Sensor-enabled Wearable Process Support in Production Industry

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Abstract. In this industry paper we describe a BPM case supporting production processes in corrugation industry. Due to increasing automation and staff reduction, less operators are available to control a corrugated paper production line. Hence, interactions between users and machinery require several location changes of users between control panels that result in delayed information flows. The general goals of the project carried out are to increase operators productivity in terms of reducing stop times and increasing production speed and to faciliate the breaking-in of new employees through transparent process knowledge. Therefore, we implemented a sensor-enabled wearable process management combining collected sensor data, wearable interfaces and executed BPMN models. First evaluations show that the solution improves the certainty of how and when specific work steps should be carried out and reduces the delay between work steps through mobile and sensor-enabled real-time task provision.

Keywords: Sensor-based Process Execution, Internet of Things, Wearables, Production Industry

1 Introduction

Business processes are executed within application systems that are part of the real world involving humans, cooperative computer systems as well as physical objects [1–3]. The Internet of Things (IoT) enables continuous monitoring of phenomena based on sensing devices, e.g., wearables, machine sensors, etc. Process execution, monitoring and analytics based on IoT data can enable a more comprehensive view on processes. Embedding intelligence by way of real-time data gathering from devices and sensors and consuming them through Business Process Management (BPM) technology helps businesses to achieve cost savings and efficiency. In literature, several concepts are emerging on combining IoT and BPM [4–7]. Still, there are many open challenges to be tackled [8].

In this industry paper we describe a BPM case implemented within a production industry scenario. More precisely, we introduced BPM support for several production processes of corrugation industry plants where paper is glued together to produce corrugated paper as raw material for cardboard boxes. Due

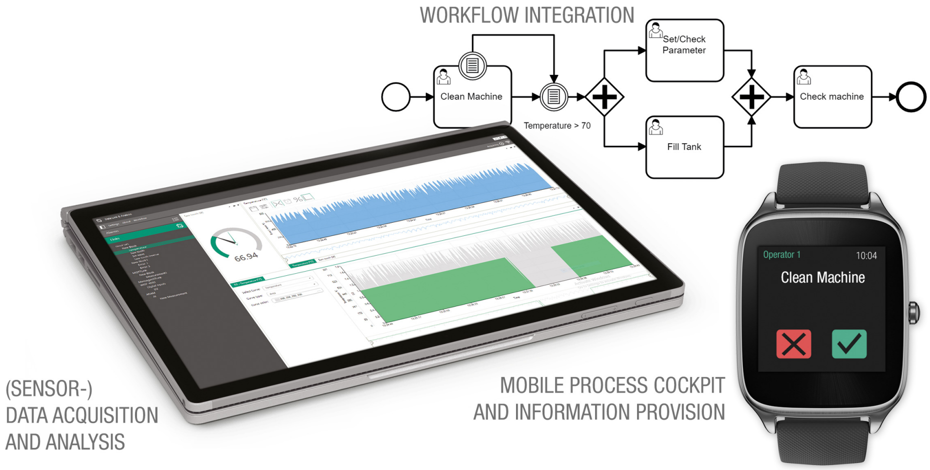

Fig. 1: Overview of the implemented solution

to increasing automation and staff reduction, less operators are available to control a corrugated paper production line. Hence, interactions between users and machinery require 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. Furthermore, corrugation plants currently have to face a high fluctuation of employees such that process knowledge is lost over time. As a result frequently new employees have to learn a basic understanding of production process control from scratch.

Based on these issues the general goals of the project carried out are *(i)* to increase operators productivity in terms of reducing stop times and increasing production speed, *(ii)* to faciliate the education and onboarding of new employees through transparent process knowledge and *(iii)* to ensure traceability of work steps. These goals have been approached in several phases as visualised in Fig. 1:

- Introduction and implementation of a wearable production information system, providing up-to-date sensor-based process information and process control capabilities on a smartwatch interface for production operators.
- Modelling the existing production processes of the corrugation plants using the Business Process Model and Notation (BPMN).
- Combining collected sensor data, wearable interfaces and executed BPMN models to realize a sensor-enabled wearable process management in corrugation industry.

The described solution has been rolled out in different plants in Germany and the United Kingdom in 2018 and 2019. In total, fourty production operators have been equipped with smartwatch devices and assigned a user in the BPM system. Our approach demonstrates process innovation in three dimensions:

- Feasibility: we introduce an innovative wearable process user interface based on smartwatches and a sensor-enabled process management solution
- Desirability: the presented case demonstrates the first process-based and mobile production information system in corrugation industry.
- Viability: the introduced case enables customers to realize an integrated BPM based solution for machine control and maintenance.

First evaluations carried out with operators show that the solution *(i)* improves their general understanding of the underlying production process, *(ii)* improves their certainty of how and when specific work steps should be carried out, and *(iii)* reduces the delay between work steps through mobile and sensor-enabled real-time task provision.

This paper is structured as follows: first, we describe the initial situation that led to the introduction of the solution in Section 2. In Section 3 we describe the actions that have been taken including technical details and occuring roadblocks during the introduction. Section 4 describes first evaluation results and finally concludes the paper.

2 Situation Faced in Corrugation Plant

Due to increasing automation and staff reduction, less operators are available to control a corrugated paper production line. Hence, interactions between users and machinery 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.

Typically, such a corrugation production line is divided into several areas (cf. Fig. 2). 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.

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}

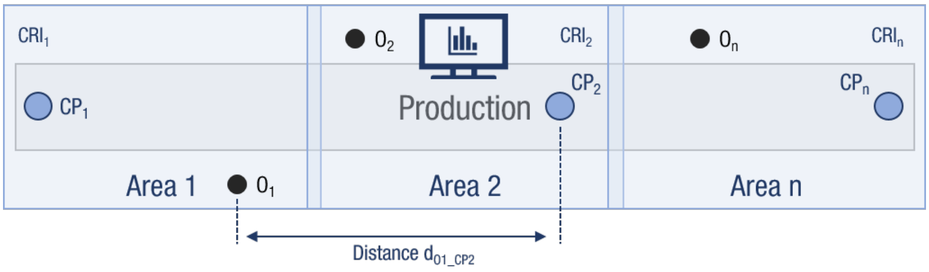

Fig. 2: Conceptual modelling of a production hall

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. Fig. 2 illustrates the problem by depicting a situation in a corrugation plant. In this plant, a production area is about 140 meters long. An operator is located somewhere in that production area. To be informed about potential intervention, the operator has to go to the local information device (t_{noti}); 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 seconds and that an operator on average covers a distance of 40 meters per intervention. In total, it takes about 2 minutes for a necessary intervention. Within this reaction time, e.g., deficient products are produced. Furthermore, we noticed that corrugation plants have to face a high fluctuation of employees. Frequently new employees have to be taught and learn a basic understanding of the production process from scratch.

Summing up, we identified different problems and needs on corrugation production shop floor:

- The need for *wearable user individual production process information and control systems* to diminish the timespan for information provision and process intervention.
- The need for *transparent process descriptions and active process support* to synchronise and guide production operators.

3 Actions taken

The described BPM case has been implemented in two phases. First, we introduced a wearable production information system that visualises current process data and allows operators to control production. Second, after still facing remaining issues, we enhanced the solution by realizing a process model based task coordination for all operators.

3.1 Phase 1: Wearable Production Information Systems

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.

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.

Wearables provide a multiplicity of monitoring functions to operators: *(i)* visualization and confirmation of alarm and error messages; *(ii)* observation of current status information and process parameters of different production modules; and*(iii)* 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 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 changed situations immediately.

Alongside to observation of process data, it is also possible to actively influence production processes. Users are able to control functionality that is necessary to operate machinery by means of wearable devices. For example, production speed can be adjusted by a corresponding operation on the 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 users' role. 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.

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. 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. 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.

3.2 Phase 2: Sensor-enabled Process Support

Despite the introduction of wearable information systems, plant administration still faced the issue of uncoordinated operators: for example in case of machine alarms that required operator intervention, either none or more than one person took care of it. These remaining synchronization problems required a completely new approach: the introduction of a BPM solution based on well-defined workflows and task assignment and coordination.

Therefore, the whole production processes have been defined and modelled during four months. We observed and documented production as well as operator tasks over several days and discussed our observations and model drafts together with operators and production supervisors.

Exemplarily, we describe a subprocess that is executed every time paper source rolls run empty, i.e., where new paper rolls need to be spliced with the paper from the low running roll. In order to effectively execute this process, several real time interactions with IoT devices, i.e., sensors and operator equipment, is necessary: the process execution system (BPMS) must be aware of sensor data which indicates that a splice will happen soon, triggering the splice subprocess. Operators located somewhere along the machinery need to observe the splice process to avoid issues. Therefore, they need to be notified in real time to walk to the splicer. This requires wearable interfaces communicating with the BPMS over the IoT. Depending on a sensor value indicating the next roll quality, the BPMS has to execute different paths. In case the environment changes, operators tasks need to be reordered based on priorities or cancelled by the BPMS. In addition to current tasks to be executed, operators require context specific information at hand, e.g., the location of the splicer and the quality of the next paper roll. Furthermore, operators continuously need to observe viscosity and temperature of the glue to ensure a successful splice process.

The process is initiated by defining internal variables. Subsequently, the control flow splits into several branches depending on the priority of tasks and the machine characteristics. Note that each task makes use of the variable *Element Documentation* that captures current machine information and is visualized as an additional remark below the actual task name.

To directly notify operators when human actions are needed, plant personal has been equipped with smartwatches (Fig. 3). Therefore, a user-group model has been defined in the BPMS. Here, available operators were assigned to a specific area of production that depicts their area of responsibility. Thus, depending on the area operators are working, the BPMS assigns a different set of tasks. Furthermore, operators are used more effectively because low priority work is aborted in order to perform high priority work that could lead to machine stops. This way, concrete and goal-oriented information in error cases or warning mes-

Fig. 3: Wearables: a) unclaim/complete task; b) tasks; c) and d) context info

sages for supply shortfalls can be transmitted to operators and enhance the over all process transparency and thus the quality of task execution.

3.3 Technology Stack and Implementation

The described approach has been implemented based on a four layer architecture that is visualised in Fig. 4. It consists of the following layers: *(i)* IoT objects like sensors as data sources; *(ii)* IoT infrastructure and communication middleware; *(iii)* the BPMS and *(iv)* data sinks in form of IoT objects of human process participants. The layers are connected based on standard communication protocols.

In order to connect arbitrary sensor objects we make use of the open source platform Node-RED of IBM. The platform acts as a communication middleware between various IoT protocols and data sources like TCP sensors and the BPMS. To allow the IoT objects at layer *(i)* to communicate with the IoT middleware at layer *(ii)* and the BPMS, respectively, a Message Queue Telemetry Transport (MQTT) Broker is used. IoT objects, i.e., sensors or actuators, represent publishers. They are connected to an IoT gateway using specific architectures such as Profibus, LAN, WLAN or Bluetooth. A specific IoT variable v_x is acquired and published on a MQTT topic $/v_x/data$. Through a MQTT Broker the acquired data is sent to an acquisition application at layer *(ii)* that stores IoT data into a high performant NoSQL database. In our implementation we used the latest version of the Apache Cassandra database.

A distribution application at layer *(ii)* keeps the BPMS updated with the latest sensor values. All running instances of a particular process receive the corresponding data value. The application cyclically acquires the values from the database in a key-value structure and sends them to the BPMS. In our architecture we used the latest version of the Camunda BPMS and therefore communicated with the workflow engine by means of the Camunda Rest API. The tools at layer *(ii)* ensure that process relevant information stemming from the IoT is up-to-date. Through the acquistion tool, IoT data meta information

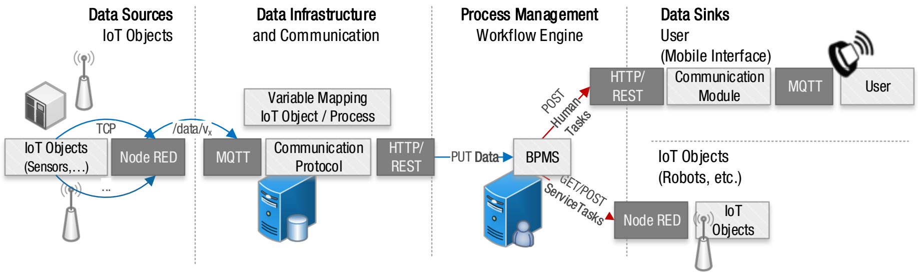

Fig. 4: Integrated communication architecture for sensors and BPMS

is provided that makes clear where the data stems from. Given the current IoT data values, the engine calculates available activities.

As a mobile user interface we implemented an *Android* based smartwatch application that subscribes to specific MQTT topics. The distribution application cyclically requests the current user tasks from the Camunda API for each defined user and publishes to the correct MQTT topic, given the mobile device identifier, i.e., smartwatch device, configured on the BPMS. The application allows users to start and complete tasks as well as to initiate new process instances. The process of the device recognizing its configuration is implemented as follows: the distribution application cyclically checks the user configuration in the BPMS. When a change is detected, it publishes the new configuration to the topic $/\{actor\_id\}$. The assignment of a smartwatch to a specific user is implemented by means of a unique device id, i.e., the smartwatch of a certain actor subscribes to the topic of its specific device identifier. Having established such connections, the smartwatch communicates with the MQTT broker by subscribing to the following topics: the current tasks for a specific operator are published on the topic $/\{actor\_id\}/tasks$. The device sends operators commands, such as *complete task* to the topic $/\{actor\_id\}/command$. The content of the message is forwarded straight to the BPMS using a *POST* request. In case of active interactions with the IoT environment BPMN Service Tasks are used. Here, we make use of the Camunda HTTP connector either to directly communicate with IoT objects that support HTTP communication or to send current variable values to Node-RED.

3.4 Roadblocks

During the project we were facing several problems and roadblocks. These roadblocks can be divided into two categories: *(i)* technical issues and *(ii)* social and organisational issues.

First of all, we needed to establish a well working WiFi infrastructure to ensure full coverage of the production hall for real time communication. For reasons of blocking machinery, cabins and access restrictions, this turned out to be difficult and cumbersome. For a long time, we were facing connection problems resulting in task notification delays. Finally, a network with nine access points covering the whole shop floor was installed. A wifi controller ensures fast roaming and hand over such that each device is always connected to the access point with the best signal for a specific location.

Social and organisational issues turned out to be even more challenging. Sensor-based event invocation heavily depends on the accessibility of sensor and machinery data. A big part of required data stems from external device providers that were asked to either provide their data in an accessible way or to implement an interface such that the data can be collected and be referenced in executed processes. Both solutions turned out to be difficult to realize and took months to be established.

Last but not least, the fundamental modelling of running shop floor processes proved difficult as well. There was no written document of activities and work steps and operators and supervisors on site were frequently busy. As a result gathering necessary process information turned out to be a longsome procedure implying occasionally unpleasant conversations.

4 Results achieved

The established wearable process solution of a german production plant is captured in Fig. 5. Through the described implementation it was possible to significantly reduce reaction time intervals. The amount of deficient products was 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. Hence, the overall equipment efficiency could be increased effectively. To quantify these findings, we analysed process execution. We tracked the corrugation process *(i)* for five days without operators using wearable devices and *(ii)* other five days with operators being notified using smartwatches. In particular, we measured the average instance throughput time for splice processes. The effectiveness of the approach has been measured based on machine stop times and waste reduction. On average, 100 splices are executed per shift, i.e., 8 hours of production. In case *(i)* we recorded a total stop time of approx. 180 min, i.e., on average 12 min per shift. In case *(ii)* the stop time has been decreased to approx. 60 min in total, i.e., 4 min per shift on average. The results show that the application of the wearable sensor-enabled BPMS leads to less machine stops because users need less time to recognize work to be done.

Additionally, we performed a qualitative usability evaluation involving operators of two shifts, i.e., 8 people. A usability evaluation of the wearable process user interface was performed by calculating its' System Usability Score (SUS). A SUS questionnaire consisting of the following ten questions was presented to operators at the Wet-End group:

1. I think that I would like to use this application frequently
2. I found the application unnecessarily complex

Fig. 5: Exemplary process based user interface in corrugation plant

3. I thought the application was easy to use
4. I think that I would need the support of a technical person to be able to use this application
5. I found the various functions in this application were well integrated
6. I thought there was too much inconsistency in this application
7. I would imagine that most people would learn to use this application very quickly
8. I found the application very cumbersome to use
9. I felt very confident using the application
10. I needed to learn a lot of things before I could get going with this application

The evaluation resulted in a system usability score of 93,33 out of 100. Fig. 6 visualises the evaluation results. As can be seen is this score located between the ratings *EXCELLENT* and *BEST IMAGINABLE*, showing that the wearable process support is easy to use and helpful for operators.

5 Summary and lessons learned

In this paper, we described an innovative BPM case carried out in corrugation production industry. Within the project, we implemented a sensor-enabled wearable process management combining collected sensor data, wearable interfaces and executed BPMN models. First evaluations show that the solution improves the certainty of how and when specific work steps should be carried out and reduces the delay between work steps through mobile and sensor-enabled real-time task provision. Of course the presented solution can be generalized to other

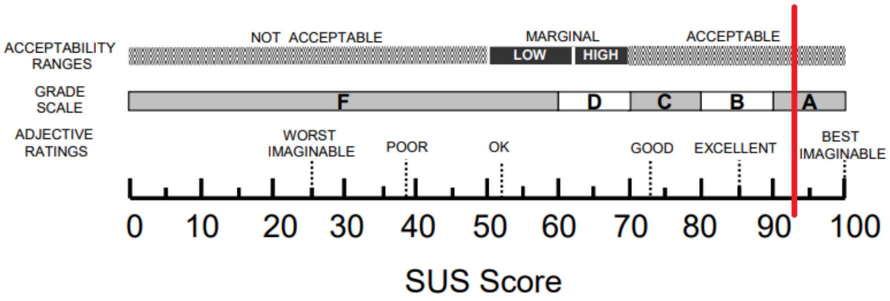

Fig. 6: Qualitative user experience evaluation according to the System Usability Score (SUS)

industry types as well. As a summary, we want to outline the most important aspecs that we learned throughout the project and which factors were mainly contributing to the successful completion of the case.

- We recognized the advantages that BPM technology yields compared to traditional information systems for production shoop floor. User specific task coordination based on sensor data as a process oriented solution can provide it, seems to be the missing link between production information and operator guidance.
- Modelling production shop floor process models is a cumbersome task that requires both deep technical background w.r.t. the production system as well as w.r.t. the used modelling language, e.g., BPMN. To establish a working and accepted solution, an expert in both areas has to tackle this job.
- Organizational issues, e.g., with external companies, should be identified at an early stage of the project to reduce waiting times for adjustments.
- Understanding BPMN modelled processes by production employees is not as simple as expected. Models have been misinterpreted frequently and several explanations have been necessary to consolidate a common understanding of the notation and the defined processes.
- As a result, other than planned, BPMN models turned out to be less important as a communication basis for all participating people. Instead, executed processes and concrete task assignments fostered certainty of operators, without knowing the overall flow of work.

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