Digital Connected Production: Wearable Manufacturing Information Systems

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Abstract. A manufacturing information system is targeted for use anywhere production is taking place. Modern manufacturing information systems are generally computerized and are designed to collect and present the data which production operators need in order to plan and direct operations within the production. The application of mobile and wearable devices can support operators' tasks without distracting them from their core duties. In this paper, we present an approach towards a wearable manufacturing information system that is able to implement decentralized production monitoring and control and supports users in their core tasks. Building upon acquired and digitally stored production data, these devices provide different user-specific information and services when required. A practical example from corrugation industry highlights advantages of mobile devices compared to conventional centralized systems in the field of manufacturing.

Keywords: Production information systems · Process monitoring Smart devices · Wearables · Industry 4.0

1 Introduction

The term *Industry 4.0* describes the support of manufacturing processes by means of information technology [1]. A manufacturing information system is targeted for use anywhere production is taking place. Modern manufacturing information systems are generally computerized and are designed to collect and present the data which production operators need in order to plan and direct operations within the production [1,2]. The growing interest and further development of concepts and systems that use digital information in industrial environments opens up several possibilities to optimize information processing and therefore to increase efficiency in production processes [3]. Furthermore, *Industry 4.0* concepts frequently imply a turning away of fully centralized equipment control towards a more flexible, decentralized production control [4].

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The connection between production and information technology leads to an ubiquity of digitally supported information processing systems in production environments. This situation can generally be summarized under the term *Ubiquitous Computing* [5,6]. In the field of manufacturing this term comprises the digital integration of production equipment and subordinated information systems. This way, all participating production objects and entities, i.e., machinery as well as human production operators are able to communicate and interact with each other based on a digital, potentially mobile infrastructure. Thus, such a manufacturing system represents a typical *cyber-physical system* where computer based controlling and monitoring facilities are tightly integrated with its users, e.g. human operators. In such a system environment, relevant information can be tracked and made available in realtime whereby processes alongside the whole value added chain can be designed efficiently [7].

One way of integrating human users into a cyber-physical system seamlessly is to equip them with *Wearable Computing Systems (Wearables)* like smartphones or smartwatches [7]. These *mobile* and *smart* devices support users in their operative tasks by directly proving them - ubiquitously, independent from their physical location - with most recent information about the production process and production equipment. Additionally, this information can be highly personalized.

In this paper, we present an applied approach towards a wearable manufacturing information system that is able to implement decentralized production monitoring and control and supports users in their core tasks. First, we give an overview of related work (Sect. 2). Section 3 discusses a conceptual approach how to efficiently and effectively identify tasks that can optimally be supported and enacted through a cyber-physical system approach, here based on wearables. Subsequently, Sect. 4 introduces a general applicable technical architecture of a digitally connected production site supported by mobile devices based on the protocol MQTT. Section 5 describes the evaluation and application of our approach in corrugation industries that highlights the advantages of mobile devices in the field of manufacturing. The paper is finally concluded in Sect. 6.

2 Enabling Technologies and Related Work

Within a digitally connected production, different devices such as sensors, actuators and controllers can record the current status and values of objects [8]. Different heterogeneous devices can communicate with each other and server gateways by means of Service-Oriented Architecture (SOA) protocols like the web-service oriented Hypertext Transfer Protocol (HTTP) or the local network oriented MQ Telemetry Transport (MQTT)[1] protocol enabling interconnectivity at an object level. Sensors have the capability of measuring a multitude of parameters frequently and collecting plenty of data. Analysis of Big Data, both historical and real-time, can facilitate predictions on the basis of which proactive

[1] OASIS, http://docs.oasis-open.org/mqtt/mqtt/v3.1.1/mqtt-v3.1.1.html.

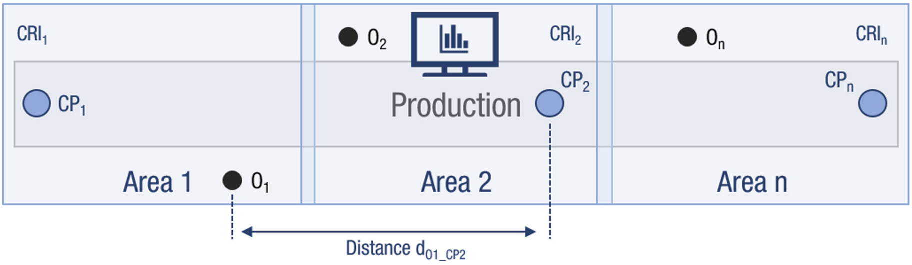

Fig. 1. Conceptual modelling of a production hall

maintenance decision making can be performed [9,10]. The e-maintenance concept can significantly address these challenges. There are several research works that introduce intelligent agents that are directly implemented at the shop floor level [11]. Furthermore, there is research about web-based production maintenance services and architectures that include wireless sensing of process data and identification technologies, data and services integration and interoperability [8].

Portable computing devices have been used for production monitoring for many years. Though initially offered as an integrated instrumentation solution, mobile devices such as PDAs and tablets have been programmed with a mobile capacity to analyze and present data, disconnected from the actual sensing components [5,12]. These solutions introduce concepts, architectures and prototypical implementations for configuring the sensing infrastructure and for presenting certain process and equipment data on mobile devices.

The work at hand extends current solutions by introducing an architecture for context relevant information provision and actively influencing and controlling production processes and equipment by means of mobile devices. Furthermore, we present a full-fledged implementation of a wearable manufacturing information system by means of smartphones and smartwatches.

3 Process Monitoring and Control Using Mobile Devices

Inspired by the promising prospects of ubiquitous computing and its combination with wearables we investigated how these new technologies could be utilized best in our applications.

3.1 Problem Description and Conceptual Solution

We focus on shop floor applications where products are manufactured in automatized production lines. Typically, such a production line is divided into several production areas (cf. Fig. 1). Each area is independent from the others with well-defined interfaces between them. Each part of the production line has a couple of so-called control panels (CP). A CP is needed for different operators O to intervene the production processes, sometimes due to errors, but mostly due to maintenance tasks. It is also typical that error and maintenance information as well as other context relevant information (CRI) is depicted on one (or a few) central information devices. There is a simple rule of thumb saying that the longer the reaction time of an operator to take care of the intervention is, the worse it is for the production process.

When we were looking for a good deployment site for wearables, we were recapitulating their main benefits. One of the major advantages of wearables is immediate notification of operators independent of where the operator is located and where the information stems from as long as it is part of the information system. This fast notification enhances the situational awareness of the operators on the shop floor. A second major benefit is the ability to actively intervene production through a wearable device, i.e., that a production line could be controlled remotely.

Combining the need for intervention and the chance of immediate notification and remote control through wearables leads to the idea of using wearables as fast information medium and control panel for operators. The gain of time fostered by the usage of wearables can easily be calculated. In the former setting, the time an operator O_i in a certain area i needed to operate a control panel CP_j is composed of three parts:

- ***(i)*** the time to find out whether at all and what control panel intervention is required, i.e., the time to go from the operators current position to the information devices (t_{noti})
- ***(ii)*** the time to select the relevant information CPI_i from the information device (t_{read})
- ***(iii)*** the time to go from the information device to the control panel (t_{cont}), i.e., to walk a certain distance d_{O-CP}.

In sum, $t_{intervene} = t_{noti} + t_{read} + t_{cont}$ is a timespan which is heavily determined by physical work, i.e., the time elapsed since operators have to walk from a current position to the information device and then from this information device to the control panel. A third time component is the time operators need to select and filter relevant information on the information device since often those devices are heavily overloaded with status information from a whole production line.

Figure 1 illustrates the solution idea by depicting a situation in a corrugation plant where we deployed the proposed solution. In this plant, a production area is about 140 m long. An operator stands somewhere in that production area. To be informed about potential intervention, the operator has to go to the local information device (t_{not}); after having found relevant status information (t_{read}), he has to go to a control panel for intervention (t_{cont}). Through observations we found out that filtering status information takes on average about 20 s and that an operator on average covers a distance of 40 m per intervention. In total, it takes about 2 min for a necessary intervention. Within this reaction time, e.g., deficient products are produced.

To cope with the observed issues we are introducing innovative technology, here in the form of wearables. These concepts change fully centralized information and equipment control towards flexible, decentralized production monitoring and control. In particular, we deploy mobile concepts for *(i) process monitoring*, i.e., the provisioning of up-to-date and individual production process and equipment information, and *(ii) process control*, i.e., actively impacting production processes from potentially arbitrary locations within the plant. We detail these two issues further within the next two sub-sections.

3.2 Process Monitoring with Mobile Devices

A complete digital interconnection of the production site offers the possibility to record and store relevant process and equipment data in a structured reusable form. Using industrial M2M communication protocols, e.g., HTTP or MQTT, and interfaces, recorded process and machine data is accessible worldwide. Mobile devices enact these standardized and web-based interfaces for accessing the recorded data. Based on that, wearables provide a multiplicity of monitoring functions to users: *(i)* visualization and confirmation of alarm and error messages; *(ii)* observation of current status information and process parameters of different production modules; *(iii)* graphical visualization of recorded process data and based on that statistic process control mechanisms (e.g., *Nelson Rules*) and *(iv)* communication between different operating users.

Thus, responsible operating and maintenance staff is pointed to current alarm messages or instructions of machinery in real time on smartphones or smartwatches on their wrist. Here, messages and instructions are transmitted to responsible users through visual, acoustic and, in case of noisy environments through haptic signals like vibration alarms. By means of configurable user roles or user priority groups, production or shift supervisors, equipment operators or maintenance staff are able to react to disturbances and changes situations immediately.

3.3 Process Control with Mobile Devices

Alongside to observation and visualization of process data, it is also possible to actively influence production processes by means of mobile devices. This way, users are able to control functionality that is necessary to operate machinery by means of wearable devices directly on site as well as off site via internet connection. For example, production speed can be adjusted by a corresponding operation on a smartwatch on the operators' wrist.

Note that both for process monitoring as well as for process control, functionality and visualized information can depend on the current position of the device (i.e., GPS signal of the device) or on the users' role that is currently logged in to the device. Hence, application specific services and information is only accessible and shown where they are necessary and needed. This is fundamental for goal-oriented work and protects users from information overload.

4 Technical Implementation and Architecture

Figure 2 visualizes an holistic architecture of a digitalized production hall. It contains the different layers that are necessary to implement the different concepts and functionalities mentioned in Sect. 2. The whole architecture is based on the communication protocol MQTT.

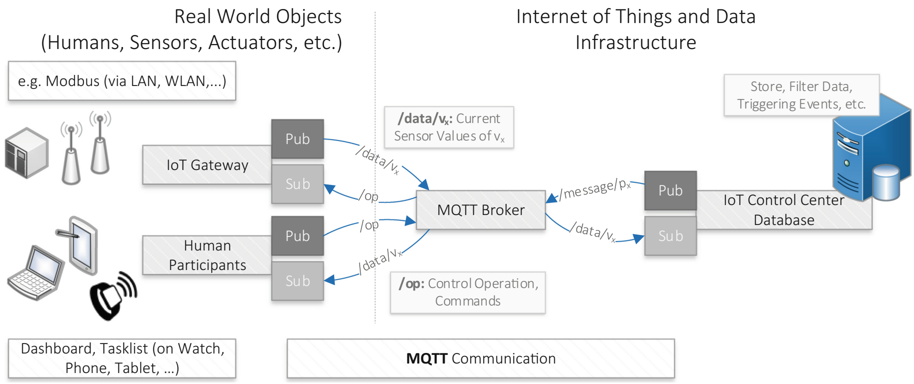

Fig. 2. Architecture of a digital production hall that uses mobile devices

In this architecture, real worlds objects, i.e., humans, sensors or actuators, represent both publishers and subscribers. Devices located on the production line (e.g., programmable logic controllers or sensors) are connected to an IoT gateway using specific architectures such as Profibus, LAN, WLAN or Bluetooth. Manufacturing data of a specific device v_x is acquired and afterwards published on a specific MQTT topic $/data/v_x$. Through a MQTT Broker the acquired data is sent to interested monitoring and controlling devices such as mobile devices of human operators. Therefore, mobile devices of interested operators have to subscribe to the topic $/data/v_x$. For data storage and alarm and info messaging, an IoT Control Center always subscribes to all MQTT topics. This way, current sensor values are continuously recorded and compared to defined thresholds and, in case of violations, certain messages are fired. These messages are then published on an operator p_x specific topic $/message/p_x$.

On the device end, which could be web browser, a smartphone or a smartwatch application the received MQTT messages are converted back to data. Therefore, the MQTT service becomes the data source, that can be accessed for different types of applications simultaneously. Note that current smartwatch technique doesn't allow to communicate directly with external services. A smartphone is currently still required that manages service communication.

The other flow direction can also be implemented, in other words the same application used for monitoring can interact with the production line and perform controlling. When the user interacts with the application, these interactions

Fig. 3. Remaining time of current job and stack size modules on smartphone

are sent via the MQTT topic */op* to the Broker. The Broker delivers the command to the subscribed actuator gateway. Here, the message is processed, i.e., converted to machine specific commands, which are processed and executed on the devices located on the production field.

5 Evaluation and Industrial Application

In this section, we describe the evaluation of the proposed concepts and techniques by means of an extensive application in industry. The described concepts have been implemented in a corrugation plant. Due to increasing automation and staff reduction, less operators are available to control such a production line. Hence, interactions between users and machinery in case of this up to 140 m long facility requires several location changes of users between control panels that result in delayed information flows. These delayed reaction times are frequently the reason for increased deficient products.

The concepts where implemented by additionally defining a user role model. Here, available operators were assigned to a specific area of production that depicts their area of responsibility. Additionally, neighbouring areas can partially overlap and therefore users can share tasks or execute them alternating. The concepts allows for dynamic changes of areas and assignments, e.g., by incorporating dynamic GPS signals of users' smartphones. This way, shift supervisors or reserve pool employees can be added on demand. Display elements can be ordered and configured individually to provide the greatest possible flexibility of information provision.

For example wearable devices offer diverse functionality to operators at the *Dry-End* (the area where produced corrugated paper leaves the plant), e.g., *(i)* remaining time of current production job; *(ii)* remaining time to next stack transport; or *(iii)* current production speed. Information modules that implement function *(i)* and *(ii)* are shown in Fig. 3. The module that shows the

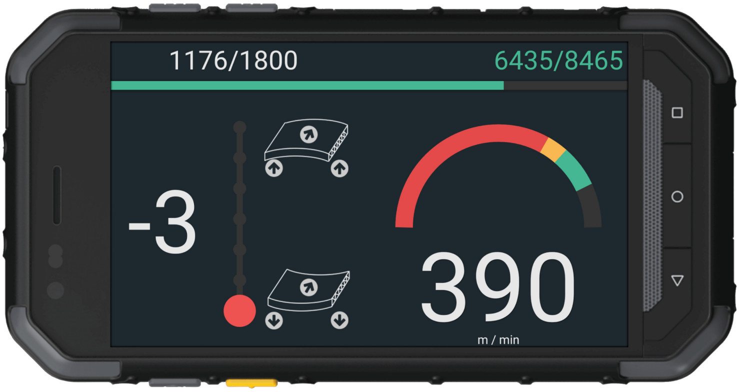

Fig. 4. Warp control service and current production speed on smartphone

Fig. 5. Error and warning message service on smartphone application

current production speed, e.g., is visualized in Fig. 4 on the right hand side. Furthermore, users can influence current process and equipment parameters in realtime via certain scroll bars, e.g., adjusting the current warp of the corrugated paper. This functionality is visualized in Fig. 4 on the left hand side. Users at the *Wet-End* (the area where original paper is inducted to the plant) receive continuously information w.r.t. *(i)* the next necessary roll change or *(ii)* occurring error and defects of machinery modules.

Alongside to process data operators receive error messages and instructions from the different plant modules. This way, concrete and goal-oriented instructions in error cases or warning messages for supply shortfalls can be transmitted to users. The implemented message service is visualized on the left hand side in Fig. 5.

Fig. 6. Different monitoring and control services on the smartwatch

Another important aspect of the implemented concept is depicted by the involvement of maintenance staff, since the greatest part of errors only occurs during actual production service. For example, a decreasing value of a specific pressure sensor or an increasing temperature value of a propulsion engine results in an instruction message that summons the maintenance staff to clean filters of a corresponding equipment assembly.

All the different information and control services on the smartphone have a corresponding interface for smartwatches that can be worn on the users' wrist. An exemplary set of services is visualized in Fig. 6. Through the described implementation of a wearable production information system it was possible to significantly reduce reaction time intervals. Furthermore, the amount of deficient products could be decreased and the overall quality of the produced corrugated paper has been improved. The overall equipment downtime was significantly decreased, since problems have been prohibited or recognized in advance and were solved proactively. As a result, the overall equipment efficiency could be increased effectively.

6 Conclusion

In this paper, we presented an applied approach towards a wearable manufacturing information system that is able to implement decentralized production monitoring and control and supports users in their core tasks. Building upon acquired and digitally stored production data, these devices provide different user-specific information and services exactly when required. A practical example from corrugation industry highlighted advantages of mobile devices in the field of manufacturing.

The implementation of the described concepts are given by example applications on smartphones and smartwatches. By means of visual controls users are able to adjust specific equipment parameters in realtime and receive corresponding warning messages or work instructions.

For future conceptual extensions we plan to further standardize the described concepts so that the approach is applicable in a diverse set of production industries without substantial adjustments of the core product.

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