Multimodal User Support in IPS² Business Model

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Abstract

The use models of Industrial Product-Service Systems are based on the idea of offering functionality, availability or results. This paper proposes a concept for multimodal user support in interaction with condition monitoring and knowledge generation, whilst taking knowledge protection into consideration. A shared-vision system connects a less-qualified person with an expert for solving problems collaboratively. The user is instructed via multimodal user interfaces, which require data related to the service design, construction model as well as the current machine condition. Such data is acquired by a process accompanying information system, which deliver information relevant to the required service from sensors.

Keywords:

Industrial Product-Service Systems, Shared Vision, Virtual Life Cycle Unit, Knowledge Generation

1 INTRODUCTION

To keep competitive in times of global economy, manufacturers of capital goods (e.g. machine tools) have to expand their business activities 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. Therefore, manufactures of capital goods should 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 supplier is responsible for maintenance and the risk of breakdowns. In the case of selling availability or results, the risk for breakdowns and the execution of maintenance processes goes over to the provider. To guarantee the functionality over a time frame or to achieve the result the provider has to have full control about when, where, what for, why, by whom and how the machine is being used and maintained. Unwanted or unqualified modifications or changes on the product might risk the loss of the granted availability or result.

The manufacturer has to provide qualified service technicians that have to be able to support the customer on the location where the machine tool is set up. From the economical point of view the required on-site activities for maintenance and support should be carried out with minimal personnel effort of the supplier. Since teleservice, as an often stated support mechanism [1], is not suitable to solve all technical problems, one possibility for on-site support is to outsource technical service to local service providers that act as subcontractors. Another way to keep the manufacturer’s effort small is to enable the owner of the machine tool to maintain it by its own staff. Nowadays, in both cases the manufacturer has to publish required information material (e.g. construction drawings, detailed service manuals). Therefore, a transfer of sensitive data and know-how is often unavoidable while the machine tool manufacturer risks loosing service contracts. The loss of know-how is a tremendous risk for first world companies producing or selling on the global market, especially regarding low cost countries [2].

So, the challenge is to enable the local machine operator regardless of the technical qualification of its staff to perform maintenance and inspection tasks for complex machines. This has to be done at the time and place where it is required and without transferring detailed knowledge. Classical use models based on selling physical products and offering product accompanying services are not able to face this challenge due to the independent design of product and service.

The idea of offering functionality, availability or result instead of selling machines and additional services leads to the necessity of an integrated and mutually determined planning, provision and use of product and service shares including its immanent software components, so called Industrial Product-Service Systems (IPS²) [3].

An Industrial Product-Service Systems (IPS²) is built by a combination of a product and a service, so solutions which are offered to customers, content shares of product and service. Depending on this solution it is possible to characterize three different IPS² use models: function-, availability- or result-oriented [4]. The product is described as a tangible, which can be delivered by the IPS² provider to the customer and is the profit making component of an IPS². The service is intangible, which provide a value to the customer [5]. The IPS² provider is the only contract and contact partner of the customer. He is responsible for all activities, needed to use the IPS² as agreed in the contract.

In this paper a concept for multimodal user support in an availability-oriented IPS² will be described and demonstrated within a micro production scenario.

2 PREREQUISITES TO GUARANTEE AVAILABILITY

The considered physical product has to feature special characteristics to enable the above mentioned use model of guaranteed availability without the provision of on-site service technicians.

Integrated Condition Monitoring

The provider of an availability-oriented IPS² needs to know when the machine is going to fail, for example due to wear of relevant components. Therefore, the conditions of all function relevant components have to be monitored by a Condition Monitoring System (CMS). This CMS uses sensor and control integrated signals to generate condition related characteristic values [6]. It detects trends of these values and, if possible estimates the remaining life-time of the respective component.

Integrated Load Monitoring

Machine tools are designed for a predefined set of loads that depends on the customer specific type of application, for example material to be machined and process parameters. The resulting load profile gives information about the way the machine tool is used [7]. The IPS² provider can combine this profile with the monitored condition of the machine to derive a cause-and-effect chain and to check up on the correct treatment of the machine. For example a shock sensor integrated into a lathe detects mechanical shocks on the spindle that may cause damages of the bearings. The recordings of these events indicate a reason for reduced life-time of the spindle.

Tamper-resistant Design

Since the IPS² provider is responsible for the availability of his production system he has to guard against manipulation. This means that all damageable parts are difficult to access by unauthorized persons. For parts where this is not possible due to functional restrictions, a monitoring system has to detect and log interventions. The design of the machine has also to ensure that no technology relevant know-how can be obtained during service operations.

Communication Interface

To inform the IPS² provider about machine conditions and maintenance activities needed, it has to be equipped with a communication interface. This interface is also used by the IPS² provider to authorize and support the local machine operator to execute service processes and for teleservice purposes [8].

Modern User Support

A possibility to facilitate users to do services beyond their qualification without additional personnel costs is the use of modern technical human-machine interface systems (e.g. head mounted displays) in combination with product and process accompanying information systems with knowledge generation. Intelligent display methods can prevent unintentional knowledge transfer.

In the proposed use model, the technical service shall be performed by the machine user. To avoid the loss of know-how, required technical information is only available during a service operation. Therefore, adapted service instructions have to be given dependent on the situation and the user on-site. The instructions should enable the machine user to perform the service operation without the need of technological know-how. To reach this goal an integrated design of relevant machine components and service processes is required.

Service Process Control and Documentation

Service and product shares influence their specifications complementary and can be partially substituted against each other in the concept of IPS². Service processes have to be designed as modules in an availability-oriented IPS² to ensure planning reliability and process reliability, as well. To control an arbitrary process it has to be almost deterministic. Therefore, measurements that indicate start and end of each process step have to be defined. Further measurable quantities are needed to evaluate the service quality. The documentation of the service process provides evidence of executed service and can be used for quality management and knowledge generation to optimize the process or its model.

The following sub-chapters give a more detailed overview of the above mentioned features and show exemplary concrete solutions.

2.1 Multimodal User Support

The integration of multimodal user interfaces is an adequate solution to reduce the complexity of human-machine interfaces and to reduce errors while interacting [9]. Automated, knowledge based, and adapted user-machine dialogues can provide a reliable support for qualified and less-qualified users.

As described above, availability-oriented use models require short downtimes of the machine and low costs of service. To reduce service costs and to realize immediate and personal support for the machine user, one established model of service is teleservice. It was mentioned first by Kearney & Trecker, a machine tool manufacturer, for the description of telecommunication regarding to customer service, e.g. start-up, maintenance, and repairing [10]. In particular, Massberg et al. point out that teleservice leads to a close relationship of customer and provider where the human being plays a decisive role [11]. The Projects ARVIKA [12] and ARTESAS [13] introduce head worn user support devices and demonstrate that technology for industrial e-services [14] already exists.

In case of support by teleservice, e.g. in repairing, two people (the technician and the remote-service expert) collaborate to solve a problem, which is called a remote collaborative physical task [15], while the process of collaboration can be called as distributed problem solving. A system which supports two persons in distributed problem solving was described by Velichkovsky, who tested the effect of gaze transfer in his experiments [16]. Gaze-position transfer in this experiment of solving a puzzle task improved the performance and changed the communication process positively.

To support a machine user in a remote collaborative physical task, a mobile and stationary device is needed. This system is called a shared-vision system and enables two persons to solve a problem from separated places. The following support process is already developed and in the phase of testing by Hoege and Roetting:

A user wears a head mounted system (cf. figure 1) at the place of the machine. S/he is connected by internet with a remote specialist who is sitting in front of a PC monitor. The scene camera of the user transmits the view on the machine to the remote specialist as well as the gaze coordinates which are measured by a head mounted eye tracker. The remote specialist can see the view and the gaze-position of the user on a monitor in front of her/him. For supporting the user, the specialist's gaze coordinates are recorded by a remote eye tracker. His/her gaze data is transmitted to the user's head mounted optical see-trough display. In this display the user can see the gaze-position of the remote specialist. Additionally, both are connected by an audio interface (headset) for verbal communication. Normally, a person is looking at the object his or her attention is focused on. Therefore, the transmission of the gaze positions of the two participants will support and ease the communication between them.

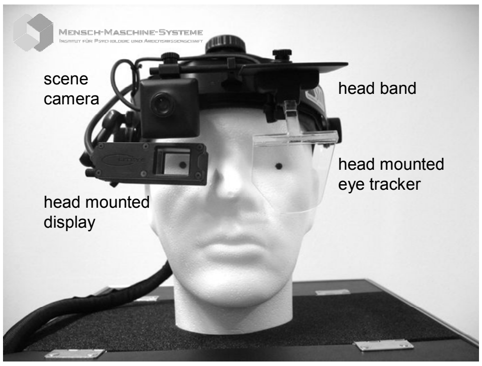

Figure 1: head worn components of a shared-vision system.

One component of the shared-vision system is a head mounted display which is used to place information directly into the field of view of a user. In case of a see-through display it is possible to augment the real world with additional information. The visualization of a person's gaze into the view of another person is an application of augmented reality (AR). Augmented reality is part of the reality-virtuality continuum defined by Milgram and Kishino in 1994 [17]. One side represents the real world as it exists and the other side represents a virtual world computed and realized by adequate technology. Additionally, AR can be used to visualize, e.g. instructions, data by integrated sensors, or exploded drawings into the view of a worker, so s/he does not have to switch his focus of attention between a printed instruction manual or a monitor displaying the sensor data separated of the machine.

Speaker-independent speech recognition and gesture recognition for interaction with the user interfaces in the HMD or the PC-based interface of the micro production machine can be easily integrated for a multimodal and hands-free interaction concept.

For optimal user support, a seamless integration of collected data by sensors and for an automated knowledge generation, an implementation of a technically intelligent [18] device into the multimodal interaction concept is necessary.

2.2 Virtual Life Cycle Unit

Effective and efficient adaptation can help to reduce resource consumption by e.g. extending the product's life span and by supporting availability-oriented use models. IPS² providers are confronted with increasing demands for product and process availability, reliability and safety. Therefore, the assessment, prediction, diagnosis, monitoring, and control of product and process behavior are desirable.

Adaptation is facilitated by IPS² accompanying information systems which are capable of acquiring, processing, and communicating relevant IPS² product and process data and information, whereby information stands for linked data. These data and information deliver potential sources to obtain experience, like inferences about conditions, wear or quality aspects and deliver knowledge about the behavior and usage of their products [19]. The Virtual Life Cycle Unit (VLCU) is a concept for an IPS² accompanying information system for knowledge generation and control (cf. figure 2). A VLCU acquires via sensors or IT-documents data and information from IPS² operations and components, wherein the term operation includes products and services. This may include technical, economical, environmental and social product and process attributes and parameters [20] e.g. location, utilization, efficiency, emissions, condition, malfunctions and failures.

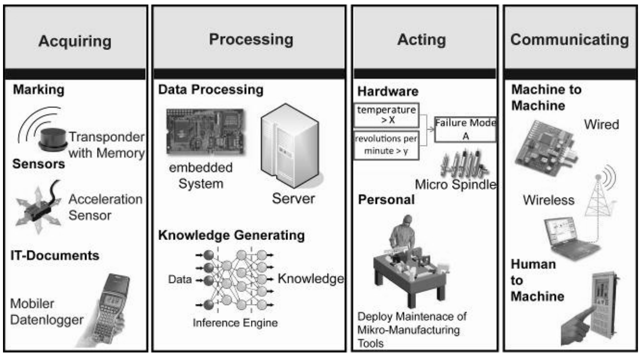

Figure 2: Modular concept of a Virtual Life Cycle Unit.

The acquired data and information will be processed with the objective to generate knowledge, e.g. inferences between product or process parameters and failures. Acquired and processed data, information and knowledge are being communicated for further evaluation. With the help of condition prognoses the need of maintenance can be identified and maintenance activities can be automatically deployed. These data, information and knowledge can also be used to assist processes of the value creation chain such as development, redesign, production, recycling and disposal, and supporting processes such as control processes in a service procedure.

In the IPS² operation phase the VLCU is able to acquire information about the usage behavior, resource needs, services and workers. This sets a base for the search of inferences, e.g. worker qualification, service efficiency or flowcharts regarding the user demands and requirements. This knowledge is invaluable for cost and resource reduction in service planning. The goal is to increase the use- and time-productivity of resources in IPS² by finding inferences about adaptations between different usage phases and to improve the IPS² work sequences.

Decision trees are used to determine the best course of action, in situations having several possible alternatives with uncertain outcomes. The resulting chart or diagram displays the structure of a particular decision, the interrelationships and interplay between different alternatives, decisions, and possible outcomes. [21]

A decision tree can be generated out of recorded process documentation data lists. There is a variety of algorithms for building decision trees that share the desirable quality of interpretability. A well known and over the years frequently used is C4.5 [22]. C4.5 builds decision trees from a set of training data, using the concept of information entropy. Information entropy is a measure of the uncertainty associated with a random variable. It quantifies, in the sense of an expected value, the information contained in a message. The decision trees generated by C4.5 can be used for classification, and for this reason, C4.5 is often referred to as a statistical classifier.

Decision trees can describe the workflow of complex processes with possible variations of process steps due to external conditions. These might be corroded parts, wrong assembled components or variations in the geometry of the assembled screws.

The challenge of acquiring and processing data from complex machines can be solved by concentrating on standard components. Standard components like bearings, gears, compressors, pumps, dampers, filters, hose lines or pneumatic components are integrated into various more complex products, e.g. assembly systems, ground conveyors or industrial robots. By focusing on the assessment of data on standard components of machines, the development effort for the assessment of complex products is distributed technically and economically on many applications [20]. Also, less overall expertise is needed in order to develop a VLCU system for complex products or components, because the subsystems can be examined almost independently of each others. The solution space is significantly reduced for each VLCU designer, figure 3.

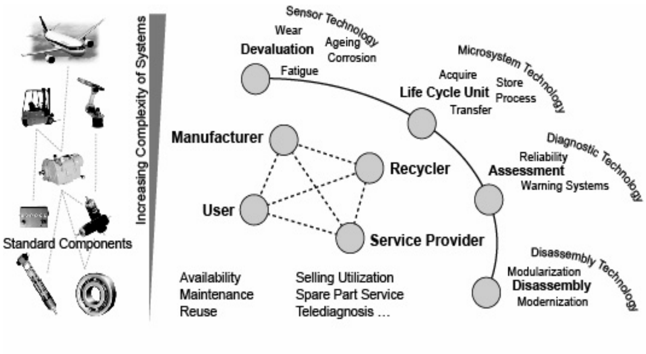

Figure 3: Products, standard components, interest groups, and business areas.

Maintenance processes on those standard components are a 'door' for data acquiring of a service. This enables a direct connection to the standards component, failure prognoses and to detect critical system parameters, inferences between services on a component and its condition, e.g. remaining life time or failure rate.

With the flexibility of an IPS² concept the influences on a customer solution is typical divided in two specific parts: the product and the service specification.

2.3 Availability-Oriented IPS² Product Specification

Each IPS² use model requires special design characteristics of machine components due to the focus of the use model. For the availability-oriented IPS² the need for easy, safe and secure user interaction for service execution is given. These tasks can be performed by constructive features, e.g. access restrictions via locked access gates.

Modular construction:

The IPS² production system is subdivided in functional sections. Each section is realized as a module with mechanic and/or electronic interfaces. Each module represents a closed system and can be disconnected separately without disassembly of the module itself. Therefore, a modular design enables an easy interchange of units. In addition, it protects technological know-how because the user does not need to get detailed information about the overall functionality of the production system.

Black-Box-components:

If a module cannot be disassembled by unauthorized persons without destroying it, it is called a black box. Such a component is described only by its input and output characteristics. Its internal configuration and technology is not transparent. Therefore, it is a suitable measure to avoid knowledge transfer of key technologies used within a product system.

Electromechanical locks:

Electromechanical locks can be installed instead of conventional connecting elements like simple screws to ensure that maintenance processes can only be executed by authorized personnel. The user has to be authorized by the IPS² provider and logged into the system to activate these locks. The login and access procedure can be realized by an internet connection, so that the provider is able to control who is maintaining the machine.

In the DFG funded research project "Disassembly Factories", magnetic connection modules have been developed, which open by an electronic signal, see figure 4 [23]. By measuring the magnetic force and recognizing the disconnection a VLCU is able to detect and control the access to machine components. Thus, the VLCU can support a sequential and simultaneous support in accessing machine modules during a maintenance process.

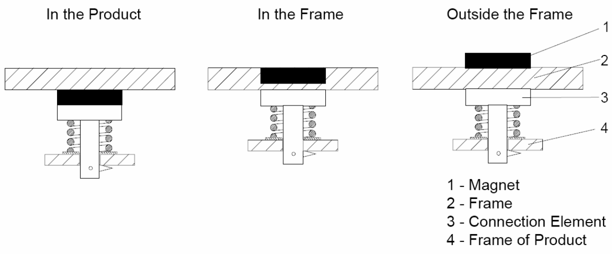

Figure 4: Arrangements of magnet and connecting element [23].

2.4 Availability-Oriented IPS² Service Specification

Not only the product specification differs from conventional approaches regarding the requirements of the chosen industrial product-service system but also the design of service processes. To enable a person to execute service processes like during maintenance of machines regardless of its technical qualification, the service specification has to be adapted. While service technicians are well schooled in the branch specific technical terminology and have operating experience, machine users often do not need that kind of qualification. Therefore, service process design has to take into account that additional support is needed [24]. This can be realized by adapted instructions and a user-friendly interface [25].

3 APPLICATION SCENARIO IN THE FIELD OF MICRO MANUFACTORING

3.1 Dynamical Adaption Assistance of Service Operations

The above mentioned shared-vision device connects a less-qualified person with an expert system for solving problems collaboratively. The expert system's functions range from automatically generated instructions to individual support by expert staff, who can give operating instructions individually and verbally. The usage of the proposed shared-vision system enables less-qualified users to execute any designed service process at a pre-defined quality level. The expert system provides the process models, data regarding the current machine condition and the required technical information to enable the service to be carried out.

The idea of knowledge protection leads to a capsular design of functionally relevant machine components, which can be accessed only by authorized personnel logged into the system. With process relevant data out of the spindle's usage phase the decision tree for the workflow of the maintenance process can be updated.

3.2 Design of a Micro Manufacturing Spindle for an Availability Oriented IPS²

For a description of an assistance of service operation a scenario focuses on the milling spindle as the most stressed core component of the machine tool. Since the spindle is the most stressed component of the milling machine, it has to be maintained due to progressing wear. The wear behavior depends mainly on the conditions of spindle operation, e.g. work piece material, and technological parameters. Therefore a periodical maintenance is not sufficient to guarantee the availability of the IPS².

The IPS² use model determines the maintenance service activities to be done by the customer's personnel regardless of its technical qualification (ref. chapter 1).

The milling spindle of this scenario is constructed of four functional modules with integrated sensors for condition monitoring (cf. figure 5). A spindle with the whole construction information from SycoTec GmbH & Co. KG is used to show the relevant processes and the needed interaction between product and service.

Media Module (1)

In this module all supplies media are brought together. The circuit points, e. g. the electricity, compressed air, to run the spindle are combined in this module.

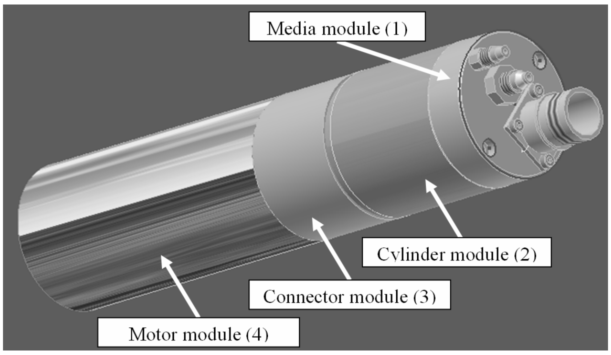

Figure 5: Modules of the spindle (CAD-file) © SycoTec.

The closure head is equipped with different connectors. The diameters of the circuit points are different, so that a connection mistake is eliminated. The plug diameter for the air sealing is smaller than the one for compressed air for the tool change (figure 5). A greater diameter means a higher pressure range; so that the user of the spindle can intuitional connect the spindle with the needed media.

This module is sealed with a seal disk against the cylinder module (2) and is fixed with two socket screws (M4x25) on the cylinder module.

Cylinder Module (2)

This module includes a system of several pistons in series to press the spindle for the exchange of the milling tool.

The inner functional cylinder is housed inside another cylinder (cf. figure 6). The functional cylinder is designed as a combination of the single elements of these pistons. Three springs are compressed when the pistons in the functional cylinder are pressurized. In the non charged system the springs close the tool chuck. The cylinder module is combined of parts with black-box character (e. g. the described cylinder).

A sealing ring seals the cylinder module against the connector module (3). Both modules are screwed together by the bottom of the cylinder module and by the head of the connector module with three socket screws (M3x20).

Connector Module (3)

To merge the cylinder unit with the motor shaft a connector is needed. This connector compensates the deviation of form and position of the parts. Furthermore the axial forces to move the chuck are transmitted over this module.

Motor Module (4)

This module includes the motor for the rotating motion. The module is built by a central shaft for the clamping mechanism, sealing elements, an outside lying motor coil and the ball bearings. The balls of the bearing are manufactured of ceramic. Furthermore, the motor module includes the tool chuck.

All modules are displayed in a CAD-model with single pieces, figure 6. A detailed description of all movements to exchange the individual parts is basically needed for the individual adaptation of a service operation.

Aspects of user interaction corresponding with the construction of the spindle:

The separation of each module can be realized due to the modular design of the spindle. Modularization reduces the amount of needed information for maintaining a single module. Furthermore, it protects knowledge about the function and the relation between all modules.

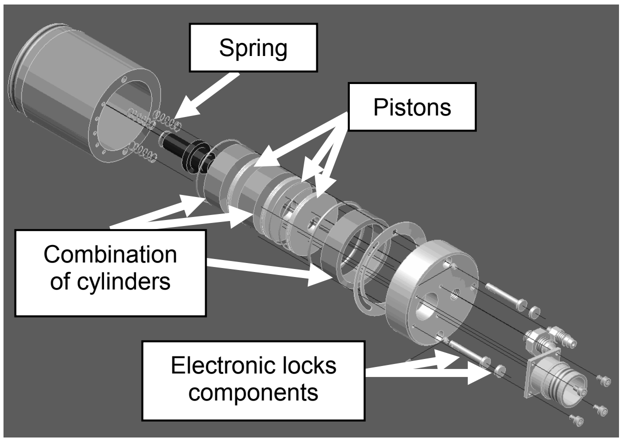

Figure 6: Module (1) and (2) © SycoTec with additional electronic locks [22] (CAD-file).

As described in the cylinder module (2) the pistons with the sealing elements can be integrated in a pressure chamber, so that this component is capsulated against the other components. The use of detailed design drawings is required for a special instruction to exchange for example the sealing elements of this cylinder.

The media module (1) can be separated by loosening the two standard screws (figure 5). The user for a service needs a socket wrench to execute this process step.

In a second design the whole rotating spindle can be secured with special mechanics combined with electronic parts against unauthorized contact (figure 6). As a lock the modules can be separated only by a login of an individual, authorized user. The media module (1) can pick up the locks to connect it with the cylinder module (2). For the exchange of for example a broken spring the locks have to be opened. The login to the specific locks can take place by a user specific transponder, which has to be placed over the media module (1). By this movement relevant user information can be logged for service documentation.

3.3 Description of a Service Process

A critical part of adaptive assistance is the qualification of the employee. Due to the huge variety of qualification patterns and the problems in the assessment of them, the employee should choose the amount of information in the adaptation process by her/himself. Instead of defining instruction sets for different levels of qualification, a simple hierarchical model (level of instruction complexity, figure 7) is suggested.

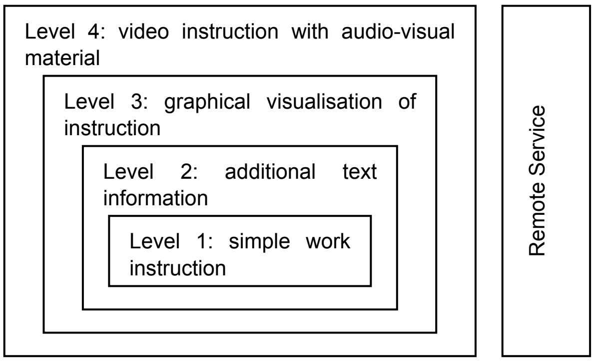

Figure 7: hierarchical model:
level of instruction complexity

In this exemplary micro production scenario the VLCU detects a change in the spindle condition. On the basis of predefined rules the VLCU advices maintenance for example “Loss of clamping force, check springs!” Is the user a less-qualified technician or has never executed this maintenance before, which is registered in his/hers personal user profile, the maintenance process has to be authorized by a remote connection to the IPS² provider. The user is warned by a signal and after authorization the service process begins.

In this case “Change the springs in the cylinder module” is the 1st level of the work instruction and is displayed in a defined area of the machine’s graphical user interface.

If there is a lack of procedural knowledge regarding the steps of the working sequence the technician can switch to a higher level of instruction complexity.

The 2nd level of instruction complexity describes the simple work instruction with additional text for each step of the procedure in a checklist. “Change the springs in the cylinder module by the following steps: 1. Loosen two screws M4 of the media module with a 3.0 socket wrench”. At least three components should be described: the operation, its position, and the tool which is needed. The user confirms the current step as soon as the action is finished and the next step of the checklist appears.

If the step takes longer than necessary or the user requests more information, the 3rd level of instruction complexity is offered, a graphical visualization of the instruction. The description of operations only by text can be very difficult and abstract. An additional graphic like an exploded drawing with added symbols for actions can facilitate comprehension and provide additional information.

Level 4 of instruction complexity explains each step of the instructions by also using aural and visual modalities if the user is still not capable to change the spirals.

As the problem could not be solved by following the previous instruction steps, obviously support by an expert is needed. So if passing through all levels of instruction material does not lead to the fulfillment of the task, the remote service has to be contacted.

The IPS² provider has different possibilities to provide this remote service, i.e. the remote assistance for the employee by an expert. One of these possibilities could be a shared-vision system. Especially in difficult and less well defined problem situations the communication through gaze information and aural instruction can lead to an efficient problem solving.

Another reason for contacting the remote service could be, if the VLCU detects unforeseen events during the maintenance process. While loosing a screw in the first step of the maintenance procedure, the VLCU detects via an electronic torque wrench with a force sensor that much more power is being used than usually needed. The user is instructed to stop the process and an expert is contacted via the shared-vision system.

The expert detects a corroded screw. This might be due to high humidity in the factory hall of the customer, which was not expected by the provider. Corroded screws were not considered in the design of the maintenance workflow. The expert will give an error report with the information “humidity and corroded screws” as input, which will be processed by the VLCU. However, not always high humidity results in corroded screws. The best input for the workflow decision tree results out of the combination of applied torque force to loosen the screw, humidity, machine model, screw type etc. A statistical evaluation according to decision tree generation leads to a significant workflow tree for future processes, figure 8.

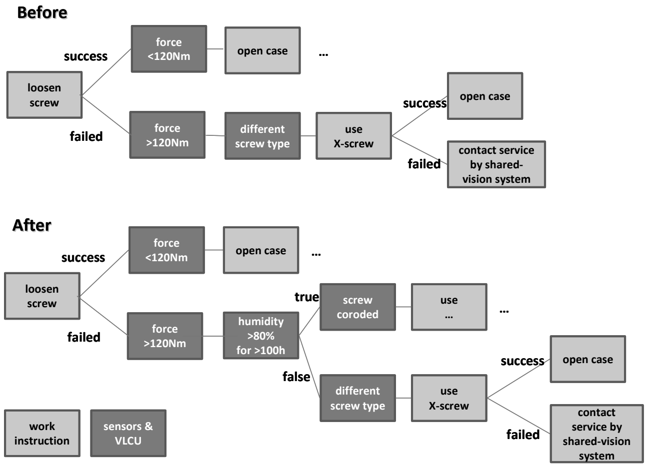

Figure 8: decision tree

After finishing the maintenance procedure the user ends the process with a functional test. Is the test successful, work can continue and the completed task is registered to the user’s personal profile. If not, the remote service will be activated or go on, respectively.

4 SUMMARY

In a maintenance scenario of a micro manufacturing spindle the user support with the use of a shared vision system, assisted by a VLCU generated decision tree has been shown. Further the VLCU enables condition prognostics for a reliable and cost effective production process. The selected use model “availability-oriented” determines design characteristics, e.g. modular construction and/or electronic locks, that differ from full user intervention possibility to a non-demountable product.

The described concept enables IPS² providers to compete in the global market, to protect their knowledge, and to offer any solution from the physical product to a complex service.

5 ACKNOWLEDGMENTS

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