AN INTELLIGENT MULTI-AGENT BASED PROBLEM MANAGEMENT SYSTEM FOR INDUSTRIAL AUTOMATION SYSTEMS

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ABSTRACT

In industrial automation systems, when a problem occurs at run-time and no technician is available instantly, it can result in the stopping of the whole industrial automation system. Often, the occurred problem addresses only few system functions. Theoretically, other functions can be performed. However, in most of the cases, none of the system functions can be used. In order to prevent the stop of the whole system and guarantee the performance of still available functions, this paper proposes an intelligent multi-agent based problem management system. This system receives the diagnosis results from the industrial automation system by means of a local communication agent. Problems are discussed in two cases, i.e. known problems and unknown problems. For known problems, the intelligent multi-agent based problem management system directly accesses the database to get the available functions and sends this information to industrial automation systems. For unknown problems, it analyzes the effect of problems as well as the scope of them in order to identify available functions with the help of different agents. Thus, these information about available functions are stored into the database and are sent to industrial automation systems. Consequently, the industrial automation system can continue to work with the available functions. Hence, the intelligent multi-agent based problem management system can enhance the availability of industrial automation systems through ensuring available functions and preventing long system break-down.

KEYWORDS

Multi-agent systems; problem management system; enhanced availability; industrial automation systems.

1. INTRODUCTION

During the past decade, with the increasing application of industrial automation systems in different domains, the number of functions that are integrated in the system constantly increases (Liu, Z. et al, 2014). For the sake of keeping the continuity of the service of a system, when a problem occurs, the technical support of the supplier is necessary. However, the technical support is non-trivial.

Firstly, various problems can occur at run-time: either known or unknown (Godhwani, Y. et al, 2014). In most cases, the developer cannot find out all problems during the developing phase. On the one hand, it is almost impossible to fully perform tests (systems have inherent faults in the development time); on the other hand, if there are no solutions to solve the problem, that will result in the breakdown of the whole system (Wang, H. et al, 2014). Secondly, the distance between the technician and the user is usually big. That leads to a long delay (Cao, X. et al, 2014; Bordasch, M.et al, 2013). Thirdly, the complexity of products hinder an effective support (Blome, C. et al, 2014). The complexity of industrial automation systems includes two factors. One aspect is a great number of product categories (Peng, D. et al, 2014.). The producer often manufactures different goods, e.g. different generations of smartphones, different coffee machines, etc. Another aspect is an increasing number of the same type of products, i.e. the producer always manufactures many products which will be sold all over the world (Turban, E. et al, 2015).

In this case, this paper provides a concept of an intelligent multi-agent based Problem management system (IMAPMS). This system enables the industrial automation system to react to not only known but also unknown problems. By impletion, it is possible to perform continuous production of the industrial automation system.

This system is made up of three main parts: a multi-agents system, an interface between IMAPMS and the industrial automation system and a database to store the information about system models and faults. During the appearance of a problem, the IMAPMS collects the information from the industrial automation system, sends the required information to the remote multi-agent system and then estimates if the problem is known or unknown. With the help of agents, the available functions and available goals can be confirmed. Afterwards, IMAPMS gathers necessary commands, sends them to the industrial automation system and influences it, i.e. it activates available functions, deactivates not-available ones and rearranges the priority of run-time goals, e.g. producing the product with a lower priority. So that the IMAPMS can prevent the stop of the whole system, even though the technician doesn't arrive at the location of the fault occurrence. Thereby, the availability of the industrial automation system can be enhanced by the assistance of IMAPMS.

This paper is structured as follows. Section 2 introduces basic aspects of the industrial automation system and problem management system. Section 3 describes an overview of an intelligent multi-agent based problem management system. Section 4 presents different agents and the structure of IMAPMS. Section 5 shows the workflow of the concept. Section 6 gives a specific example of an industrial coffee machine. In section 7, the basic questions mentioned above are discussed, conclusions are drawn, and future works are summarized.

2. INDUSTRIAL AUTOMATION SYSTEMS AND PROBLEM MANAGEMENT

2.1 Problem management for an industrial automation system

A problem is defined as the inability of a system or a machine to perform its expected functions. Problem management is an ongoing method concerned with managing problems as well as their impact on the availability of an industrial automation system. Firstly, the object of problem management in an industrial automation system is to manage all problems throughout system's lifecycle. Three important measures of problem management can achieve this objective, i.e. preventing problems with the resulting incidents from happening, eliminating recurring incidents and minimizing the impact of incidents that cannot be prevented (Barafort, B. et al, 2005). The former two measures are aimed at reacting to known problems. Conversely, the third measure is responsible for reacting to a new problem, i.e. there is no corresponding solution to solve the problem, e.g. performing available functions.

According to another classification, there are two different management methods: proactive method and reactive method (Griffiths, R. et al, 2012). The former aims at identifying and solving known problems. In this way, the user can inform the technician to repair the automation system with the help of the diagnosis results without system break-down. As a result, proactive method is able to assure the whole system viably. However, the latter is intended to deal with the occurred problem corresponding to an application failure. Traditionally, these problems take place at the first time (Malek, M. et al, 2011). After the problem occurs, the technician will analyze the course and repair it. And this will result in a long waiting time, in words, mean time between failures.

A considerable amount of researches has been done to enhance the availability of the whole system. They deal with the problems of an industrial automation systems during the last decade. Different methods can improve the availability from different point of view. Preventing the occurrences of problems and preventing the effects of problems are suitable for known problems. Redundancy can be used for reacting to unknown problems, but it is very cost-intensive and it is not suitable for all systems. Likewise, failsafe approaches usually uses this methology. Multi-agent is a useful technology to react to a problem and get a possible achievement via the cooperation of different agents. Up to now, none of the developed methods is perfect suitable for problem management and none of them is commercially available. Hence, a Hybrid method is needed for the problem management system to deal with known and unknown problems. Unknown means, there are no solutions for it and it happens for first time (Wang, H. et al, 2014).

2.2 Analysis of industrial automation systems from three perspectives

An industrial automation system is viewed from different perspectives, component view, function view and goal view. Fig. 1 shows the three perspectives of an industrial automation system.

The component view describes the hierarchy of the physical relationship of an industrial automation system. An industrial automation system (IAS) consists of different kinds of components, e.g. micro-controllers, sensors and actuators (Bordasch, M.et al, 2013; Wang, H. et al, 2014). Using this view, the IAS can be represented hierarchical consisting of sub-systems and components.

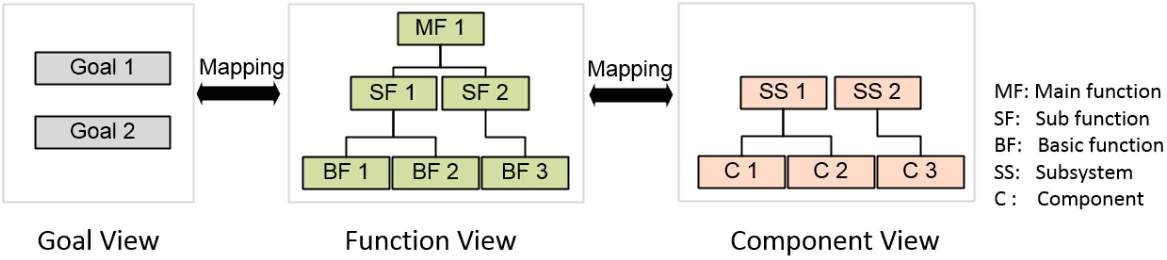

Figure. 1. Analyzing an industrial automation system from three perspectives

The function view gives a description of the hierarchy in the logical level of the industrial automation system. First of all, we use a basic function to represent the activity and ability of each component as well as each technical process. Secondly, subsystems are represented by sub functions. Furthermore, a subsystem is able to realize one or more sub functions, e.g. a water-tank-system contains three level sensors to survey the height of the liquid. Thus not every service demands these three sensors, but in physical level they belong to the same water-tank-system. There are two major advantages of distinguishing different sub functions in the function level: dynamical depicting of the activities of the components and clear analyzing the malfunctions. Finally, main-functions represent all functions which will be directly used by the user, e.g. producing different products by a coffee machine. In addition, the main functions are different combination of different sub-functions. For example, an industrial coffee machine can produce different products, such as, espresso, cappuccino, hot water, etc.

The goal view represents all functional requirements of an industrial automation system. The goals are similar as the main functions. Goal view has two main characteristics: the status of every goal and its priority, i.e. if the goal is selected by users, and the sequence of selected goals. For instance, user orders different coffees, when there is something wrong with the milk frother, cappuccino cannot be produced. In such a case, if the user has already ordered the cappuccino, this order will be set to lowest priority. And the others are set to higher priorities.

3. CONCEPT OF THE INTELLIGENT MULTI-AGENT BASED PROBLEM MANAGEMENT SYSTEM FOR INDUSTRIAL AUTOMATION SYSTEMS

There are four challenges to establish a problem management system: a) perceiving and responding to the defected component or process to and to maintain not affected functions; b) adjusting tasks of different components, preventing the stop of the whole system; c) performing unaffected functions without the intervention of user to avoid a long waiting time automatically; d) handling the problems remotely to overcome the physical distance between users and producers.

Besides, a software agent is designed to achieve a particular goal (e.g. reaching a given place for a robot) and can adapt its plans to handle unpredictable conditions (e.g. avoiding moving obstacles) (Vallee, M. et al, 2010.). The software agent has the following properties:

- They are able to perceive their environment and respond in a timely fashion to changes that occur in it in order to satisfy their design objectives.
- They are capable of achieving task selection, prioritization, goal-directed behavior and decision making without human intervention.

- They are able to exhibit goal directed behavior by taking the initiative in order to satisfy their design objectives.

With such properties the agent can analyze the problem and adjust their tasks fluently and automatically. Furthermore, the multi agent system has the properties of decentralized and self-organized systems. By means of the former, the multi agent system can overcome the limitation of the physical distance. Because they are working on the common platform - multi agent system. The self-organizing characteristic of agent allows the coordination among agents to get a new solution for a new problem.

Hence, this paper propose the multi agent system as a basic technology to establish a problem management system to realize the maintenance tasks as follows: the proposing concept aims at proactive and reactive dealing with problems so as to prevent the stop as well as minimize the downtime of the whole industrial automation system. For one thing, if a problem is known (Bordasch, M.et al, 2013), before losing the functions of the whole industrial automation system, the problem management system selects the available functions and perform them; for another, if a problem is unknown, the industrial automation system *detects the cause of the problem via an existing fault diagnosis-system* (Godhwani, Y. et al, 2014; Friedrich, A. et al, 2013). Then the available functions are analyzed by the problem management system. After a short downtime, the available functions can be activated and executed to prevent a long downtime of the whole system, so that the availability of the whole industrial automation system is enhanced. The intelligent multi-agent based problem management system allows: the supplier to remotely maintain his products which have been sold on one side and helps the user to deal with occurred problems in industrial automation systems by performing available functions on the other side.

As shown in the Fig. 2, an intelligent multi-agent based problem management system consists of three major parts:

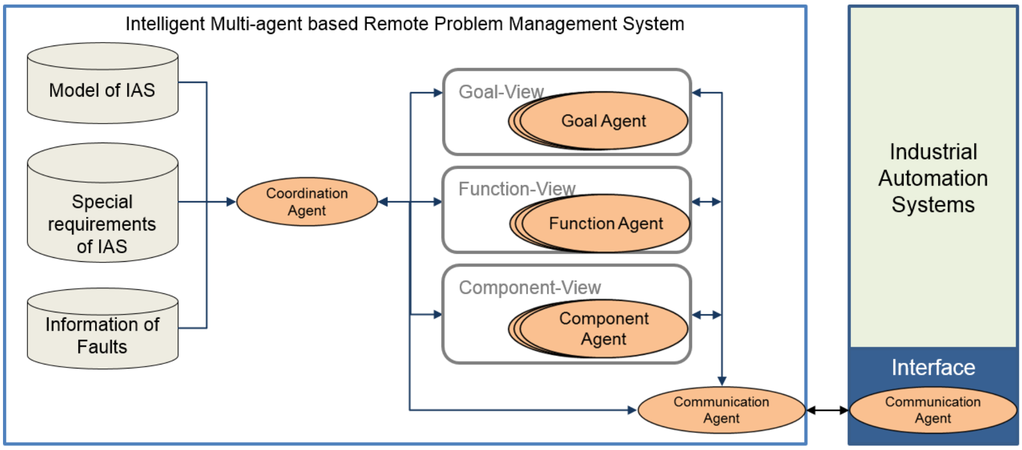

Figure. 2. An overview of the Intelligent Multi-agent based Problem management system

Multi-agent System is made up of different intelligent agents. For one thing, they are responsible for their own missions, for another, they communicate with each other to confirm a solution for an occurred problem. In this system, agents analyze a reported problem from an industrial automation system to identify the location of the problem, e.g. the defect components or functions, and the affected scope of the whole automation system. The detail of different agents will be shown in the next section.

Database organizes the necessary information about faults (e.g. fault ID, location and type), the available functions, the physical model related to components and logical model related to functions of the industrial automation system, and specific requirements to evaluate the operability of the functions.

Interface has two main tasks: on one hand, the interface collects the diagnosis results and sends them to the remote problem management system, and on the other hand, it will receive the solution from the remote problem management system and send it to the industrial automation system to activate and deactivate the functions in the industrial automation system. Besides, when a new automated system is added to get the service of the maintenance, the communication agent just need to register in the common multi agent system.

4. INTRODUCTION TO MULTI-AGENT SYSTEM IN IMAPMS

In this section the different agents will be introduced. The intelligent multi-agent based problem management system (IMAPMS) contains 5 types of agents: component agents, function agents, goal agents, communication agents and coordination agent. Fig. 3 shows all agents in IMAPMS.

Component agents: all components based on the physical model of an industrial automation system are represented by this type of agent, such as sensor agents, actuator agents, MC Agents (Wang, H. et al, 2014). They take charge of monitoring components in an industrial automation system, identifying defect components with the help of diagnosing results, communicate with the coordination Agent to confirm other affected component agents, and report to corresponding basic function agents. Sensor agents are responsible for monitoring the status of the according sensors. Actuator agents represent actuators in the industrial automation system. MC agents represent all microcontrollers in the industrial automation system.

Function agents: all functions based on the logic model of an industrial automation system are represented by this type of agent, such as basic-function agents, sub-function agents, and main-function agents. *Basic function agents* (BFA) are located in the lower layer of the logic level. The relationship between basic-function agents and component agents is a one-to-one mapping. Furthermore, status of basic function agent are consistent with the status of component agents, i.e. when the status of a component agent is “defective”, then the status of the mapped Function agent will be also set on a mode of “defective”. *Sub function agents* (SFA) are located in the middle layer of the logic level. They are the mapping of subsystems. Accordingly, they describe the status of subsystems. They will receive the status from basic function agents. If the status of one of according basic function agents is “defective”, then the status of the sub function agents is set in “defective”. Subsequently, sub function agents send the status to main function agents. *Main function agents* (MFA) are located in the top layer of the logic level. They represent main functions of the whole system. They communicate with the coordination agent and adjust their status along with the status of according sub function agents. Afterward, they send their status to goal agents.

Goal agents (GA) represent all goals and tasks, which should be achieved through the industrial automation system. Goal agents enable the system to analyze the status of all tasks in an industrial automation system and confirm the available goals with the help of analyzing the status of necessary materials and available main-functions.

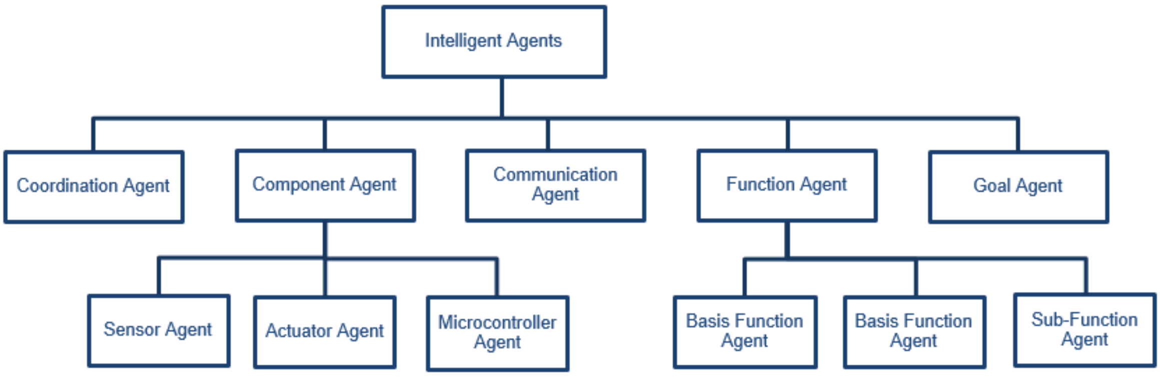

Figure 3. Intelligent multi-agents in IMAPMS

Communication agents (CmA) are responsible for the communication between IMAPMS and the industrial automation system.

The Coordination agent (CrA) takes charge of the argumentation of available functions (Mubarak, H. et al, 2010). It can check the state of the component agents and function agents, infer the affected functions by searching the database for a known problem and by using the reasoned - HermiT Reasoner - with the help of the component and function models, which describe the structure and the mission of the system via web ontology language, for an unknown problem.

In this section, different agents and their characteristics in IMAPMS are described. This will be followed by a description of the process of intelligent multi-agent based problem management system and a detailed presentation of how the required functions are realized by different agents.

5. WORKFLOW OF IMAPMS

Just as mentioned above, the IMAPMS gathers necessary information from industrial automation system and outputs the available functions not only about known problems but also unknown problems. For this purpose, the workflow of IMAPMS consists mainly of four parts (see Figure 4): problem detection, problem analysis, goal analysis and measure performing.

Figure 4. The workflow of IMAPMS

Step 1: Problem detection:

This step is in charge of collecting the information from the industrial automation system and estimating the problem. When a problem occurs, the existing diagnostic system in the industrial automation system detects the occurred problem. Afterwards the diagnosis results are stored in the local database. The communication agent monitors the status of the industrial automation system. It collects the results in the local database. Then, it sends the information to remote communication agent.

The remote communication agent communicates with the coordination agent for the purpose of estimating if the occurred problem is known or unknown. In one case, if the problem is known, the problem has already occurred at least once and the available functions have been stored in the database, the coordination agent accesses the database, and extracts the corresponding knowledge of available functions and goes to step 3. In the other case, if the problem is unknown, the coordination agent takes this problem as a new problem, sets a new ID for this problem in the database and continues to step 2. In addition, the status of goal agents will be set, including the priority of required goals, the required amounts and the status of required materials.

Step 2: Problem analysis:

In this step, the scale of the effect of the problem is confirmed, e.g. affected components and affected functions. The coordination agent identifies the defect components or functions with the aid of the diagnosis results. Consequently, the coordination agent sends the results to the corresponding component agent. The status of the component agent is set to "defective". The component agent informs other related components and sets their status to "defective". All component agents with the status of "defective" inform all corresponding basic function agents and set the status to "defective". The basic function agent communicates with the coordination agent to fix the related sub functions through the logical model of the industrial automation system. Afterwards, the main functions will be confirmed via the communication among sub function agent and main function agent. As a result, available functions are identified and they are stored in the database for repeated use.

Step 3: Goal analysis

In the previous step, available functions have been confirmed. The coordination agent accesses this information and communicates with every goal agent in order to verify the available goals. Firstly, on the basic of priority of goals, the first goal will be tested if required functions are available and if required materials are available. Then, the next goal with priority 2 will be analyzed until all goals have been tested. Besides, if the goal cannot be reached, this goal will be set in the status of "defective". In brief, available goals are rearranged in terms of the provided priorities.

Step 4: Measure performing

Just as mentioned above, the coordination agent gathers the above results of the available functions as well as the not-available functions and also available goals. Subsequently, the coordination agent gathers the necessary commands from the database in order to activate available functions and deactivate not available functions. After that, the measure will be sent to the industrial automation system via the communication agents and the internet. At the same time, the goals of the industrial automation system are reordered, the not available goals are cancelled (e.g. the order in coffee machine) or set to low priority. From the above discussion, available functions and goals can be performed with the help of IMAPMS during the appearance of problems in the industrial automation system.

6. APPLICATION OF IMAPMS IN AN INDUSTRIAL COFFEE MACHINE

Based on the described concept, in this section, we will propose an application of IMAPMS in an industrial coffee machine. Figure 5 shows an example of the analysis of a part of the industrial automation coffee machine. In goal view, it contains two goals, coffee and hot water. In function view, it consists of five functions, produce coffee, produce hot water, transport the water, heating the water, produce coffee powder and milling the coffee beans. In component view, it is made up of five part, coffee system, water system, milling system, pumper, boiler and grinder.

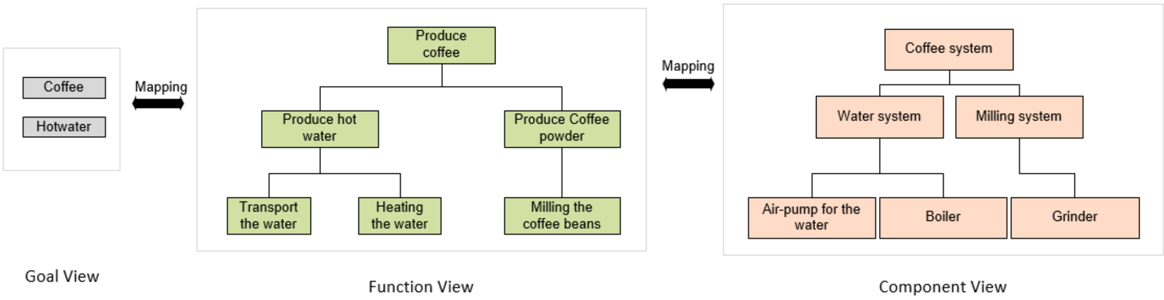

Figure 5. Analyzing a part of the industrial coffee machine using the three perspectives

Figure. 6 shows a simulator of an industrial coffee machine and a user interface of IMAPMS. The simulator provides eight products as well as eight buttons. After pushing a button, an appropriate product is produced and showed on the right side with a picture in this simulator.

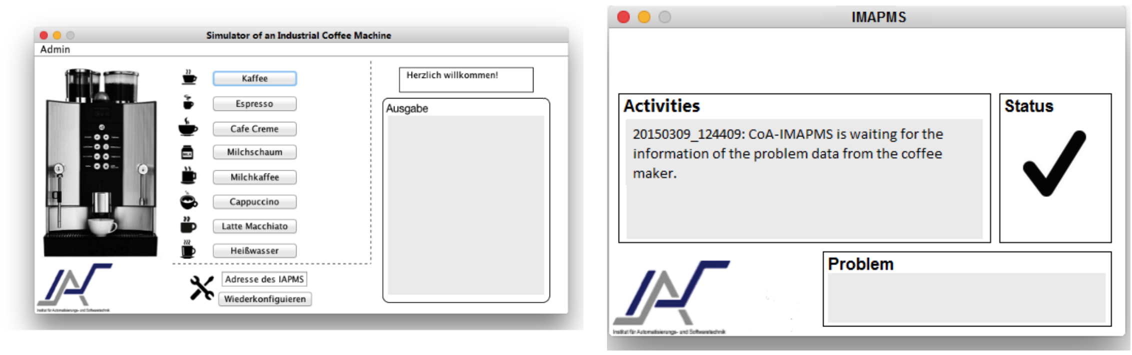

Figure 6. A Simulator of an industrial coffee machine in working order and the user-interface of the IMAPMS

The simulator of the industrial coffee machine consists of 22 components, 15 sub functions, three types of materials and eight main functions. Hence, there can be 22 faults assuming that only one component is defect at the same time. In this simulation, we assume 21 of these faults are known and one fault (the air-pump for milk) is unknown. Hence, for known faults, every fault has its own existing fault knowledge, e.g. fault-ID, fault location and available functions. Thus the unknown fault only has the information of diagnosis-results, e.g. the fault-ID and fault location.

So as a test (see Figure 7), when the air pump for milk is defect, the existing fault diagnosis system of the industrial coffee machine detects this fault. Then, the industrial coffee machine sends this information to the communication agent in the industrial coffee machine. Afterwards the communication agent sends this information to the communication agent in IMAPMS. The communication agent in IMAPMS sends this information to the air pump agent. Then the air pump agent informs the milk froth agent that it cannot provide the milk any more. The milk froth agent sends this information to the coordination agent that the milk cannot be produced.

Then the coordination agent receives the gathered information about the problem. If the problem is known, after querying the database, the available functions can be confirmed. If the problem is unknown, the coordination agent informs the correlated function agents. Along with the relationship among components and basic functions, the correlated basic function agents can also be confirmed. In addition, as a matter of the relationship among different functions, correlated sub functions agents and main functions agents as well as the available main functions are identified.

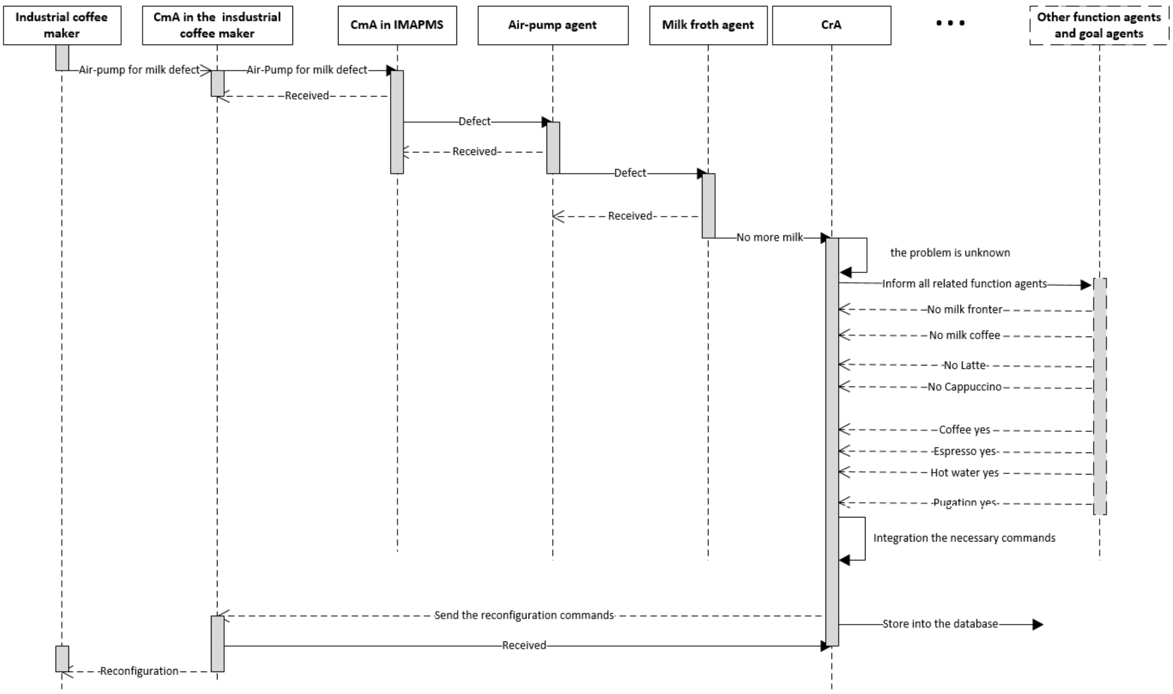

Figure 7. The activities among the agents in IMAPMS when the air pump for milk is defect

Necessary rules play an important role in either assessing available functions or assessing available goals. A rule consists of rule name, condition and action, for example,

Inquiry = Function and “is Function by” value “function name “.

According to that, the available functions will be added into the database. In order to assess the available possibilities of the industrial coffee machine, i.e. which products are available, the coordination agent communicates with the eight goal agents. Every goal agent analyzes the amount of its needed materials. When necessary functions and materials are available, then this goal can be performed in the industrial coffee machine.

Finally, the coordination agent of IMAPMS integrates the necessary commands for the reconfiguration and sends the results about available functions and available goals to the industrial coffee machine via the communication agents in the industrial coffee machine. Afterwards, the industrial coffee machine reconfigures its functions as well as the user interface, so that not available goals and its button will be deactivated and others will be activated.

Even though a problem exists in the industrial coffee machine, the effect of the problem will be delimited via activating available functions with the help of IMAPMS.

7. CONCLUSION AND FUTURE WORK

In this paper, we have analyzed the industrial automation systems. According to physical and logical description, an industrial automation system is divided into three levels: component level, function level and goal level. Therefore, in order to particularly and accurately define the automation system and obtain the available functions, the system would be represented by a multi agent system along with the above classification. Furthermore, an intelligent multi-agent based problem management system is proposed to prevent system break-down. For the purpose of dealing with problems, this system consists of the following steps: problem detection, problem analysis, measures analysis and measure performing. IMAPMS is able to gather the necessary information from industrial automation system and output the available functions not only about known problems but also unknown problems. The intelligent multi-agents based problem management system provides possibilities: the supplier can remotely maintain his products which have been sold on one side and help the user to deal with occurred problems in industrial automation systems by performing available functions on the other side. Besides, this system is a significant supplementation for fault diagnosis and fault prevention. Finally, an application of IMAPMS was realized in a simulation of an industrial coffee machine. The IMAPMS can deal with 21 known faults and one unknown fault. To sum up the main points of the concept, the IMAPMS is capable of managing occurred problems by means of ensuring available functions and preventing a long time stop of the whole industrial automation system.

In the future, as a first extension, the simulator of the industrial coffee machine will be further expanded. For instance, to increase the detected fault types, not only for one component but also two or more components being defect at the same time. Secondly, we will investigate further optimizations to realize a flexible, inexpensive and universal concept. Finally, we are planning to implement this concept in a real system and integrate further more industrial automation systems.

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