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Collaborative maintenance in flow-line manufacturing environments: An Industry 4.0 approach

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Abstract

In a manufacturing shop-floor, context-aware intelligent service systems, along with mobile solutions can be used for the provision of information services to shop-floor personnel according to their situation. This paper presents an Industry 4.0 system that provides decision support for line operators and maintenance personnel, in an industrial production scenario, where maintenance needs immediate response. A multi-layered, Service Oriented Architecture (SOA) based system, which integrates several sub-systems, such as sensor data fusion, context modelling and contextual data information provision has been developed. The solution includes a number of context-aware apps that support the collaborating users to address maintenance issues. A case study was conducted, providing insight into the suitability of the proposed solution and bringing to light further aspects that will improve the proposed context-aware system.

Keywords: context-aware; Industry 4.0; case study;foundry

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1. Introduction

The Industry 4.0 paradigm promotes the connection of physical items such as sensors, devices and enterprise assets, both to each other and to the Internet. The enormous amount of information gathered and generated by ICT systems and sensors installed at the shop-floor needs to be presented in a manner that could truly speed up production processes, enable immediate reaction to issues and shortcomings. However, the existing ICT solutions originally intended for the support of production processes, currently lack in providing the right information to the right persons, at the right time and location by imposing the development of context awareness for manufacturing information distribution systems.

Maintenance is a critical activity that takes place at the manufacturing shop-floor. Insufficient maintenance has an impact both on the performance of the production process as well as on the quality of the finished product. A proper level of detailed maintenance instructions should be provided to the maintenance personnel, according to their level of expertise. In addition, advanced context information collection and management technologies, e.g., Near Field Communication (NFC) and Service Oriented Architecture (SOA) technologies, in the shop floor, provide opportunities for the development of such context-aware information systems, in aid of the maintenance operators and engineers.

A manufacturing system can be defined as a combination of humans, machinery and equipment that are bound by a common material and information flow [1]. In Industry 4.0, machines, parts, systems and human beings will be highly connected and highly integrated. Every physical object will formulate a Cyber-Physical System (CPS) and it will always be linked to its digital footprint as well as to intensive connection with the surrounding CPSs of its on-going processes [2].

As the transformation into a highly networked environment takes place new challenges emerge. A key issue found in this rich information exchange environment is that any

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information overload be avoided and that the right information be delivered to the right people, at the right place and in the proper format [3]. This can be achieved if information delivery is aligned to the context of the agent that will receive the information. In general, context-awareness is the property for the provision of suitable services to a user, through an analysis of his context [4]. As context can be considered any information, characterizing the situation of an entity that can be a person, place, or object, relevant to the interaction between the user and a context-aware application [5]. The context aware applications define a holistic and dynamic model that takes into account the context of tools, machines, parts, products, while at the same time, utilizes information regarding the planning of manufacturing processes. Context-awareness can be used in order for the visibility of operations and their performance to be increased. It aims at enabling factory shop-floor and office personnel to make a decision, based on a systematic understanding of the system having derived from a factory's real-time sensed context, instead of a decision based on a fragmentary system view and a limited expert knowledge [6]. In order to have context-aware ICT, a context acquisition and management infrastructure should be implemented. The architecture of a context aware ICT system depends on different requirements, such as the location of sensors, the number of possible users, response times or the availability of computing power. More insight into alternative architectures is provided in [7] and [8]. In [9], an ontology based approach is used for the development of a context repository in a manufacturing environment. Similarly in [10], an ontology-based approach for context modelling has been developed. In [11], an ontology-based context model also for real time decision making is proposed for the optimization of the key performance indicators of Flexible Manufacturing Systems (FMS). An approach for the realization of self-adaptive and highly available production systems, based on a context aware approach, allowing self-adaptation of flexible manufacturing processes in production systems and effective knowledge sharing to support maintenance, is presented in [12]. In [13], a system for context-aware AR maintenance applications is proposed. The use of AR goggles, coupled with other mobile devices for the communication of people, working on the shop-floor and in the engineering offices is proposed in [14]. Finally, in [15] they propose a collaborative system that provides decision support for team leaders.

In this work, the multi-layered approach has been selected for the implementation of the context-aware infrastructure with the use of ontology for the modeling of context data and the mobile device approach for delivering information to the users. The approach has been demonstrated in support of a maintenance scenario in the automotive industry.

2. Industrial pilot

An important process, through the value chain of the automotive ecosystem, is performed in the foundry. The foundry usually follows a fishbone-like structure, as presented in Fig. 1. In each sub-line, different cores are produced for different models of the automotive company. The foundry, among others, produces engine blocks, cylinder engine heads, brakes' components, gearbox components and others. In each sub-line there are a number of stations that prepare the mold and the cores and at the end of each sub line there is the flasks' line. Each flask consists of two parts: the upper section and the bottom section, which are put together at the end of the line. Only one part type is produced at a time. The machines are linked by automated material handling devices, such as conveyors. The structure of a flow line presupposes that there is a well-defined, rigid process sequence for the different parts, and that the lot size of each part is high enough to guarantee that the capacity of the equipment be fully exploited and not wasted on the setups. In the foundry, Fig. 1, the core making sub-lines prepare the cores (e.g. for the cylinder heads) and then the sub-lines are feeding lines to the molding line. In the molding lines, there are flasks and the cores are mounted onto the flasks. As a last step, the melted iron is poured into the flasks and then moved to the cooling area. The major shortcoming of this type of production system is that one machine failure could stop the line's entire production, making maintenance a challenging process. There are a considerable number of breakdowns per day, with considerable duration of line interruptions. A typical day may have a few hours of line interruption. There are several sources for the breakdown detection: a) the line operator detects a failure indication, while monitoring the SCADA system, b) the field operator detects a malfunction, during the regular inspection of machines and processes and c) an operator reports a problem to the line or field operator. The duration of resolving the problem of a breakdown is critical. Team members typically use radio for voice communication among them.

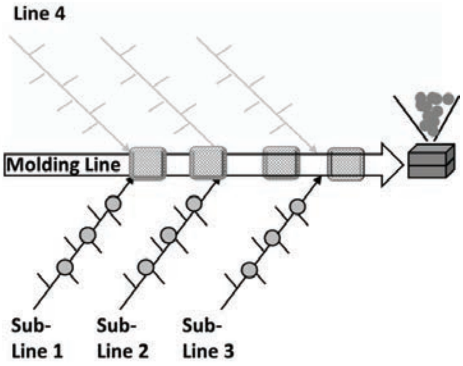


Fig. 1. Foundry fishbone structure

The operations in the line are supported by a number of legacy ICT systems. All line stoppages that are not resolved within a two-minute period are logged in a maintenance repository together with information regarding their causes. A typical SCADA system is also available and it provides real-time information on the line status as well as current information on line stoppages.

A team composed of 6 members resolves the breakdown issues. The way of communication depends on the breakdown case, its nature and the assigned priority. For a working shift, the following table summarizes the roles of the above team, their main function and their usual location.

Table 1: User roles involved in the maintenance process

Role	Function	Usual Location
Line Manager	Overall responsibility	Office
Shift Manager	Responsible for the shift.	Office
Line Operator	Line Operator. Monitor SCADA and detect problems Coordinates team	Control Room, and he is not allowed to leave the monitors unwatched
Field Operator	Field work Visit location where the breakdown occurs Supervise processes and machines	Walking within the Molding area of Line 4
Maintenance	Maintenance	Workshop within Line 4

3. System design

3.1. Analysis of the industrial requirements

The most important use cases, having derived from the analysis of the requirements, are the following:

- Use case 1 (UC1): Line stoppage identification.
- Use case 2 (UC2): Line operator and field operator's collaboration resolving line stoppage.
- Use case 3 (UC3): Line personnel and maintenance personnel resolving line stoppage

In UC1 (see Fig. 2), a line stoppage event (S10) is initially sensed by the "Line events monitoring system (legacy)" that is connected to the backend system of the context-aware infrastructure (more in chapter "3.2 the context-aware system for collaborative maintenance"). The Line operator becomes aware of a line stoppage, through the context-aware *Operator Monitor App (S11).* The application provides the line operator with possible causes on the specific line stoppage event (S12). The knowledge-based support is used by the line operator to contact the proper personnel that will be involved in resolving the maintenance issue (S13).

The data source, for the knowledge based support, is the raw historical data lying under the legacy system that reports the stoppages. This system for each stoppage holds information such as time and duration of the stoppage, the sensor that caused the stoppage and a quick description of the resolution if handled solely by the line operators without requiring the maintenance personnel. The knowledge support system analyses these data by grouping them into data structures that relate sensors with stoppage events and causes/resolutions and finally, persists the output on its internal database. When a line stoppage is identified, the knowledge support service looks up the sensor that caused the current stoppage, retrieves a specific sensor's stoppages data and finally, ranks the results according to by the frequency of the stoppages in order to provide the end user with information as to what would be the most possible cause/resolution to the stoppage.

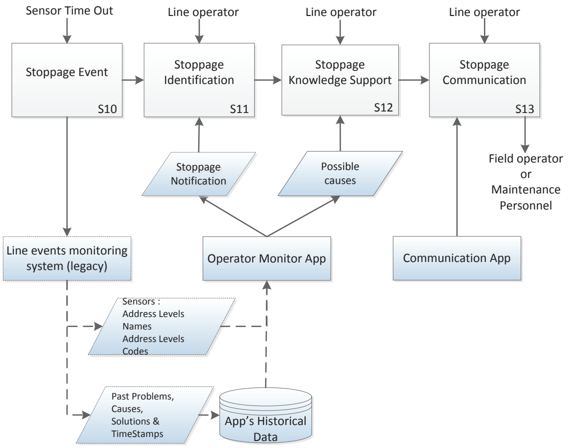


Fig. 2. UC1: Line stoppage identification

In UC2 (see Fig. 3), the field operator works together with the line operator to resolve the line stoppage issue. The field operator carries a mobile device that runs the context-aware apps. The mobile device is equipped with a Near Field Communication (NFC) tag reader. By the time the field operator approaches the NFC tag, located in the machine that has initiated the stoppage event, the Operator Monitor App opens up (S21) and the context-aware system provides him with event data and information on the possible causes retrieved by the legacy system (S22) on this occasion. If the field operator succeeds in resolving the issue, he communicates (S23) the resolution of the problem to the line operator, who documents the maintenance event (S24).

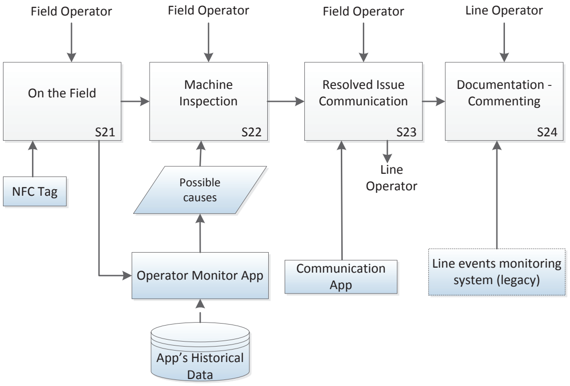


Fig. 3. UC2: Line and field operator resolving line stoppage

In UC3 (see Fig. 4), the line operator has to involve maintenance personnel in order to resolve a machine breakdown. The maintenance person arrives at the workstation and uses his tablet to scan the NFC tag mounted onto the machine. Immediately, the Maintenance Support App opens up (S31) revealing details about the problem's possible causes (S32), such as breakdown history and machine documentation. After having the problem resolved and communicated to the line operator, the maintenance personnel document has the details of the maintenance task using the “Emergency Work Order (EWO) Form” app accessible through the tablet (S34). The line manager using EWO form app through his desktop, reviews the documentation and submits the report to the maintenance repository system.

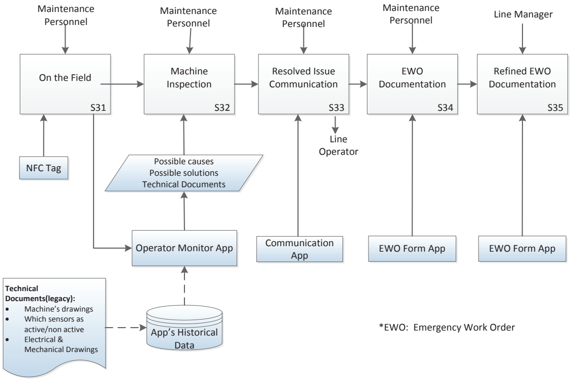


Fig. 4. UC3: Line personnel and Maintenance personnel resolving line stoppage

3.2. The context-aware system for collaborative maintenance

This chapter presents the proposed configuration and deployment of the context-aware system in the pilot environment. The detailed framework discussed in this section (Fig. 5) is based upon a layered architecture, having the following layers: sensors and raw data retrieval, pre-processing, storage/management and application.

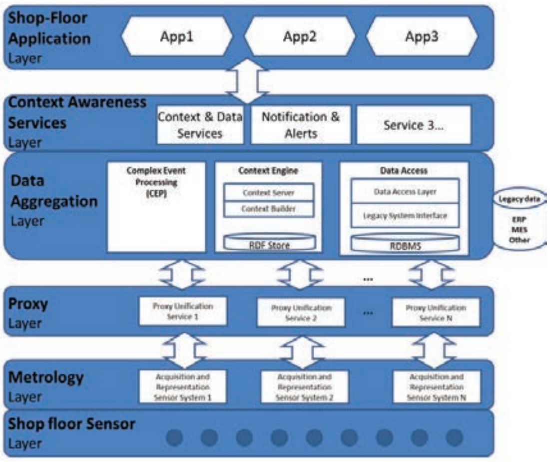


Fig. 5. System layered architecture (described in detail in [6])

- *Metrology and shop-floor sensor layer*: The Metrology layer interprets the sensor’s ‘raw’ data into initial context information.
- *Proxy layer*: The approach that would tangle the data, coming from the network of sensors, follows the ‘divide and conquer’ principle by dividing the data into different proxies with pre-processing capabilities.
- *Data aggregation and context-awareness layer*: the information produced by different shop-floor sources and the proxy layer are aggregated, and a database holding the relevant information (real-time information, roles repository and historical data) is maintained.
- *Context-awareness services layer*: The SOA approach is used for providing context-aware functionality to client apps.
- *Shop-floor applications layer*: Different context-enabled applications are deployed and provided to the final users (line operators, maintenance engineers and others).

The system’s overall architecture has been presented in detail in [6]. In this study, the system has been extended and customized to support different roles and connectivity with different legacy systems. In order, to support the industrial scenario, within the pilot environment described above, the system presented in Fig. 6 has been deployed in the pilot area of the foundry line. Moreover, a number of specific end-user apps have been developed to support the collaborative maintenance scenario.

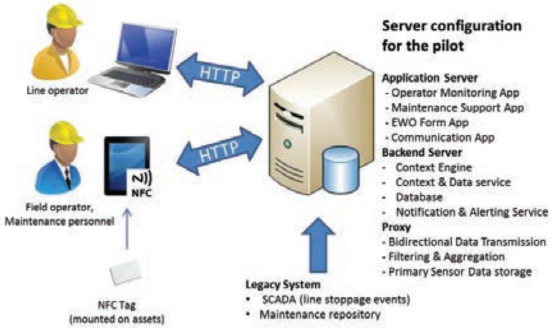
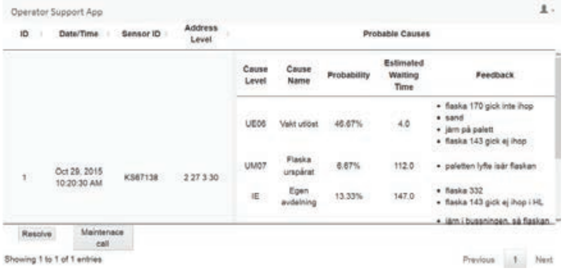


Fig. 6. Pilot system configuration

The apps (see Operator Support App in Fig. 7 as an example) have been implemented into the Spring Web Model-View-Controller (MVC) framework. Moreover, the Graphical User Interfaces (GUIs) have been implemented using HTML5 libraries that enable developing responsive, mobile first projects on the web. This approach provides the capability of reusing the same code for running the apps, either in a typical desktop or in mobile devices.



ID	Date/Time	Sensor ID	Address Level	Probable Causes				
				Cause Level	Cause Name	Probability	Estimated Waiting Time	Feedback
1	Oct 29, 2015 10:20:30 AM	KS67138	2 27 3 30	UE06	Vakt utlöst	46.67%	4.0	• flaska 170 gick inte ihop • sand • järn på palett • flaska 143 gick ej ihop
				UM07	Flaska urspårat	6.67%	112.0	• paletten lyfte isär flaskan
				IE	Egen avdelning	13.33%	147.0	• flaska 332 • flaska 143 gick ej ihop i HL • järn i bussningen, så flaskan

Fig. 7. Screenshot of the Operator Support App

4. Evaluation

In order to verify the applicability of the proposed system, the system has been installed in the foundry and has been demonstrated to and tested by the shop floor personnel. More specifically, the study's objective was to confirm the following hypotheses:

- **H1**: End users will appreciate the functionality offered and can imagine using them in their daily work.
- **H2**: The solution has the potential of bringing the expected benefits to the specific industry.

Moreover, another objective of the study was to gather feedback, regarding possible enhancements of the system that would improve the quality of their work.

The study was conducted during the working hours at the workplace of the end-users. The study verification was carried out in two sessions, involving specific user group. The first session took place in the control room, where the line operator and the managerial personnel were present (UC1). The second session was carried out at the shop floor and was focused on maintenance activities (UC2 and UC3). The mobile application was shown on a 7-inch tablet. Every session lasted approximately 60 minutes. The study was finalized with a group discussion that involved all participants.

Feedback from the participants has been collected through questionnaires. The latter had five sections: a) background and user profile info (age, experience etc.), b) system usability assessment, c) free comments on the solution, d) apps specific questions and e) questions on the expected impact. The questionnaires were filled in by different personnel with various roles (Line Operator, Maintenance personnel and Line Manager) as well from high level management (not being users of the proposed system though) with varying years of experience at the foundry. The study was conducted with five team members. The average age of the participants was 43.8 years (Std. Dev =8) and with various years of experience (Avg=11.7, Std. Dev=8.5).

1) *Assess the usability of the functionality offered.* The prototype received favourable scores most of the time. All of the participants would like to continue using the system and most of them felt that the system was easy to use. However, there were comments that it might require some training before they were comfortable using it. In Table 2, the details of the usability assessment are being presented.

Table 2: Usability evaluation results

Usability aspect	Avg*	Std. Dev
I would like to use this system frequently	4.3	0.5
The system is unnecessarily complex	4.0	0.8
The system was easy to use	3.3	1.0
I would need the support of a technical person to be able to use this system	3.3	1.2
The various functions in this system were well integrated	3.8	0.5
There was too much inconsistency in this system	3.5	0.6
Most people would learn to use this system very quickly	4.0	0.0
The system very cumbersome to use	3.8	1.0
I felt very confident using the system	3.0	0.0
A lot of things to learn before get going with this system	3.8	1.3
Overall solution score	3.5	1.0

* 1 is low (bad) score; 5 is high (good) score

2) *Assess the potential of the system to bring expected benefits.* The solution has been implemented targeting at improving the performance of the maintenance activities in the flow-line. The experts were asked to rate the solution regarding the expected benefits. A score of 10 indicates high/good potential and a score of 1 indicates low potential. The assessment from the team of experts has concluded that the solution has good potential, there is a strong belief, that it may reduce costs (Avg. = 8.5, Std. Dev = 0.6) mainly by reducing the time spent on the maintenance activities (Avg. = 7.8, Std. Dev = 1.3). However, the team was not convinced that the solution could substantially contribute to the reduction of production stoppages (Avg. = 5.5, Std. Dev =3.5).

A number of potential improvements that should be considered, if the solution is to be operable in the pilot environment, were reported during the pilot case workshop.

- Personalized settings on the tablet so that the user may configure the apps for his use.
- Improved integration with the existing legacy systems. More information available on legacy could be distributed via the apps.
- In order for the mobile solution to be efficiently utilized, more apps should be installed. For example, production status data could be accessed through the apps.
- A significant advantage would be the inclusion of automatic ordering of the parts for the Maintenance Support App. This would allow the maintenance personnel to remain on-site and start preparations on the activities, while at the same time the required parts are being delivered. Such functionality will contribute towards further reducing the time spent on maintenance.
- The font size used was too small especially when the apps were accessed via the tablet.

5. Discussion and conclusion

Based on the results, it can be concluded that the usability offered by the proposed system is adequate enough for the application scenario of the pilot case and that hypothesis H1 has been verified. However, there are additional comments that should be considered, especially regarding the integration with the existing legacy system, before the solution can really support the daily activities in the line. The conducted case study has also shown that the proposed solution can bring considerable benefits, especially due to its potential to reduce time spent on maintenance. The solution using the knowledge base and context data provides specific information to the right user, dealing with the maintenance problem on hand.

It should be mentioned that the users had only an exploratory investigation of the solution to make. In order to have a clearer view, a further study in which one could observe the way that the solution can be used in one's daily work is required.

In future work the system's integration capabilities will be improved with legacy systems and the utilization of additional information. In this context, a set of new features that was suggested by experts will be included.

Acknowledgements

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