Defining a Collaborative Platform to Report Machine State

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Abstract. Nowadays, we are seeing the evolution of Industry, and with it, the development of technological solutions that can assure sustainability and competitiveness in the manufacturing environment. Along this evolution, Cyber Physical Systems were developed with the goal to merge both physical and computational processes and to allow predictive, proactive and collaborative maintenance of industrial machines. The work here presented has been integrated in the Cyber Physical System based Proactive Collaborative Maintenance (MANTIS) project and has the main goal of proposing a collaborative platform to report current machine state. This way, it will be possible to facilitate and support the interaction between all stakeholders that will participate in the collaborative decision-making process. With this approach we believe to be possible to reduce machine down-time and the unnecessary waste of machine components and workhand while attempting to solve different machine problems.

Keywords: Industry, Collaborative Decision-Making, Human Machine Interfaces, Multi-Agent Systems, Cyber Physical Systems

1 Introduction

The current globalization and the growth of worldwide demand for global resources has led to several social, environmental and economic problems such as global resources depletion, climate change, environmental pollution, and economic stagnation [1]. To overcome this trend, Industry must evolve towards sustainability. In fact, manufacturing companies are now implementing their own metrics and strategies that will allow to assure sustainability while preserving competitiveness. Examples of such metrics could be the elimination of unnecessary waste of resources, a more efficient control of energy consumption, development of products designed for disassembly, reuse and recycle, preservation of natural habitats and reduction or even elimination of the consumption of non-renewable resources [1]. At the same time, manufacturing companies are also concerned with improving their manufacturing performance which can be achieved by improving equipment up-time and optimizing product quality [2]. Several maintenance strategies have been deployed by manufacturers for this sole purpose which include a combination of reactive maintenance, preventive maintenance, predictive maintenance, proactive maintenance [2] and also collaborative maintenance [3].

We are now seeing the dawn of a new era of industrialization, the so-called Industry 4.0, and with it, the improvement of the manufacturing industry. New technologies are being developed towards Industry 4.0 such as the establishment of smart factories, smart products and smart services embedded in an internet of things and of services and this will pose many new opportunities in the area of sustainable manufacturing [4]. With the emergence of Industry 4.0 real-time diagnostic, prognostic and collaborative technologies have become widely discussed [3, 5, 6] and new technological solutions that can make the best use of existing physical manufacturing assets are starting to be developed. Among those technologies, Cyber Physical Systems (CPS) which represent the fourth Industrial Revolution have established a bridge between physical and virtual worlds. The advances developed in the field of CPS have affected Industrial Systems greatly in many different applications such as predictive, proactive and collaborative maintenance of industrial machines [7], industrial process control, automation systems, among others [8]. Some of the main characteristics of CPS have been identified in [9] and are: CPS can enhance physical entities with cyberspace capabilities; CPS can be networked at multiple and extreme scale; CPS can provide dynamic behaviour (plug and unplug during operation); CPS can offer high degrees of automation, leading typically to closed control loops; CPS can offer tight integration between devices, processes, machines, humans and other software applications; and CPS can provide a high degree of autonomy and collaboration to achieve a higher goal.

Collaboration has been regarded to improve both the technical quality of new manufacturing solutions and the extent to which relevant social and ethical considerations are integrated into their development [10]. Besides that, one of the main strategies identified in this context is to assure quality design and trustworthy services and platforms for intelligent, adaptive and autonomous CPS [11]. It seems that efforts should be made to include collaborative components in the development of CPS. The greatest challenge is to pay attention to the human element which has been an impeding factor for organizations to take advantage of the entire benefits of adding collaboration to manufacturing solutions [12]. Among all available collaborative technologies, collaborative decision-making systems could be used to help individuals reach the maximum efficiency in the proposed tasks [13]. The key word of these systems is "consensus", where it's required that the knowledge is shared by all involved parts, being then analysed by each one, leading to a collective decision of which path to follow. "Collaborative" indicates that this kind of system requires the involvement of multiple participants, that can be human users or even other software modules related to the task, to solve the proposed problem. Therefore, the usage of a multi-agent approach during the implementation of a collaborative decision-making system is the appropriate step to take. A multi-agent system is composed by several intelligent agents, each with a specific task, that interact with each other to solve the proposed problem [14]. Multi-agent systems have been used in manufacturing [15, 16] for all sort of task such as cooperation between smart shop-floor objects [17], preventing deadlocks [17], manage production flow of different supply chains [18, 19], among others.

The work here proposed is to develop a collaborative platform to be included in the Cyber Physical System based Proactive Collaborative Maintenance (MANTIS) project [20]. MANTIS is an international initiative that includes the collaboration of several partners and that aims at building a platform for proactive and collaborative maintenance of industrial machines. This platform will be included in the architecture developed thus far [7] and will be used to report current machine state which often requires collaborative decision-making between different stakeholders and depending on its complexity increased machine down-time and extra workhand may be necessary. Therefore, the goal of this work is to propose a collaborative platform that will facilitate the interaction between stakeholders and that includes an intelligent component (Multi-Agent System) that will be used to support those stakeholders throughout the entire decision-making process. The proposed platform will also generate an automatic report detailing the decision-making process which can be used in future similar situations to decrease unnecessary machine down-time and workhand.

The rest of the paper is organized as follows: In the next section, the reference architecture is exposed. In the following sections the proposed platform is described, as well as the Multi-Agent System. Finally, some conclusions are taken in the last section, along with the work to be done hereafter.

2 MANTIS Architecture

The objective of the MANTIS project is to reduce maintenance costs by means of novel monitoring techniques. This requires detecting faults as early as possible to avoid catastrophic failure, predicting failures to facilitate the scheduling of the parts replacement and providing tools that ease the diagnosis and resolution of different problems. This approach reduces machine down-time, eliminates excess spare-parts stock, improves product quality, increases operator safety and lowers the overall cost of maintenance [21].

The reference architecture has been presented in [7] and is composed of a number of modules that can be grouped into 5 logical blocks: Machine, Edge Local, Data Analysis and Human Machine Interface (HMI) connected together by a Communication Middleware, which can be split in Local Middleware and Cloud Middleware. This section includes information on the logical blocks (see Figure 1) and describes how they interact to provide an infrastructure that can be deployed and integrated into existing systems.

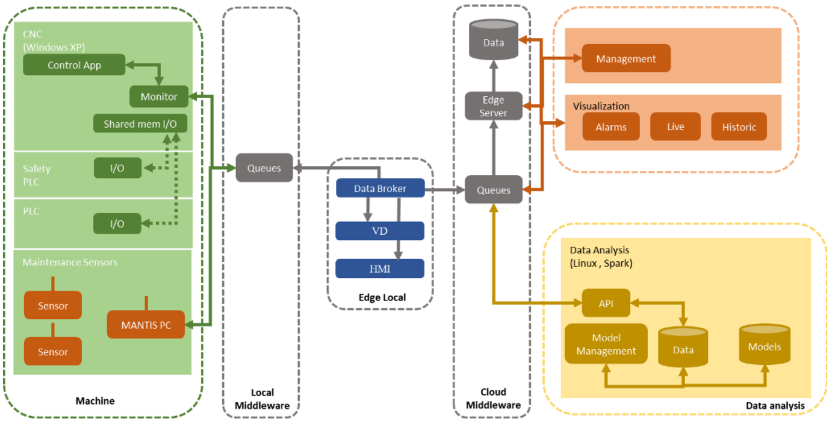

Figure 1 Reference Architecture (adapted from [7])

Data on the machine are collected by means of sensors that are part the machine's control systems or from sensors which were added specifically for maintenance purposes. This logical block can consist of several modules, each representing a machine's subsystems. The Edge Local logical block provides mechanisms to support communication and management of the data acquired across multiple heterogeneous and distributed data sources. The Cloud Middleware manages the data, by storing and transporting it between the Edge Local and, both, the Data Analysis and HMI modules. The Local Middleware is used inside a factory connecting its machines with management systems. The Data Analysis uses and manages models for the detection, prognosis and diagnosis of machine failures. It also outputs predictions from the models and provides data to feed and train the models.

The HMI provides a Human Interface for the proactive maintenance system. It has two main components, one for data visualization and another for data management. In the visualization component it is possible to view historical and live data, which is collected from specific machine sensors (e.g. machine status, speed, positioning and pedals state). It is also possible to show the results generated by the data analysis module, more specifically the alarms for unusual sensor data and the warnings regarding impending failures. It is possible to match the warnings from the Data Analysis block with historical data collected from the sensors. The Management component includes all the administrative operations, like users and roles management, as well as factories and machines setup. Role management is a very important process that allow one to dynamically assign specific permissions to each type of user (e.g. a user with the "operator" role can view historical and live data only). Factories and machines management, allows an authorized user to setup a new factory and its machines. The HMI follows a web-oriented design and therefore can be accessed from anywhere, at any time and through all sort of electronic devices with the only requirement being the use of the Internet to do so. This allows both remote (administrative) and on-site operations such as analyzing the machine's state or view its past performance.

3 Proposed Platform

The architecture proposed in this work is going to be integrated in the HMI platform and is presented in Figure 2.

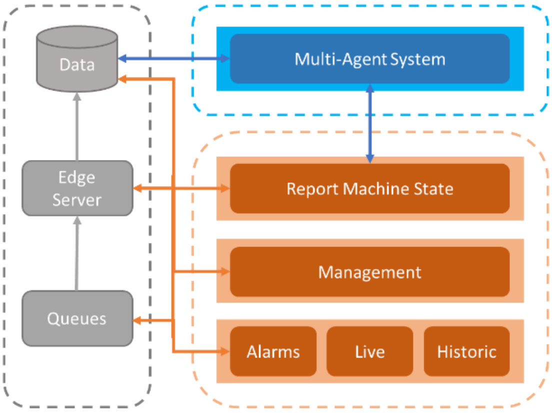

Figure 2 Proposed Platform Architecture

- A web application which allows the factory to report current machine state. This state includes machine failures, interventions and retrofitting. The web application will be accessed by several stakeholders. The main stakeholders for this platform will be the Technical Engineers, On-field Technicians, Technicians from the supplier (on-field and offices), Client and sometimes Agents (in this case, Agents act as an intermediary between the Backoffice Service and the Client). The web application is accessible by desktop and mobile browsers thus being available to almost any kind of electronic device. This web application will also be the interface between the multi-agent system and each stakeholder as agents will represent different stakeholders and perform specific tasks on their behalf;
- A database where the information exchanged between stakeholders will be stored. This information will allow to build automatic reports that can be used on similar future situations to guide the factory. Example of such information could be media files (videos, images, etc.) uploaded by stakeholders which are then stored in the database;
- A multi-agent system where agents support different stakeholders and act on their behalf. Three different types of agents have been considered. There is a problem organizer agent which is responsible for organizing the problem according to the information provided by the Client/Agent. There are several interaction agents that represent each stakeholder during the interaction phase and will perform certain tasks on their behalf. There is a report organizer agent which has the task of build the report based on the information exchanged throughout the interaction phase.

Machines are produced using mechanical components manufactured internally and other components (like electrical, security systems, etc.) from suppliers. During machine failures, interventions and retrofitting, the factory collaborates with different technicians internally and from the suppliers. There is a requirement of a common platform for information exchange during these processes. The source for using this platform can be the failures detected by the MANTIS platform or created manually by the Backoffice Service.

Looking at these requirements the platform here proposed has been structured to report current machine state and is divided into three action phases: Problem Identification, Interaction and Report Generation.

3.1 Problem Identification

In this process, all the configurations needed to start the interaction between different stakeholders must be provided by the Client or the Agent. This information, as can be seen in Figure 3, is related to the machine and includes basic machine information such as problem description, machine identification and type, problem type (whether it is a machine failure, intervention or retrofitting), detected alarms (or not), warranty details (if the machine is still under warranty or not) and the current working state of the machine (if it has stopped completely or working with failures).

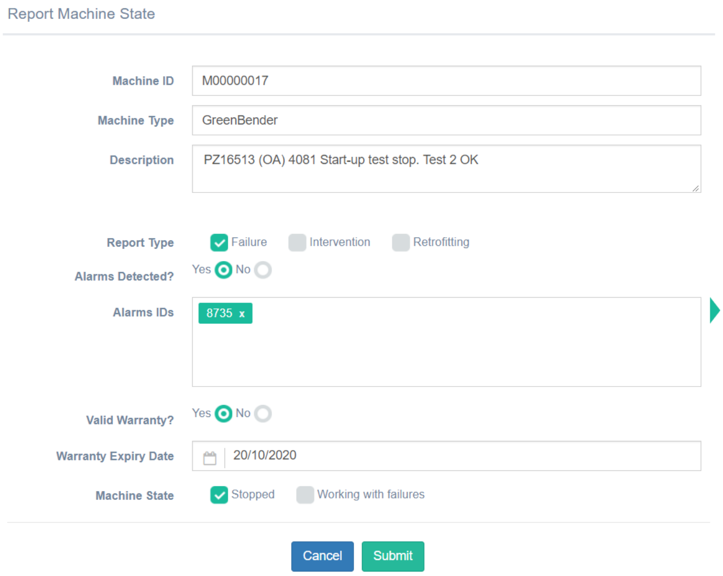

Figure 3 Problem Identification

This information is sent back to the factory and the platform will automatically look for similar past occurrences based on the given description and provide a generated report with the resolution steps required to solve the problem (example of such report can be seen in Figure 5). The factory must identify the stakeholders which will participate to begin the interaction phase. Those stakeholders will be notified (for example, by email) to join the interaction phase.

3.2 Interaction

In this phase all selected stakeholders and the factory may interact with each other to attempt to solve the problem. The system supports the following actions: Start Interaction, Message Exchange, File Upload, Register Intervention and End Interaction.

- **Start Interaction** – For this action, all selected stakeholders should join the interaction session GUI (Graphical User Interface) and after that be able to exchange information.
- **Message Exchange** – This action resembles a chat window where stakeholders and the factory can exchange text messaging regarding the problem. Besides that, the Client/Agent may approve/disapprove every exchanged message in case it helped solving the problem.
- **File Upload** – For this action every stakeholder and the factory may upload different files to assist in the resolution of the problem. These files can be in either an image or video format or even in a document format (for example a technical guide).
- **Register Intervention** – To register an intervention, the factory should log all components that are supplied/used in the intervention (ex: Technician will have an idea on what kind of component to be carried/dispatched before leaving to the remote location). After the intervention, the factory should log intervention times of all the stakeholders involved in the process (ex: will be helpful for billing the Client).
- **End Interaction** – The Client/Agent may end the interaction phase whenever the problem has been solved.

Figure 4 Interaction Session

Figure 4 shows an example of an interaction session between different stakeholders while dealing with a current machine state.

3.3 Report Generation

The last phase refers to the generation of an automatic report with detailed information of the interaction phase. Whenever an interaction ends the factory should verify all the information regarding the interaction phase which includes messages approved/disapproved by the Client/Agent and the details of each intervention (more than one intervention may be required to resolve more complex issues). The factory should then specify which interactions helped solving the problem (besides the interactions approved by the Client), which technical guides were used to solve the problem, etc. An automatic report is generated with all interaction and intervention actions that were performed (see Figure 5). This includes:

- Detail which components should be used to solve the problem and when they should be used;
- Show videos/ images depicting the problem;
- Show interaction messages which were approved by the factory and that helped solving the problem;
- Show suitable technical guides uploaded and that helped solving the problem.

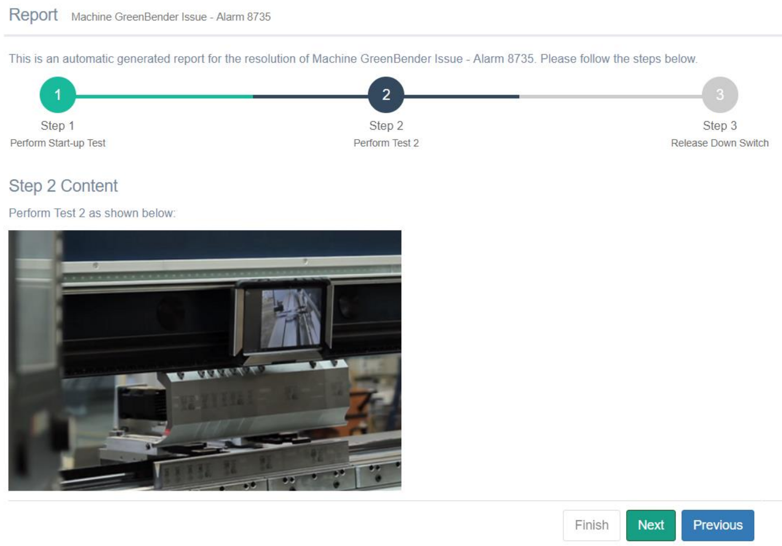

Figure 5 Automatic Generated Report

The automatic report can be used in the future, whenever a similar problem is observed by the factory and will be provided before a new interaction process begins. This helps reducing problem resolution costs drastically and avoid increased machine downtime and unnecessary waste of machine components and workhand while attempting to solve the problem.

4 Multi-Agent System

As mentioned above, multi-agent systems have been widely used in the industry to automatize different tasks that can improve production efficiency and performance and allow a better management of the available resources (both factory assets such as machines and workhand). In this work we developed a multi-agent system where agents support different stakeholders and may act on their behalf to deal with different machine problems. We have considered three different types of agents with different responsibilities: problem organizer agent, interaction agent and report organizer agent.

In Figure 6 we present the Multi-Agent System Architecture considered for this work.

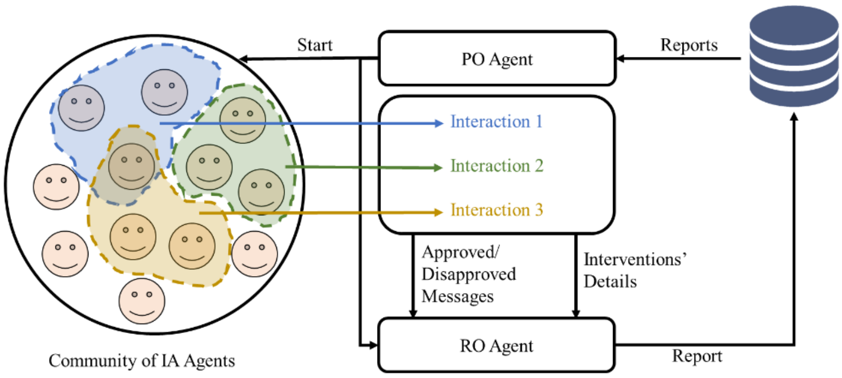

Figure 6 Proposed Multi-Agent System Architecture

4.1 Problem Organizer Agent

There is a problem organizer agent (PO Agent) which is responsible for organizing the problem according to the information provided by the Client/Agent. The problem organizer acts during the problem identification phase is responsible for the following tasks:

- Select auto-generated reports from the database based on past similar occurrences according to the problem identification that can be used to assist in the resolution of the problem;
- Identify the most appropriate stakeholders to answer the verified issue;
- Fasten the resolution process in case the machine is still under warranty, by promptly notifying the factory according to remaining warranty period of the machine;
- Start both interaction and report organizer agents that will at in the following phases.

4.2 InterAction Agent

There are several interaction agents (IA Agent) that represent each stakeholder and will perform certain tasks on their behalf. The interaction agent acts during the interaction phase and is responsible for the following tasks:

- Track Messages approved/disapproved by the Client/Agent to resolve the problem;
- Send Messages approved/disapproved to the report organizer agent;
- In case of intervention, register intervention time/ location and parts used for billing the client;
- Send intervention details to the report organizer agent.

4.3 Report Organizer Agent

There is a report organizer agent (RO Agent) which has the task of build the report based on the information exchanged throughout the interaction phase. The report organizer agent acts during the Report Generation phase and is responsible for the following tasks:

- Present messages approved/disapproved by the Client/Agent;
- Track new approvals/disapprovals from the factory;
- Merge and present all interventions' details;
- Generate/present the report to the factory with all the steps required to solve the issue and save the report in the Database.

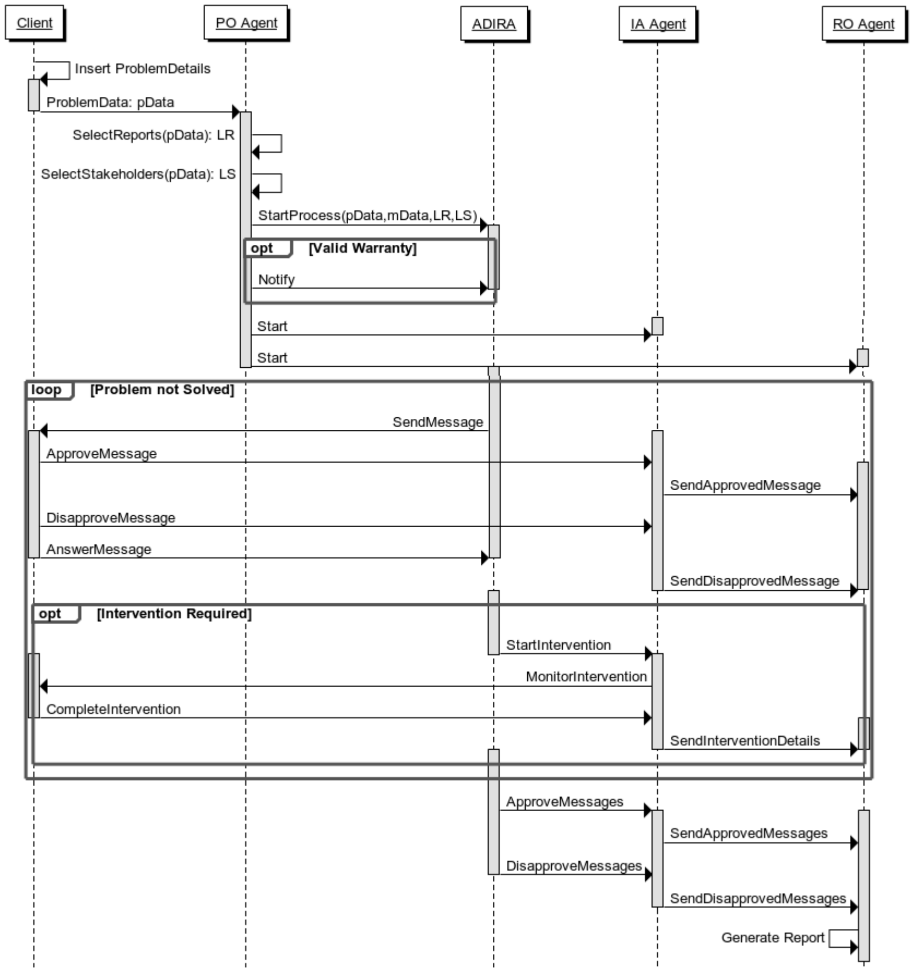

Figure 7 Communication Flow

Figure 7 shows the entire communication flow with all possible actions performed by each agent and its interactions with other agents and stakeholders.

5 Conclusions and Future Work

In a world increasingly more global, the demand and management of available resources has become a real issue in our society, especially in the industry context. We are currently seeing the fourth industrial revolution, also known as Industry 4.0, and the development of manufacturing solutions that can answer this issue while assuring both sustainability and competitiveness. CPS are the representation of Industry 4.0 and have completely changed the way maintenance is carried out. The work here presented has been integrated in MANTIS project and has the mail goal of proposing a collaborative platform to report current machine state and that will facilitate and support the interaction between stakeholders. It is important to refer that the goal of this work is not to present a system which is better compared to other systems, but instead propose a solution to deal with a growing necessity of developing a solution that can support collaborative decision-making (in this case, to support decision-makers while dealing with machine problems). Therefore, we believe that this approach can be easily integrated/ adapted to other existing manufacturing systems. Besides that, with this approach, we believe to be possible to reduce machine down-time and the unnecessary waste of machine components and workhand while attempting to solve different machine problems. As future work we intend to validate the efficiency and performance of the proposed platform in a real scenario with the collaboration of ADIRA Metal-Forming Solutions, SA.

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