Towards Collaborative Plant Control using a Distributed Information and Interaction Space

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***Abstract*—As Smart Manufacturing, Industrial Internet, Industrie 4.0, and Cyber-Physical Production System (CPPS) are becoming reality, the way process and manufacturing plants are operated has to change. Additionally, these developments – constituting the pervasive digitalisation of industry – have a profound effect on the way human workers and machines interact. This paper contrasts the current state of the art in plant control with a vision for the future. The scenario is illustrated by a realistic problem-solving process in a chemical plant. It describes an integrated industrial information and interaction space that leverages emerging technologies to enable plant operators to remain in control of future flexible modularised process plants. Our approach shows the advantages of an integrated information space which feeds interaction and collaboration using Virtual Reality (VR), novel display technologies and mobile devices.**

I. Introduction

The advent of Smart Manufacturing, Industrial Internet, Industrie 4.0 , and Cyber-Physical Production Systems (CPPS) leads to profound changes to the process and manufacturing industry [1], [2]. These changes will affect all stages of the plant life cycle – from basic engineering to operation. In order to cope with the rising volatility of the market, ever decreasing product life-times and highly individual customer demands, design and operation of process and manufacturing plants needs to become more flexible.

Today, process plants are monolithic and typically operated from a central control room. Several desktop workstations are located in front of large displays that show overview screens, trends and alarms. Usually, more than one operator is present and each has her own workstation. Long periods of low stress during normal operation alternate with stress peaks, when cooperation is crucial for solving immediate problems. Collaboration occurs mainly verbally, either face-to-face, via phone or radio. This is sufficient when high product volumes are manufactured over long periods of time and intensive collaboration is rarely necessary.

In future, plants that consist of flexibly arranged modules and integrate self-organising CPPS need a different approach to control. Frequent plant reconfigurations, product changes and output volume adjustments require a much higher level of expertise from all involved humans. The need for a passive operator who just keeps an eye on the gauges will decrease further and the qualification gap between complex tasks and remaining non-automated trivial tasks will grow.

To be able to reliably operate such dynamic plants, finding new ways for effective collaboration is crucial. Today, the experts and operators gather around a workstation of an operator, discuss printouts or show some information on a large wall display. There is no way for an operator to take his current work to a colleague, illustrate a problem in an interactive manner, maybe transfer the work to the workstation of the colleague and take the result back to his own workstation. But how could effective collaboration really look like in the future? What will be different from today? In this paper we present a scenario that illustrates our vision for plant operation in the future.

II. Future Scenario

To illustrate how plant control could adapt to the expected changes in a positive way, we follow a realistic problem-solving scenario in a chemical production plant. The storyline contrasts the current situation with our envisioned future scenario. The scenario takes place in a small manufacturing plant owned by the fictional company *Alpha Inc.* that produces low volume chemical specialties.

Today: The chemical specialties by *Alpha Inc.* are quite expensive products because they are produced in small batches and the plant is modified frequently to cope with changing market necessities and customer demands.

Future: In order to improve efficiency of their highly flexible production processes, *Alpha Inc.* has built a modular plant. It is composed of different modules that are connected via a backbone and can be easily replaced or rearranged [3]. Therefore, chemical specialties can be produced more efficiently, according to customer needs and market necessities.

It is a common situation in the chemical and manufacturing industries that some assets in the plant are built by external contractors that provide maintenance on the terms of Service Level Agreements (SLA). One of the contractors is the fictional *Delta Inc.* who provides all necessary services for operation and maintenance.

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Today: *Delta Inc.* is responsible for a specialised high precision pump that is tightly integrated into the plant structure of *Alpha Inc.*

Future: The contractor leases a module to *Alpha Inc.* that encapsulates the pump and surrounding equipment. The module is coupled only loosely with the process.

There are four roles which are relevant to the scenario: At management level the *supervisor* (SU) Alice is responsible for ensuring normal operation of the plant. All decisions critical to the production process are made by her. The *control room operators* (CRO) Bob and Carol are responsible for smooth operation and monitoring the current status of the plant. The *field operator* (FO) Dave handles on-site maintenance, cooperates with Bob and Carol and performs tasks assigned to him by Alice. The *external specialist* (ES) Erin works for *Delta Inc.* She has detailed knowledge of the assets serviced by her company.

Bob's shift has started and he is now responsible for observing the operation of the plant at Alpha Inc.

Today: Most control rooms follow a rather uniform concept with large displays to visualise the most important information about the plant status. The control room personnel has dedicated workstations in classical desktop layout with multiple monitors. The monitors are positioned in a way to ensure a good visibility of the observation displays. Supervisors often have their office located next to the control room.

Future: Our envisioned control room will feature large multi-touch displays that cover a large areas of the control room walls. They can not only be used to display data but also for interacting with the plant controls. There are still workstations, but they now consists of a tabletop or a large interactive display. Every worker may also use a mobile device such as a tablet or smartphone that can be used in combination with the bigger displays. The user interface utilizes the same interaction metaphors across all form factors. It automatically adapts to the preferences of the control room worker operating it. In front of the display wall, an adaptive and collaborative work space has emerged.

Bob notices an unusual change in an important process parameter: A supply pump shows increasing power consumption while maintaining its throughput.

Today: Workers generally keep an overview of the plant by observing the values, trends and alarms on their own monitors and on the large displays. In order to navigate to the correct place inside the control system, the operators must frequently switch between different screens. To reach information not available in the dedicated control system, such as historical data or video feeds, auxiliary systems have to be consulted.

Future: Since the display wall is interactive, a worker may directly interact with the visualised data, e.g. through multi-touch. Thus, a user is not required to use a workstation at all. He may adapt the screen to show relevant information on a certain part of the display. The system is able to identify all workers and track their position in the control room. This means that workstations no longer need to be dedicated to a specific person but adapt automatically to the workers next to it. Independent from the type of device, the user interface is adapted to a worker's role, level of authorisation, special skills, context of work, and personal preferences. The ability to use either the display wall, a workstation or a mobile device, enables a user to solve his tasks in a large number of ways, providing much flexibility.

Suddenly, an alarm sounds.

Today: To call the attention of operators in case of urgent events that require immediate action, there are several established methods: All alarms are added to the alarm list, a warning light flashes and an alarm bell sounds. If he is not already there, the responsible worker must return to his workstation immediately to take the required actions.

Future: In addition to the established methods for gaining operator attention, alarms are shown directly in the current work context of the responsible workers. For example, if an operator is discussing an issue with a colleague in front of the wall, the alarm notification is placed directly in his viewing area. If, alternatively, he is having a coffee at a table next to his work place, his mobile device will notify him. Additionally, the operator can solve simple issues directly on the mobile device.

The alarm indicates that the pressure of the pump has moved out of the normal operation range. The alarm is new for Bob. Thus, he asks his colleague Carol for help who is a senior operator and has lots of experience with this type of problem.

Today: Workers collaborate with each other verbally, join their colleagues at their workstations to discuss displayed information or use the display wall to point out certain visual elements. The point of interest can only be transferred between workstations by manually navigating to a certain piece of information. Data is usually not exchanged between devices.

Future: Our envisioned system provides several novel ways for collaboration of plant personnel. The display wall is used as a large collaborative area. A user can work on his own but may to also choose to cooperate with a colleague for solving a certain problem. Workers can use mobile devices to directly show interesting information to their co-workers, such as a relevant trend or a picture taken by a field operator. They can also seamlessly transfer the current context and state of their work from one device to another, across all form factors. For example, a worker might send a graph of historical data she has found to a colleague using her mobile phone. Together, they can now work on solving a problem collaboratively at a workstation and then take the result back to their mobile devices.

Carol and Bob analyse the problem and decide that the pump needs maintenance. Carol continues with her previous work while Bob asks the field operator Dave to perform an audio-visual check on the pump.

Today: The communication between operators in the field and in the control room is mostly verbal and often takes place via radio. Field operators may have paper documentation for devices and procedures at their disposal. Additional information must be requested through the CRO, who looks up the corresponding information in the system. If the FO needs additional information, like maintenance documentation or protocols, he has to retrieve them, often in form of printouts, and return to the place within the plant.

Future: The error-prone part of the communication between CRO and FO is reduced by the ability of the FO to directly access the process parameters using a mobile device. Thus, there remains more time for high quality and efficient verbal collaboration assisted by information transfer between devices. Collaboration between personnel inside the control room and in the plant is facilitated in the same manner. Information and context of work can be seamlessly shared between users.

Dave finds the pump in the plant and checks it. He can hear unusual sounds which confirm that the pump needs maintenance.

Today: In general, FO know their plant very well. In the case that a FO doesn't know the exact location of an asset, floor plans are used and a label-based identification scheme to locate specific parts is followed. Any data that is needed on-site, must be gathered beforehand.

Future: Assuming that the position of a worker within the plant is also tracked, he can be guided by a mobile device or by electronic glasses that augment his view with navigation information. These devices can also indicate which parts of the plant are relevant for the current task. Workers can also annotate existing data with comments or location specific notes, to add important facts not covered by the original data.

Bob informs his supervisor Alice about the situation. Since fault-critical assets are usually placed redundantly in a plant, Alice decided to switch the process to the alternative pump. She proceeds to request support from the responsible company. Delta Inc. instructs their specialist Erin to help solving the issue.

Today: According to general conditions there is an information gap between the operating company and external service providers. Usually, no digital information is allowed to leave the plant. Very often the data available to the ES is outdated or fragmentary in comparison to the existing plant, due to undocumented changes. The ES also faces distributed and heterogeneous data bases that impede unproblematic collaboration. Several different interface solutions, as well as various software solutions are omnipresent and typical for her daily workflow. There is no form of standardised data access. Verbal communication and various non-digital media are the predominant ways for information exchange, which makes recording and documentation complicated. Handwritten notes belong to the daily routine business and project works. Communication by radio may be hindered by a lot of random noise on the audio channel. All these facts lead to misunderstandings and mistakes right during collaboration work. If single steps have to be processed in the future, extra efforts are inevitable.

Future: The ES can request remote access to all necessary information relevant to the problem, like engineering data, plant documentation as well as recorded and live data. Digital information remains decentralised on different data bases, whose data is matched to achieve a comprehensive and uniform data model. A distributed client-server architecture has points of access, which are standardised to a certain extent. Data will be available at any location and will always be up-to date by using digital media that allow further documentation steps.

Erin guides Dave and Bob through the repair process.

Today: The ES is forced to make a time-consuming business trip for checking the issue on-site, when the communication via phone is not sufficient to solve the problem. The preparation for the specific problem is difficult because the ES has to take all possible circumstances into account.

Future: If the ES is informed about the problem, she can instantly visualise the geometry of the broken asset in Virtual Reality (VR). All relevant process data can be replayed in VR to visualise the process situation leading to the issue. During replay, quick navigation in space and time helps finding the cause of the problem. Assisted by collaboration technologies for information support and feedback, the ES works together with the CRO and FO, in a solution-oriented and efficient manner. Visual information from VR such as viewports or motion sequences can be shared to support any type of task. By presenting this information and explaining details of the problem, the ES can help the FO to focus on the relevant parts. This can be assisted using innovative digital techniques, such as Augmented Reality (AR). Based on the mentioned approaches, many problems can be solved remotely, without the need to be on-site.

Bob informs Alice about the successful repair and switches back to the original pump.

III. Discussion

When Alpha Inc. shares business relevant process data with *Delta Inc.*, it extends the classic boundaries of the control room. We argue that future control rooms will not consist of one physical room, as today. They will constitute distributed information and interaction spaces, located close to the plant or far away. They will allow to collaboratively control plants, adapted to the situation and tasks to be solved. Relevant information will be shared in secure and trustful ways between internal and external stakeholders [4].

This requires integration of information from different domains, tools and phases of the product life cycle. E.g. Bob, Dave and Erin need a 3D visualisation, live data from sensors and the plant topology. In order to facilitate a unified data access, the integration should take place at data level and not at application level. This allows a syntactic homogeneity as well as links between datasets without knowledge necessary on the client device. Semantics gaps can only be handled by adding knowledge to the clients or by providing semantic descriptions of used concepts. There are different approaches for closing the information sharing gap. Some extend the Semantic Web approach in order to fulfil industrial requirements [5]; others face Product Lifecycle Management (PLM) as enrichment of a product model in order to achieve a continuously growing, comprehensive and uniform representation that is applicable for any purpose [6]. Beside the advantages of sharing of information between different companies, it always raises the question of information security. This topic can be tackled by strong standard internet methods like TLS which secure the transport of data. This must be complemented by data privacy which applies a defined information loss on data and transfers only the uncritical part.

Interactive surfaces can provide a good alternative to the predominant interaction with computers through mouse and keyboard. Touch, multi-touch and digital pens as input devices facilitate collaborative work. They offer the advantage of enabling direct manipulation of data by merging input and output to a more natural form of interaction. The size of interactive surfaces ranges from smartphones or tablets over tabletops to even large, wall-sized displays. While it is possible to use them separately, they can also complement each other for solving particular tasks [7]. Especially interactive display walls promise novel ways for naturally and efficiently working with large amounts of data. Large displays have been used for tasks like information visualisation for years [8], allowing users to see both overview and detail at the same time. With the addition of physical navigation, they are also well suited for collaborative work [9] and may improve the performance of a user [10], [11]. The utilisation of multiple devices leads to additional requirements, which need to be addressed to ensure a satisfying user experience. User interfaces on all devices should adhere to common concepts and metaphors to make switches between them as seamless as possible. Since different devices might be used for different tasks and by different users, the system should adapt itself accordingly. E.g. the FO, using a tablet, will get a device-centric view, while the CRO, using a workstation, will get a function-centric view of the same plant-module.

VR can provide an efficient way for solving a problem. This is achieved by the ability to quickly represent a product close to reality and true to scale. It has been shown that humans can experience virtual environments intuitively in a more extensive way as on-site work [12]. VR improves coordination of distributed development activities. It supports tasks based on information derived from many sources [6]. For instance, hazardous situations, operation, maintenance and training scenarios can be examined with the help of virtual product models. Immersive VR systems like Oculus Rift and Cave Automatic Virtual Environment (CAVE) have emerged during the last decades. The level of acceptance for industrial application of these technologies keeps rising and their capabilities are continuously growing. These developments indicate that VR has the potential to revolutionize the way humans communicate and work [13]. The same is true for AR technologies [14]. AR can help by providing additional information for problem-solving, both in virtual environment [15] and on-site [16].

Of course, the level of automation in plants will continue to rise. More and more tasks will be performed by machines. However, humans will remain an important part of the operation of a plant performing more sophisticated tasks and, thus, need to be highly qualified. In our scenario, this means that Bob's responsibilities grow – he is deeply involved in the problem-solving process. Observing the plant during normal operation, which used to be his predominant occupation, has become much less important.

IV. Conclusion

This paper argues that plant control will change in many ways. It will leverage emerging technologies and facilitate cooperation of humans. Information sharing in companies as well as across organisational boundaries will become common in industrial applications. In future work, we will show prototypical implementations of the presented scenario using a real plant, an interactive display wall, a CAVE and mobile devices.

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