has to register with the AMS agent first, before it can register its services with the DF agent.

Via internet it is possible to connect distributed data sources in different locations, e.g. companies or data centers. Unfortunately security reasons within the internet demand that each location is protected by a firewall. The asynchronous communication in a single platform is difficult without reducing the effectiveness of the firewall by opening a communication port. Therefore each location has its own platform, which communicates with the help of the Message Transport System (MTS) [6]. This facilitates an easy connection of two or more platforms. That way the services from an agent in another platform can be used. In our example scenario three locations that are distributed but connected by internet have to be connected to the DataAdministrator Agent. Those are e.g. the customers' administration building with the personal database, the customers' factory with the usage and machine control protocol and the service provider 'maintenance' with the service and maintenance protocols, see Figure 3. A communication sequence diagram of the agents for the knowledge generation in the VLCU network is shown in Figure 2.

In the VLCU agent network the service 'data-service' provides a uniform connection to the data managed, stored or monitored by the agent, as well as its documentation by its partial ontology. The DataAdministrator Agent is looking for services of the type data-service. It requests each agent providing such service to transmit what kind of data it provides along with the partial ontology. The DataAdministrator Agent can then generate a comprehensive ontology of all the data available in the network and the agents providing it.

The DataAdministrator Agent analyses the requested enquiry to tasks the agents having access to the data which has to be considered in the knowledge generation process. Here the ontology helps to identify which data sources are relevant for the given knowledge processing, see Figure 4. In our example scenario the electric wire discharge machines are being used for micro-production. As micro production is sensitive for temperature changes, data from the production room´s air condition is required. The ontology holds this relation and refers to the air condition protocol as one of the required data source for the knowledge generation process.

The agents transmit the data back to the DataAdministrator Agent which stores it then in the central VLCU-Data-Warehouse database. The analysis is performed by the Knowledge Generator that operates on the data stored in the VLCU-Data-Warehouse. Further the processed knowledge will be archived in the IPS²-Life Cycle Management System (HLB-LM) [9]. This allows documentation and fast access to all kind of actors within the IPS² network.

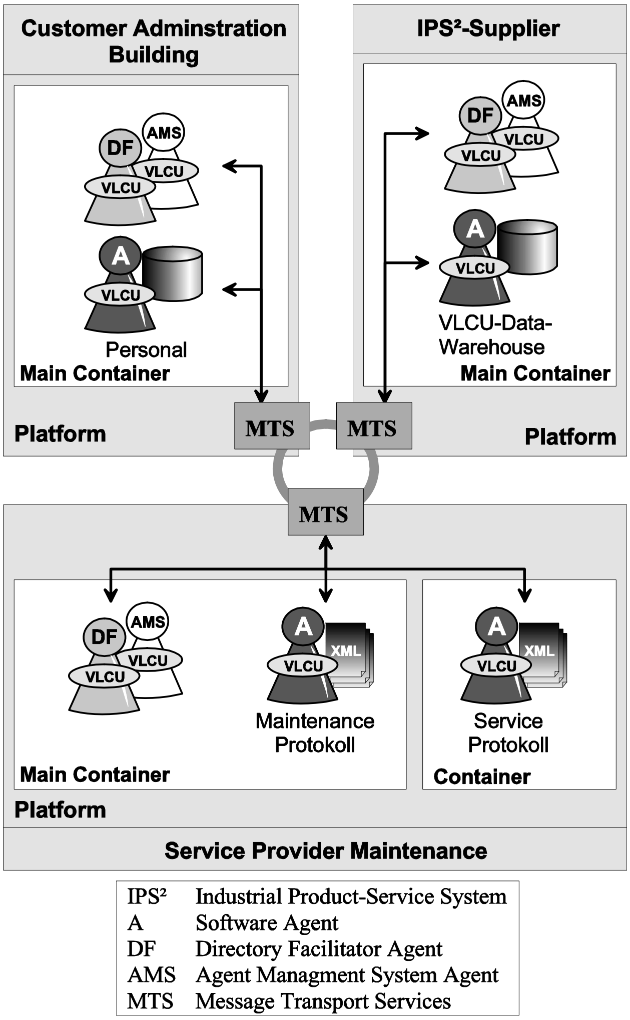

Figure 3: VLCU Agent Network

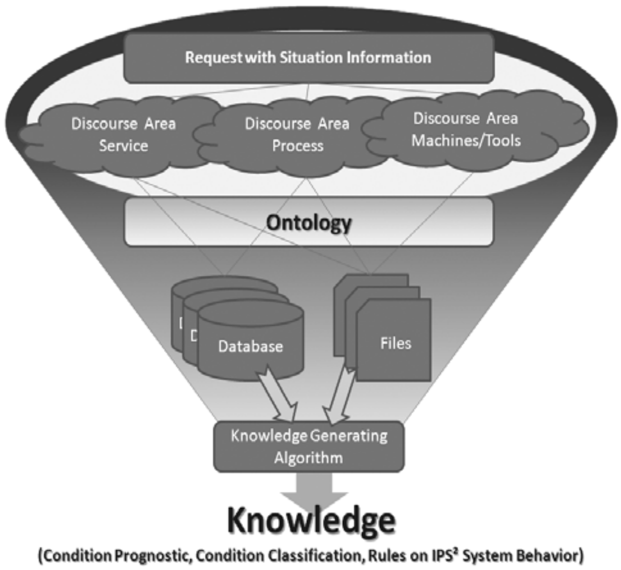

Figure 4: Ontology enables a request-based selection of relevant data sources

At the state of the research the distributed data is transferred as needed to the VLCU-Data-warehouse and the knowledge generation process is done centralized. As a perspective the knowledge generating process shall be done decentralized on the agents where the data is stored. The knowledge generation process would be executed on a VLCU-agent-mesh. This would lead to a network without the data warehouse, which is actually a storage, communication and processing demanding system. Further the access to the knowledge processing can be done via the software agents themselves, which gives access to all supply chain members, be connected in the VLCU network.

6 KNOWLEDGE PROCESSING

Knowledge is generated by linking IPS² operation information and describes the system performance within the IPS². This includes rules about the process flow of the IPS² and its operations, as well as prognoses and classification of ISP² health condition [10]. Rules about the IPS² workflow can be generated from the operation data. It is possible to classify the influencing parameters and variables to each parameter with e.g. the aid of the C4.5 algorithm, which is based on the ID3-algorithm, basing on the Bayes theorem. The hereby generated dependencies can be displayed in a decision tree structure. This decision tree can be used as a system of rules for the decision making processes within the IPS² development and supply chain.

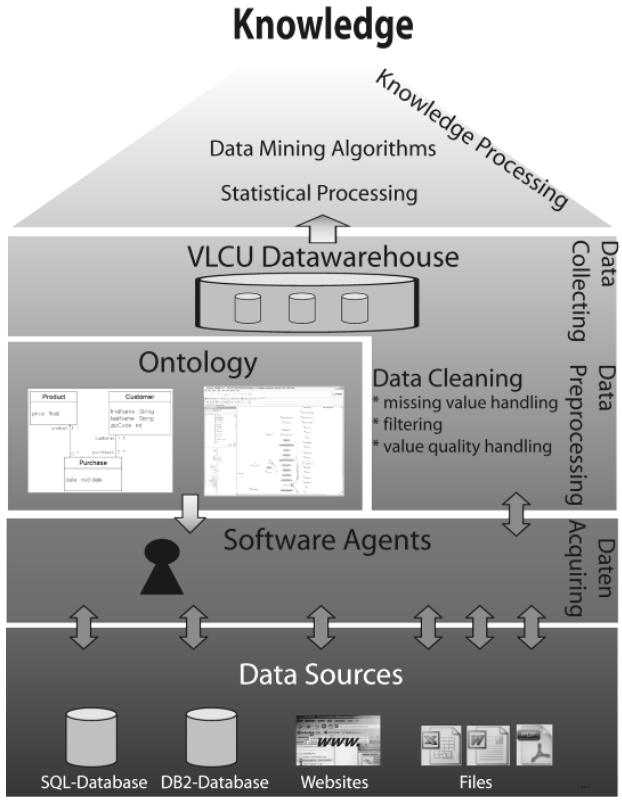

Figure 5: VLCU Concept Structure

Prognoses of the system condition are important knowledge, e.g. for the strategic planning. That way the service can be planned with the aid of a forecast for the time to failure, based on the actual condition of the machine. Controls act according given rules via fixed parameters - whereas the real lifespan is influenced by a multitude of influences, e.g. surrounding temperature, used tools or even the handling during the assembly. Via clustering algorithms like Statistical Pattern Classification it is possible to identify failure cluster and define or classify product health conditions.

By interpolation of the system conditions out of the IPS²-control, condition based prognostics is enabled – with failure mode statements. Prognoses also facilitate questions regarding the reuse of components, which stays in connection with the reconfiguration of IPS².

In the mentioned example scenario the C4.5 algorithm was able to identify a inference between the failure event and the used discharge wires. If an amount (length) of thicker wire (250um) has been used the transport of thinner wire (50um) failed. This knowledge leads to an investigation about the reason and it could easily identified, that the use of ‘thick’ wire lead to a wear on the transport rolls – which were actually not listed as a wear part. Roping avoid the needed contact for the correct transportation and so the ‘thin’ wire. The generated knowledge helps to locate the failure and enables a more focused problem search. The solution finding process is part on the level of planning and design.

This scenario leads to a result, which could be argued to be out of one data source, the control protocol. But this is not true. In dependence of the documented data of the machine control, the used length might be stored in the storage data base, where the available discharge wire is being listed. Then are already two sources minimum required. But as the inference is not identified at the time of the question, all data need to be investigated to identify the inference. The agent technology helped in the access of those data to process this in an automated network system.

The presented scenario based on a real problem with an AGIE electric wire discharge machine at TU Berlin, when the wire transport role was not declared as a wear part. Due to the research activities on this machine the wire has been unusual often being changed, why this problem occurred there first. Long and hard hand investigation identified the transport rolls in combination with the mentioned wire thickness. AGIE adopted this knowledge and declared the transport rolls as wear parts.

7 SUMMARY

The need of knowledge for the creation of competitive IPS² is essential. The available digital data along the IPS² life cycle are a source for an IT based knowledge generation to support the IPS² creation and design processes. The concept for an IT architecture has been presented in detail for the data acquiring and communication with the help of software agents, see Figure 5 – the so called Virtual Life Cycle Unit. Software agents enable a simple and adaptable way to access the data and also to give access to the knowledge generation for every partner within the IPS² supply chain. Further this technology allows and dynamic growing of the network, which is crucial for an effective and competitive supply chain network. The presented JADE implementation is widely used for software agents and allows an easy adaption and implementation for the most available computer systems.

In an example scenario the chances and needs of the IT based knowledge generation with VLCUs for supporting the design and creation processes to deliver a competitive IPS² has been shown.

8 ACKNOWLEDGMENTS

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