Higher Availability of an Industrial Automation System Based on a Remote Problem Management System

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***Abstract*—This paper puts forward a novel concept of a Remote Problem Management System that allows an industrial automation system continuing to work with available functions during the appearance of a problem. The concept of the Remote Problem Management System consists of passive and active management to handle problems. The passive management aims at handling known problems by means of receiving the Fault-ID from a Fault-Diagnosis System, accessing the producers' knowledge base and getting available functions. On the contrary, the active management attains to handle unknown problems via processing diagnosis results, analyzing the sphere of the influence, confirming available functions and storing these information in the producers' knowledge base with the help of this system, the producer is able to manage the problems in his sold machines remotely and the user can use his machine with available functions before the machine is repaired.**

***Index Terms*— problem management, model of an industrial automation system, higher availability, fault knowledge**

I. Introduction

Nowadays, the continuous service of an industrial automation system becomes an essential qualitative requirement. That means, the availability of an industrial automation system must be increased. Due to different reasons (e.g. short development time, few test cases, etc.), faults - no matter whether in hardware or in software - cannot really be avoided in the operation state [1]. Thus, a sudden fault can cause a stop of the whole industrial automation system and interrupt the service as well as decrease the availability of the system. So plenty of researches about the fault-diagnosis has been carried out many approaches to handle faults in an industrial automation system. In practice, even though faults can be found, they are not able to be eliminated immediately. Hereby, a Remote Problem Management System is proposed to guarantee the performance of available functions in an industrial automation system, even if a problem occurs. In the sight of the givenness of the problem in this system, problems can be divided into two categories: known faults that have happened once and unknown faults that happen for the first time. For the former, the Remote Problem Management System can directly obtain corresponding available functions from the knowledge base. On the contrary, the effect of the latter is confirmed by the Remote Problem Management System on the basis of fault diagnosis results. In addition, the Remote Problem Management System confirms available functions at last. By means of this concept, users can use the machine with available functions instead of having to wait for the help by maintenance service. Naturally, producers can deal with problems remotely.

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II. Related Works and Theoretical Aspects

A. Fault-Diagnosis and Fault Tolerance

In this concept, the most important task of the Remote Problem Management System is to limit the effect of a fault, i.e. which functions are affected. However, before restricting the effect of a fault, the fault (the location of the fault) must be detected in the first place. Generally speaking, a fault in industrial automation systems can be located in four-levels: components, processes, subsystems and systems. For instance, the defected components can be diagnosed by using an output estimation approach, in cooperation with residual processing schemes [2]. In addition, Akhlaghi proposes a multiple adaptive neuro-fuzzy inference system to monitor different processes by using independent component analysis [3]. Moreover, in [4] a subsystem level fault diagnosis approach is introduced by means of process estimation, residual generation, and fault detection and diagnosis. Alternatively, a framework of Discrete Event System considers the relationship between component-level faults and system-level faults for the wind turbine system [5]. It is expected that the location of faults can be successfully detected by a great number of methods.

Typically, fault tolerance is a familiar technology as an effective measure to avoid or limit the effect of a fault [6]. Usually an automation system has to add additional parts (hardware or software) to realize the fault tolerance. Obviously, the cost of the system can be increased. In addition, the producer has to perform some more tests to verify the tolerance parts. Otherwise, we cannot take the fault tolerance for all the components in practice. Hence,

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we need a novel approach, which is low cost but can limit the effect of a fault. So we propose the Remote Problem Management System to guarantee the performance of all available and possible functions.

B. Industrial Automation System-Model

As mentioned above, the main location are different reference units, i.e. components (also elements) [2], processes [3], subsystems [4], systems [5]. In this paper we discuss the application fields only in one industrial automation system. So the reference units are restricted to components, processes and subsystems. The results of the Fault-Diagnosis System refer to these units. The state of these units is also used as inputs for the Remote Problem Management System.

In order to describe a system, two important properties are proposed, the architecture of the system and its behaviors. In order to reach this goal, we proposed the Industrial Automation System-Models (IAS-Models) which contain a Component Model to describe the architecture of an industrial automation system and a Function Model to interpret the behaviors or activities of the system (see Fig. 1).

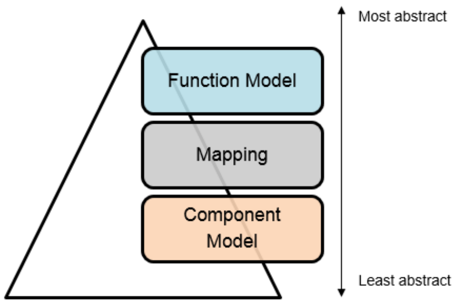

Figure 1. Overview of the industrial automation system models

Firstly, the component model describes all physical elements and their connections of an industrial automation system [7]. That means, a system includes different subsystems, at the same time, every subsystem is connected by different components for a specific purpose in order to achieve some specific tasks.

The function model describes all functions from the logical sight and their connections of an industrial automation system. This model consists of basic functions, sub-functions and main functions. This model is the mapping from the component model. Each basic function represents the corresponding component with its behaviors' pattern. Likewise, each sub-function is the mapping from the corresponding subsystem with one of its behaviors. Otherwise, the whole system has a lot of different main functions. In addition, each function contains the transformation of different processes, e.g. the sub-function of boiling hot water is the material transformation in the process from cold water to hot water.

III. Concept of the Problem Management System

This section gives an overview of the Remote Problem Management System (see Fig. 2). The objective of the Remote Problem Management is to enhance the availability of an industrial automation system through offering the available functions and keeping the industrial automation system working with limited functionalities during the appearance of a fault. This concept consists of three parts.

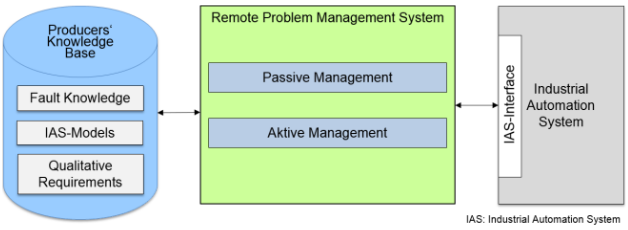

Figure 2. Overview of the remote problem management system

A. IAS-Interfac

It is responsible for the exchange of the information among an Industrial Automation System, an existing Fault-Diagnosis System and the Remote Problem Management System. It is a special part in an industrial automation system. It collects the information about faults from existing Fault-Diagnosis Systems, e.g. Fault-ID, the location of a fault, and sends them to the Remote Problem Management System. Meanwhile, this IAS-Interface interprets the received commands from Remote Problem Management System to activate the available functions in the industrial automation system.

B. Remote Problem Management System

This part is the core of this concept. It is in charge of reprocessing the obtained fault information, accessing the producers' knowledge base so as to get available functions concerning variant faults and sends the available functions to IAS-Interface. In addition, this system contains two different ways to achieve the management of faults, i.e. active management for handling unknown problems and passive management for treating known problems [8].

C. Producers' Knowledge Base

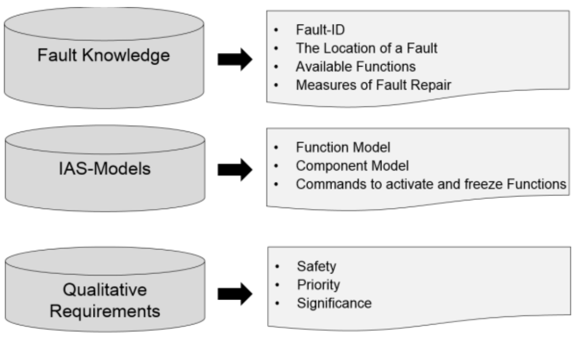

Figure 3. The knowledge in the producers' knowledge base

This part organizes and stores all necessary information for the Remote Management System (see Fig. 3). It consists of the fault knowledge, IAS-Models and qualitative requirements. The fault knowledge contains all the necessary information about faults, e.g. fault-ID, fault-type, the location of a fault, fault-cause, available functions, measures of regular fault repair, etc. The IAS-Models have different rules and matrices to describe the industrial automation system, including component model, function model and commands to activate and freeze functions. Qualitative Requirements (for example, safety, priority, significance, etc.) are some special criterion to verify the available functions whether they can be performed or which ones can finally performed in the industrial automation system during the appearance of a problem.

IV. Passive Management for a Problem

This chapter describes the passive management of the Remote Problem Management System to process known problems in an industrial automation system (see Fig. 4). In the case that fault tolerance is not addressed, when a problem occurs, the whole industrial automation system stops working. Via monitoring or checking the state of the industrial automation system, a Fault-Diagnosis System analyzes the occurred problem, compares with its own fault-knowledge (characteristics about activities, parameter, fault-ID, etc.), gets the fault-ID for a known problem and sends this information to the IAS-Interface. Secondly, the IAS-Interface sends this fault-ID and an identifier flag (i.e. givenness = 1, this problem is known) to the Remote Problem Management System. Then, verifying the identifier flag, the module of passive management can be activated. Afterwards, the Remote Problem Management System accesses the database, readouts available functions with the help of the fault-ID, and sends the available functions (including the related commands) to the IAS-Interface.

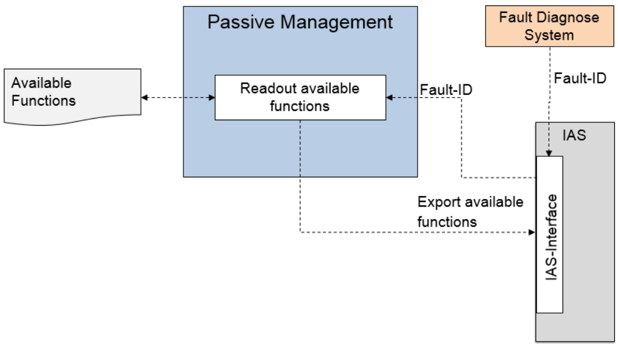

Figure 4. Passive management of the remote problem management system for a known fault

Finally, the IAS-Interface activates the available functions in the industrial automation system. Then the system can keep working with limited functions even if a problem occurs.

V. Active Management for a Problem

The active management, different from the passive management, is contributed for unknown problems. Via the active management, an unknown problem (here means, this problem occurs for the first time and there exist no corresponding measures as well as available functions in the producers' knowledge base) can be processed by the Remote Problem Management System. Afterwards, the effect of a fault and available functions are identified (see Fig. 5). The detail of this process will be discussed as follows.

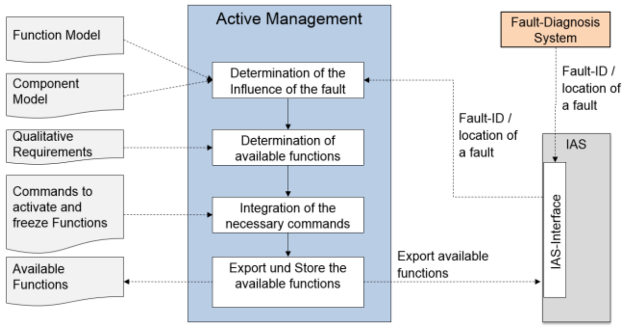

Figure 5. Active management of remote problem management system for a unknown fault

In the first place, an unknown problem occurs, the existing Fault-Diagnosis System or the maintenance service analyzes the fault with the own knowledge to confirm the location of the fault, e.g. the air-pipe for milk of a coffee maker. Meanwhile, a new fault-ID is created by the system. In such a case, the identifier flag about the problem is set as unknown, i.e. givenness = 0. Then, all the information is sent to the Remote Problem Management System through the IAS-Interface.

Subsequently, due to the unknown problem, the active management is activated. Then the Remote Problem Management System tries to confirm the influence of the fault at first. With regard to this, this paper proposes a model-based method including two ways, i.e. a black-box model and a white-box model. On one hand, when the problem occurred in one component and the system is very simple, e.g. there are not too many components in the industrial automation system, the black-box model will be performed. By means of using the special matrix about the relationship between components and functions, the Remote Problem Management System can directly deduce available functions. On the other hand, if the problem correlates with more than one components or the system is complex, e.g. there are a great deal of components in an industrial automation system or the structure of the system is very complex, the Remote Problem Management System uses the white-box model to identify the effect of the fault. As introduced in chapter2, the white-box model consists of a component model and a function model. First of all, the Remote Problem Management System makes use of the component model which has different correlation matrices to describe the physical connection of the whole industrial automation system. In the reasoning the matrices and the rules are used together [9].

For example, we use a connection matrix (see Fig. 6) which is used for describing the relationship among components and functions. And we use specific rules to analyse the effect of a problem, e.g.

If CF11 = true and C1 = false, then BF1 =false.

Here, CF11, C1 and BF1 are the elements of the matrix. CF11 = true means that the component 1 is related with the basic function 1; C1 = false means the component 1 is broken; BF1 = false means that the basic function 1 cannot be carried out.

Likewise, the Remote Problem Management System checks the availability of all basic functions in the industrial automation system. Accordingly, in terms of different correlation matrices among basic functions, sub functions and main functions, the influence of the problem, i.e. the affected functions, can be eventually fixed. At the same time the not-affected main functions can be identificated.

Furthermore, with the help of qualitative requirements, the Remote Problem Management System checks the usability of the not-affected functions from the previous step whether the functions can be activated. We propose the method via the cooperation between particular rules and matrices again, e.g. importance of functions, priority, etc. After this test, the Remote Problem Management System eliminates nonconforming functions still further more. Meanwhile, the real available functions are finally confirmed according to this certain problem.

Afterwards, for the sake of activating the available function in the industrial automation system, the Remote Problem Management System integrates the corresponding commands for each available function.

Finally, with the available functions and their related commands, two different missions are performed. On the one hand, the Remote Problem Management System outputs the commands to the IAS-Interface to activate the available functions as well as to deactivate the non-available functions in the industrial automation system. On the other hand, this information about the problem and available functions should be stored in the producer' knowledge base for reuse at the next time.

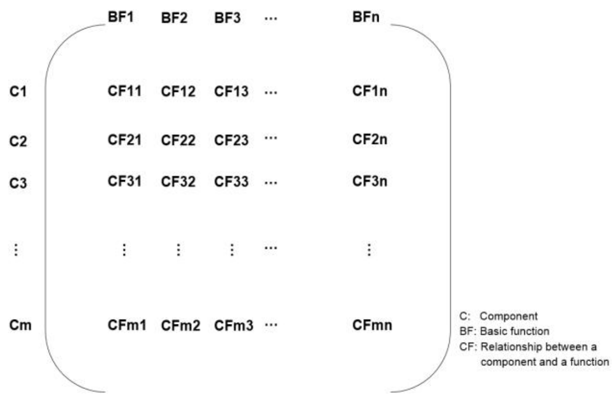

Figure 6. An example of the connection matrix between componets and funtions

VI. Conclusion and Future Work

To summarize, this paper presented a concept of the Remote Problem Management System to guarantee the available functions for industrial automation systems even though a problem appears. To achieve this objective, the Remote Problem Management System deals with the problem from two views. On the one hand, the system obtains available functions directly from the producers' knowledge base related to known problems. On the other hand, relying on the IAS-Models, the fault-diagnosis results are reprocessed by the Remote Problem Management System. Thereby, the influence of an unknown problem is confirmed as well as not-effected functions. Then, the Remote Problem Management System verifies those not-effected functions if they satisfy the pre-defined qualitative requirements. Finally, real available functions are identified related to the problem. At the coarsening proceeds, the number of known problems increases more and more, and in comparison, unknown problems decreases. In the upcoming months, this concept will be implemented in two different industrial automation systems (Industrial Coffeemaker and Bottling-plant) at the Institute of Industrial Automation and Software Engineering at the University of Stuttgart to enhance their availability.

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References

[1] H. Wang, N. Jazdi, and P. Goehner, "An agent-based concept for problem management systems to enhance reliability," in *Proc. 2014 Theoretical and Applied Aspects of Cybernetics*, Kyiv, 2014, pp. 283-293.

[2] S. Simani, C. Fantuzzi, and R. J. Patton, *Model-based Fault Diagnosis in Dynamic Systems Using Identification Techniques*; London: Springer -Verlag, 2013.

[3] P. Akhlaghi, A. R. Kashanipour, and K. Salahshoor, "Complex dynamical system fault diagnosis based on multiple ANFIS using independent component," in *Proc. 16th Mediterranean Conference on Control and Automation,* Ajaccio, 2008, pp. 1798-1803.

[4] W. Y. Lee, J. M. House, and N. H. Kyong, "Subsystem level fault diagnosis of a building's air-handling unit using general regression neural networks," *Application Energy*, vol. 77, no. 2, pp. 153–170, 2004.

[5] B. Lu, Y. Li, X. Wu, and Z. Yang, "A review of recent advances in wind turbine condition monitoring and fault diagnosis," in *Proc. Power Electronics and Machines in Wind Applications, IEEE*, Lincoln, NE, 2009, pp. 1-7.

[6] K. Kim and S. Cho, "Automated synthesis of multiple analog circuits using evolutionary computation for redundancy-based fault-tolerance," *Journal of Applied Soft Computing*, vol. 12, no. 4, pp. 1309-1321, 2012.

[7] V. Vyatkin, "Software engineering in industrial automation: State-of-the-art review," *IEEE Transactions on Journal of Industrial Informatics*, vol. 9, no. 3, pp. 1234-1249, 2013.

[8] B. K. Williams, "Passive and active adaptive management: approaches and an example," *Journal of Environmental Management*, vol. 92, no. 5, pp. 1371-1378, 2011.

[9] W. H. Chen, "Fault section estimation using fuzzy matrix-based reasoning methods," *IEEE Transactions on Journal of Power Delivery*, vol. 26, no. 1, pp. 205-213, 2011.

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