User-Centric and Contextual Interaction in IPS^2

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Abstract

In the SFB/TR29 a focus lies on Human Factors and their integration into Industrial Product-Service Systems (IPS^2) to prevent errors and malfunction due to e.g. changing structures and conditions. Thus, it is necessary to integrate adaptive, contextual and user-centric interaction techniques into IPS^2. In this article an approach is presented that enables the predictive and automatic detection of human errors and malpractice and their contextual prevention. Therefore cognitive user models, actual knowledge of the systems and the operator and multimodal human-machine interacting mechanisms are used. This approach provides the base for an efficient and error-free execution of services within IPS^2.

Keywords

Industrial Product-Service Systems, Cognitive User Models, Multimodality, Error Prevention.

1 INTRODUCTION

Industrial Product-Service Systems (IPS^2) are characterized by an integrated and reciprocal determined design, development, provision and utilization of products and services. This includes the possibility to substitute partial aspects of services and products [1] during the design and provision phases of IPS². A strict separation of both the services and the products is no longer possible. In regard to these interdependencies of products and services and the involved human operators an IPS^2 can be described as socio-technical system. Socio-technical systems comprise a structured set of humans and technologies that interact in a defined way to process a specific product [2]. They also refer to the relationships and interrelationships between technical processes and human behavior.

For IPS² this means that the subsystem human operator controls the technical system, i.e. the technical system is influenced by the social system. All information within an IPS² is carried out or supported by technical components. Also the technical system itself is content of the communication within IPS², e.g. when a component or a process have to be maintained by two distributed human operators. This shows that within the socio-technical system IPS² both partners (i.e. human and technical system) are important factors that have to be taken into consideration in all phases of the live-cycle. In sum, this leads to three aspects that are important for IPS²: (1) interaction between humans, (2) human-computer interaction and (3) interaction between technical components.

Especially in the provision-phase the first two kinds of interaction are very important because several stakeholders are part of an IPS² (i.e. service provider and product provider). The involved parties are responsible for the productivity and stability of the whole system. But each involved party has different aims (e.g. maximization of profit, security or availability) and requirements (e.g. organizational policies, procedures, structures and conditions of work). Hence, the social system of IPS² is formed by a heterogeneous group of companies, groups and individuals.

There is a need to support all involved stakeholders individually regarding the current context. This includes the interaction between all components. But the primary goal is to support all kinds of interaction involving humans. Thus a special focus is laid on human factors and the support of cognitive processing of operators while interacting. This includes information gathering and processing as well as decision-making and actions.

For this reason an approach was developed that enables the predictive and automatic detection of human errors and malpractice and their contextual prevention integrating cognitive user models, actual knowledge of the systems and the operator and multimodal human-machine interacting mechanisms. This approach provides the base for an efficient and error-free execution of services within IPS^2.

1.1 Illustrative Scenario

As an example for the motivation of the conceptual frameworks presented in this article a typical process of repairing a technical component within the provision-phase of IPS² is described as it was performed in a preceding research experiment [3]. The findings of this experiment indicate the need of contextual support of human operators within IPS² with special focus on human cognition and human factors.

The scenario of the experiment is reported briefly in the following. The aim was to repair a clamping device of a high-speed spindle for micro production that did not work properly. Concerning the provided manual the human operator has to check the steel springs inside the spindle housing and if applicable change broken springs to repair the spindle.

This scenario was conducted with untrained participants (students of engineering courses). They had to solve the problem with help of a written manual. In the manual the process of disassembling and assembling was described in several successive steps. Since the participants did not have any knowledge about terminology and necessary tools every step contained detailed information on the required tool and the corresponding interaction. In some steps graphical visualizations were included; some contained written advices for the correct handling.

The results of the experiment showed that all participants were able to follow the instructions to execute the task. But in one case it happened that against strongly advice in the manual to hold the spindle safely with one hand, a participant loosened all holding screws without holding the spindle safely. The spindle fell on the working plate and was seriously damaged. The user was not aware of his faulty workmanship, i.e. his mental processes did not fit the actual state of the technical system or the technical system did not considered the participants actual knowledge.

The described incident needs to be considered especially in socio-technical systems such as IPS². As mentioned in the introduction, IPS² are characterized by a heterogeneous group of stakeholders and individuals within a mutable and changing system. Therefore, special efforts have to be made to guarantee the use of the technical components in IPS².

In the described incident the easiest solution to overcome the mismatch between technical system and human operator could have been to control the conducting user by a second user or a technical method (i.e. supervision). Other possibilities are constructive modifications to prevent the drop of the spindle. But in both cases the individuality of human operators regarding cognition is not taken into account.

Colloquial said, it lies in the nature of human to make mistakes. Most of all learning and experience of human beings is building upon error making. In a technical sense an error means in general that the recommended and failure free procedure is interrupted and requires the intervention of the user or a supervisor. Possible reasons for wrong behavior could be (1) the user does not know the correct procedure and is trying to solve the problem using his knowledge and reasoning, (2) the user does know the correct procedure but makes the mistake by accident, (3) the user remembers wrong the correct procedures and makes the mistake by purpose, or (4) there is no procedure yet since this machine state had never occurred before and had not been described.

In all these cases the user could interact with the system in different ways either solving the problem or failing. The idea to prevent an incident by an assisting supervisor is in most cases not practical (due to costs, time and resources). Thus, it seems to be a promising approach to integrate knowledge of the human and the scheduled tasks into the technical system. This helps to supervise the behavior of operators within IPS² and allows the technical system to initiate notifications, warnings and assistance when differences occur. By this approach, all except the last action (4) could be prevented if reference patterns for the user's interaction exist.

In the following chapters, this approach of cognitive user model supported human-computer interaction and the corresponding frameworks for contextual and multimodal user support within IPS^2 are described in detail.

2 COGNITIVE USER MODEL SUPPORTED HUMAN-MACHINE INTERACTION

As shown in the previous chapter, IPS^2 integrate different stakeholders that are responsible for the technical components and processes such as maintenance, operation and provision of components. This implies a vivid and changing system during operation relating to working conditions, responsibilities and procedures. That means that employees are not able to concentrate only on a single working process or a specialized set of procedures but need to handle different tasks and working conditions (i.e. there is a need of multi-tasking). Thus, for instance, a business model change within an IPS² can lead to a change of responsibilities and tasks of an employee who has to adapt to this changes. This adaptation of the human operator to a new environment or to new working conditions involves complex and dynamic information processing (e.g., following new rules or slightly different procedures). Regarding psychological findings humans have restricted and limited capabilities and resources [4]. This has an influence on the interaction with changing environments, the amount of represented data to perform a task and the possibilities to integrate new knowledge into procedures. Especially for IPS^2 this is a critical aspect in regard to the mutability of these systems. This means that there is a growing chance of malpractice or errors in comparison to conventional systems. In order to be able to profit from all advantages of an IPS² and its universalism it is necessary to provide systems that take into account human factors and human cognition. Cognitive user model supported human-computer interaction seems to be a good candidate to provide a technical system with manageable and adaptable knowledge of human information processing and reception. This provides a base for contextual and individual support of human operators within IPS^2.

For this reason an approach that enables the predictive and automatic detection of human errors and malpractice and their contextual prevention by either adapting the technical system or by providing multimodal support methods was developed. For this, cognitive user models (i.e. optimal task models) are compared with online user behavior to reveal irregularities. Detection leads to the estimation of future consequences for the system state based on a system knowledge base and probability functions. If the benchmarking system forecasts a critical situation, suitable counter actions or support are initiated (e.g. assistance functions, adaptation of the technical system). Additionally, this approach enables human operators to access online help and contextual support that is provided by external experts through state-of-the-art service devices (e.g. head-up displays, augmented reality components).

2.1 Cognitive user models

Cognitive modeling attempts to provide symbol structures for selected cognitive processes and attempts to show that these symbol structures can generate the corresponding cognitive behavior [5]. Modeling can be done within cognitive architectures, i.e. software frameworks integrating cognitive and psychological theories, such as visual information processing, decision-making, and motor commands. For an overview, see [6]. These architectures are independent of the simulated task and its domain and require a constant task-development in time [7]. Formal cognitive user models can be applied to predict the users' behavior and future needs by simulating observable user behavior. In the case of operator tasks cognitive user models are able to simulate operator behavior for specific tasks [8]. Two levels of cognitive architectures can be differentiated: high-level and low-level approaches [9].

High-level architectures such as Goals Operators Methods and Selection Rules (GOMS; [10]) describe behavior on a basic level and define cognitive processes involved as a pre-coded sequence of human actions. In the area of usability and human performance prediction they are most suitable to investigate errors and difficulties in using interfaces. Complex phenomena as for example signal-detection or decision-making are not fully describable within high-level architectures.

Low-level architectures, for example Executive-Process/Interactive Control (EPIC; [11]), Atomic Components of Thought - Rational (ACT-R; [12]) and Soar [13], describe human behavior on an atomic level. They allow a more detailed insight into cognitive processes than high-level architectures. Most low-level architectures use production systems to simulate human processing and

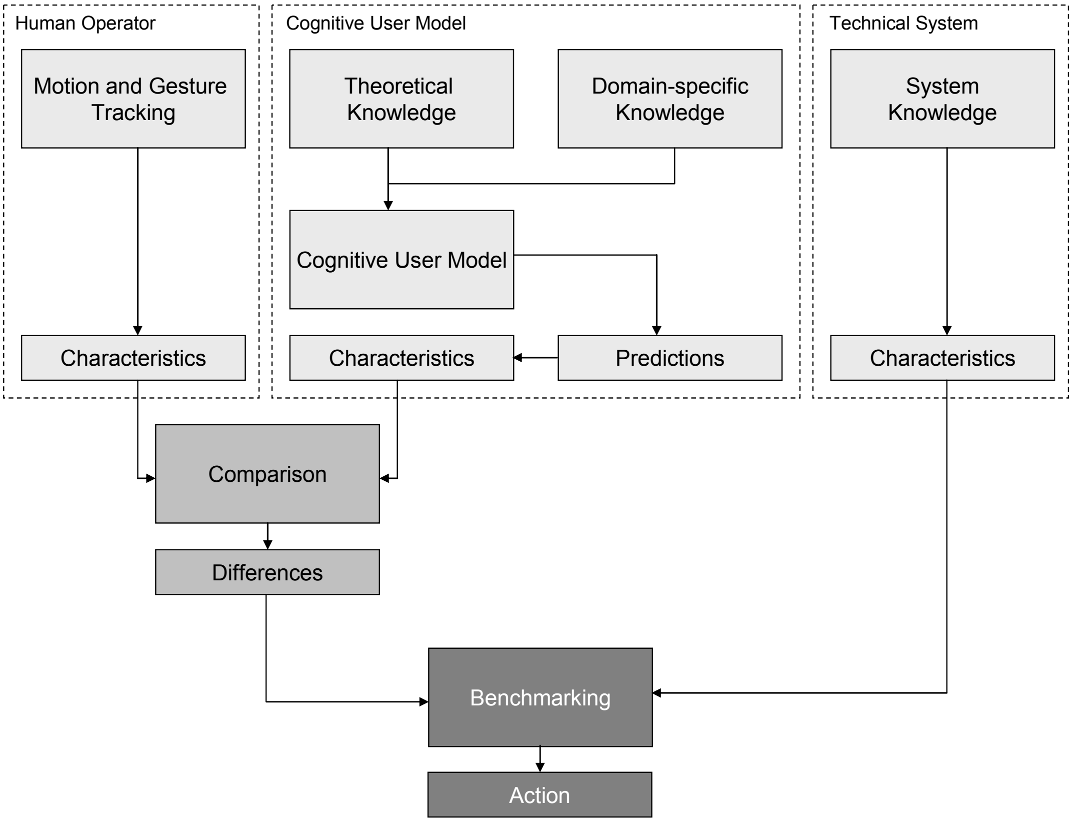

Figure 1: Conceptual framework for cognitive user model supported human-computer interaction within IPS². Illustrated are the three consecutive steps: date gathering, comparison of human and simulated data to detect differences and benchmarking of the differences in respect to the actual system state. The process ends with an initiating an action if necessary.

cognition. The use of independent production rules allows cognitive models to react on external stimuli (bottom-up processes) and to model interruption and resumption of cognitive processes. Complex paradigms (e.g., dual-tasking, decision-making, and time-estimation) and their underlying processes can be simulated with cognitive models [14, 15]. The predictions of cognitive models based on low-level architectures are more natural and take into account human complexity and dynamic.

Most cognitive user models are applied to predict user behavior offline. These models are used to evaluate alternative designs of human-computer interfaces [16]. In the context of adaptive user interfaces in some cases high-level cognitive user models are applied to predict emotions or workload of humans interacting with a technical system [17, 18, 19].

The development of high-level models to simulate and predict human cognition is a contemporary topic in the cognitive research community [20]. Simplifying the model-building process and improving concepts for sharing and reusing model components are the main objectives. Examples like ACT-Simple [9], ACT-Stich [21], G2A [22] and HTAmap [23] represent high-level frameworks that compile existing high-level models to ACT-R syntax (for an overview see [23]).

2.2 Conceptual Framework

The aim of the conceptual framework is to establish the fundamentals for contextual support of human operators within IPS^2 taking into account human cognition and human factors. This approach combines simulated operator behavior by cognitive user models with sensory knowledge of the technical system and the behavior of the operator. The technical data acquisition allows algorithms to detect critical situations based on formal online data. This approach enables the automatic initiation of supportive or provisional support actions within an IPS² by the technical system to prevent malpractice due to human errors (e.g. errors of emission or confusion).

The contextual framework consists of three consecutive steps: (1) date gathering, (2) comparison of human and simulated data and (3) benchmarking of differences in respect to the actual system state. The process ends with initiating an action whenever necessary. In the following these consecutive steps are described in more detail. The conceptual framework is illustrated in Figure 1.

In the first step required data is gathered. For online data gathering (i.e. human date and technical data) several methods and mechanisms exist. Human data can be gained by using motion or gesture tracking software and hardware. Technical data can be provided by sensors that are already integrated parts of technical systems or added for this purpose (e.g. sensors for process stability, target values and goal-orientation). For the simulation of operator behavior cognitive user models are used. These cognitive user models provide quantitative and theoretical data of ideal operators for specific tasks (e.g. eye movements, execution times) within IPS² that tend to be error-prone (e.g. changing a technical device). The data can be provided by cognitive models and used for further processing. All data is processed and defined characteristics are extracted from both the online data and the simulated data (e.g. sequences, times, cornerstones) that are provided in a general-purpose format for ongoing analyses.

The second step deals with the comparison of the simulated and the online operator data. Abstracted data of the cognitive user model is compared to online user data in real-time to reveal differences. These differences can occur for instance on the level of execution times or action sequences and provide a contextual view on the behavior of human operators.

The last step within the conceptual framework comprises the benchmarking of revealed differences in context to the actual system state. Differences between the behavior of human operator and cognitive user model are combined with the gathered characteristics of the technical system. By using machine learning algorithms pattern can be recognized in the data that allows forecasting critical situations or states of the system. These situations are benchmarked and classified using a system knowledge base provided by the IPS². That way, appropriate measures can be taken in time. For a detailed description of possible actions please refer to chapter 3.

Due to the complexity of cognitive user modeling and of human cognition this approach should be initially applied for specific tasks and could be extended in the future. Therefore a learning mechanism is integrated into the conceptual framework (not displayed in Figure 1). This learning algorithm feed backward the initiated action and its utility for the given context, the benchmarked situation and the success to the cognitive user model and the benchmarking module. The cognitive user model uses the information to update its knowledge base (i.e. declarative and procedural memory) and in this way can use the data in subsequent simulations and predictions. Analog the benchmarking module updates it knowledge base. This mechanism allows providing a system that learns and adapts itself to the user behavior and the conditions of IPS² such as multimodality and interpretability.

2.3 Discussion

The presented approach allows integrating human cognition and human factors into IPS^2. The conceptual framework uses cognitive user models to support human operators interacting with technical systems and to prevent malpractice or human errors. It allows for a formal integration of human aspects into technical systems. At the current state parts of the theoretical framework are developed including cognitive user models, software and hardware frameworks and algorithms to gain, compare and benchmark data from different sources. Regarding the complexity and the level of cognitive modeling decisions have to be made if high- or low-level cognitive user models should be used. Both seem to be good means to simulate operator behavior. But it is not determined on which level the comparisons between human and cognitive user model should be made. For the comparison a set of characteristics needs to be identified to compare empirical data and simulated data on both an overall (e.g. sequences) and a detailed level (e.g. eye-movements). But there are some problems concerning this point. First it has to be shown that characteristics derived from theoretical knowledge are comparable to human data. In the case of cognitive user modeling there is the need to take into consideration several levels of analysis such as the interaction within cognitive user models (i.e. between or within separate modules) and the interaction of a cognitive user model with its environment [24]. Using a multilevel approach of data analysis helps to reveal overlapping characteristics that are applicable for human and simulated data. A second problem is the huge variety of user behavior performing a task (i.e. intra- and interpersonal differences). To overcome these problems, a solution could be to provide cognitive user models of specific and formal tasks as described in the scenario that contain several procedures to perform the task. Furthermore, these models are able to extend their knowledge base and to adapt their internal processes to the captured human behavior. The last challenge is the possibility to perform the comparison in real-time. This is critical for the whole system. Without a near to real-time capable comparison of human and simulated data none contextual support based on simulated cognitive processes is possible. Regarding this problem a solution could be to either use very simple matching algorithms. Or it could be possible to predict several user behaviors and map the predictions and its preconditions to the current system and user states in order to decide an appropriate simulation as the cases arises.

3 CONDITION-BASED REGULATION

To err is human, so errors can never totally be avoided. But with efforts consequences of errors can be minimized, systems can be stopped into a failsafe mode and users can be assisted and advised before or close to the moment of making an error. An approach of how a user's interaction can be compared with a reference user model was introduced in the previous chapter. In this chapter, first examples of existing condition-based regulations will be given, and then the conceptual framework for the implementation within IPS² is introduced.

3.1 Fault-tolerance and regulation

There exist already many successful concepts for avoiding errors while interacting with machines or computers. Examples for mutual controlling in human-human interaction can be found in command bridges of vessels as well as in cockpits of commercial aircrafts (i.e. crew coordination concepts), where one person is acting and the other person is monitoring the actions. Also for human-computer interaction examples exist like in systems, which control the user's inputs and proof them for correctness and appropriateness in the current context. This can be found in software applications to avoid false inputs for example in text forms or in a more complex way in fly-by-wire systems within aircrafts. In these systems steering inputs are controlled by control laws that limit the set of commands depending on the situation to prevent undesirable conditions of the aircraft [25].

A final example for computer-computer controlling also comes from flight data computers. There, three individual computers monitor each others in a computer framework. If one system behavior is different from the remaining two, the one will be shut down to avoid unforeseen consequences caused by a malfunctioning system [26].

Daily life condition-based warnings and notifications are known from all kind of systems for example in the automotive sector. Navigation systems give multimodal warnings regarding the speed limit by comparing the movement of the GPS-sensor with the internal map data. To inform the user several mechanisms can be used such as a vibrating steering wheel, displays and spoken information. Assisting systems can already adapt to the driver's and the car's condition to reduce potential errors due to exceeding work load [27]. In the automotive sector also approaches exist for a *Context-Sensitive Error Management during Multimodal Interaction with Car Infotainment and Communication applications* [28].

Examples for systems entering failsafe mode in critical situations can be found in the area of industrial automation. Light barriers protect human operators against welding robotics or touching cutting or drilling tools. Is the light barrier broken, the machines stop or move into a failsafe position [29].

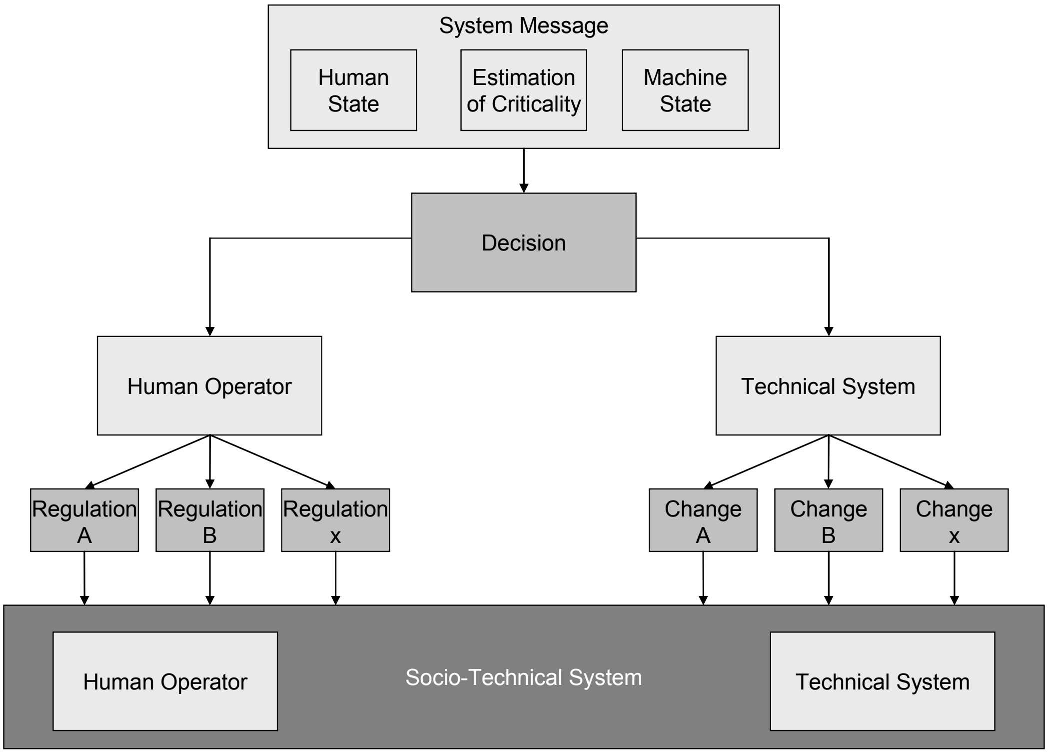

Figure 2: Conceptual framework for condition-based regulation of human-operators and technical components within IPS². The regulation is initiated by a system message about the human-operator's state, the machine's state and an estimation of the situation's criticality. The assisting system decides to regulate the human operator and/or to change the state of the technical system. This leads finally to a new state of the socio-technical system.

3.2 Conceptual framework

After the comparison of the user state with the reference model a message is generated in case of a mismatch (please refer to chapter 2). The provided message contains information on the machine state, the estimation about how critical the current situation is and the state of the human operator.

The second conceptual framework deals with the choice of an appropriate support mechanism for the human operator. This consists of three steps: (1) deciding to assign the action to the human operator or the technical system, (2) definition of the granularity of the action and (3) the accomplishment of an action. This framework is illustrated in Figure 2.

In the first step the incoming message of the pre-located system is analyzed by a rule-based decision making component. It has to be decided to regulate the user, to change the machine state or both. For example if the situation is estimated for being very critical, the machine could be stopped and the user informed about the reason.

On the second level the complexity and granularity of the future action should be made. On the human side decisions have to be made regarding the user's situation, knowledge, state and equipment. It has to be determined which modality is possible and optimal for the current state to inform or warn the user. If the user wears a head-mounted display, visual text warnings could be shown or augmented reality components could be displayed. On the machine side the processes regarding the machining can be adapted by changing the order, by re-organization the system state or stopping running processes and actions.

The third level facilitates the initiation of an action. Regulating notifications on one or even on both sides lead to a new state of the socio-technical system and thus affect both the human operator and the technical component that are computed by the first framework.

Part of the research for this realization of this conceptual framework is also the analysis of possible dependencies between the human-operator and the technical components during the regulation. Another focus lies on the selection of corresponding support systems and in the design of the regulations for a multimodal support concept.

3.3 Discussion

The presented approach enables to regulate the human user or to change the machine state dependent on the condition of the holistic socio-technical system. Prevention and assistance in malpractice has several advantages for the provision-phase within IPS². (1) The operator is protected and supported by a surrounding system and can be stopped by technical components before injuring himself or anybody else. (2) By rule of logic everything is possible after an error occurs, so the user can even do more mistakes and even impair the situation. By providing online benchmarking mechanisms all actions can be assessed and avoided by the technical system if necessary. And (3) interruptions due to human errors of planned processes, which lower the productivity and stability of processes, can be avoided by contextual and human-centric support.

A weak point of this approach is that only notifications or support information can be provided in conditions which are already known or which were supposed to occur. A second weak point lies in the system itself, wrong decisions might be made and inappropriate notifications and process changes might be executed.

For a successful implementation of the introduced concept a detailed task analysis has to be conducted, a decision rule set has to be generated and a classification of possible consequences of every task's step has to be made.

4 SUMMARY

The described approach enables a user-centric and contextual interaction within IPS². This is done by providing a theoretical base for the benchmarking of operator behavior by cognitive user models and a mechanism to initiate appropriate support actions whenever differences are revealed between the human and simulated behavior. The presented concept of condition-based regulation of operator support mimics the monitoring by an instance, which should ideally be a second and experienced human operator. The focus lies more on the assistance of the human operator than in supervision since controlling or even the feeling of it can have a negative impact on human operators.

All described concepts and theoretical accounts of this paper will be implemented, tested and evaluated in a scenario which is used in the collaborative research project SFB/TR29, i.e. manufacturing of components for watches by micro production. The concepts and frameworks offer and require various possibilities for collaboration and cooperation within the distributed research project (e.g. agent-based regulation, knowledge generation and knowledge base initiation).

The introduced approach cannot replace conventional and existing efforts to minimize malpractice of user interaction. But this approach can lead to a higher productivity of a socio-technical system and therefore will make IPS² more attractive for application since this approach offers a high flexibility and mutability of human and technical parts. The approach also does not lead to error-free interactions of operators but will probably lead to more error-tolerant systems. Consequently this will raise the usability and the use of IPS².

5 ACKNOWLEDGMENTS

We express our sincere thanks to the German Research Foundation (DFG, Deutsche Forschungsgemeinschaft) for funding this research within the Collaborative Research Project SFB/TR29 on Industrial Product-Service Systems – dynamic interdependency of products and services in the production area.

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