Model of Secure Informational Messages for Ensuring Informational Interaction in Smart Factory

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Abstract. The need to reduce costs and human involvement in the production processes has led to the development of new production approaches such as the Smart Factory concept. Smart Factory is the basis of Industry 4.0. The model of the information space provides a wide spectrum of opportunities for developers to implement new methods of information interactions within the system of Smart Factory. In this paper we propose the model of informational message and the basic model of information space for Smart Factory networks. The following model helps to ensure confidentiality of the data transmitting by the elements of Smart Factory.

Keywords: Smart Factory · Informational Message · Industry 4.0

1 Introduction

The Smart Factory is a vital part of Industry 4.0. At the present moment it is desired as a fully autonomous and self-organized manufacturing system that aimed to reduce the influence of the human factor in the production process. It brings a wide list of topics to be discussed. Authors of [4] defined 8 research fields for a smart factory model such as decision making, cloud computing, infrastructure, data handling, cyber-physical systems, Internet of Things, digital transformation and human-machine interaction.

The main disadvantage of the existing smart factory models is the lack of the information interactions' formal description among system elements. Generally all basic operations conducting by agents are dependent on the type and the content of the received messages. Errors in messages transmission can lead to the system malfunctions or crashes.

In the present work, we focus on the representation of information in the Smart Factory. We proposed a general description of informational interaction, described model of informational messages and defined their features.

2 Related Work

Nowadays the smart factory is represented as a fully connected and flexible system [1], which uses information and adapts it for new technological requests. Supply manufacturing chains transformed from a static sequence to a dynamic one that utilize many sources of information to drive a production process. According to this paper, the five key characteristics of a smart factory are: connected, optimized, transparent, proactive, and agile.

One of the approaches for smart factory processes modeling is ontology-based proposal [2]. In this case, the researches are focused on the main concepts of a factory, objects, and their features. The purpose of the approach is to represent the most important relations in the industrial domain to achieve context representation and context reasoning.

Another solution for Smart Factory architecture is to build a blockchain-based cyber-physical system [5]. In this paper, the informational interaction among Smart Factory elements is described. The internal network has a management hub and storage level, the information in the system is encrypted using private and public keys.

Some of the researchers had already published frameworks for simulation of information flows in a smart factory [3].

3 Smart Factory Model

Generally, the Smart Factory may be presented as a structure $< A, I, R, P >$ which consists of the sets of the following objects.

The set $A = \{(a_1 \mid q_1), \ldots, (a_n \mid q_n)\}$ is a set of autonomous agents which communicate with each other via informational messages. The agents are not static, they may change their position according to the task which they perform. The task is a set of operations in a unique order for completing the stage of product assembly. The system of agents is self-organized, it does not need a computing center for manufacturing management. The process of task distribution may be random or follow a predefined rule. When the agent gets his position and the task, it may start functioning and product assembly. Parameter $0 \leq q_i \leq 1$ is a value that characterizes the access level of each agent of the system to an elementary message placed in informational space. The higher the value of q_i an agent has, the higher the access level it has. We propose the assumption that the number of robots involved in the production process is constant and the system is not scalable.

Set I is a set of elementary informational messages described in Section 4. The set $R = r_1, \ldots, r_s$ is a set of resources used for product assembly.

The production result is a set of products $Pr = pr_1, \ldots, pr_s$ that is assembled as a result of the uniquely defined production algorithm. On the other hand, the product is a result of a function $pr_i = f(A_i, R_i, I, t)$ which is indirectly dependent on the informational messages transmitted by agents and the time spent on product assembly.

4 Representation of the Information in Smart Factory

4.1 Informational Message Model

A set of all the informational messages is presented as a set $I = \{i_1, i_2, \ldots, i_l\}$. This set has an additional set of the parameters characterizing the security level for the particular message or the access level. This is the set $D = \{d_1, d_2, \ldots, d_l\}$, $0 \leq d_i \leq 1$. The higher the value of the parameter, the higher access level the particular agent has to have.

Figure 1 represents the proposed structure of the informational message.

field 1	field 2	field 3	field 4	field 5	field 6	field 7
a	*b*	*d*	*time*	*type*	*info*	*DS*

Fig. 1. Structure of the informational message for Smart Factory elements communication

The content of the messages is represented as a fields of the particular type and length. The fields description is given below:

- a is the ID of the agent who sent the information message;
- b is the ID of the agent who received the information message;
- d is an access parameter for the following message. Agent-sender may specify this parameter by himself but it cannot be higher than his own access parameter. Alternatively, it may be specified automatically. In this case it will be calculated as $d_i = min(q_a, q_b)$, where q_a is an access parameter for agent a, q_b is an access parameter of agent b;
- $time$ is the time, when the message was sent. We propose the assumption that the transmission time tends to zero value. Consequently, the value of the sending and delivery time are equal;
- $type$ is the message type;
- $info$ is a content of the message;
- DS is the digital signature used for the security of message transmission.

4.2 Informational space

Basically, the informational space is a set of information messages in the Smart Factory. In fact, it may be presented in several different ways.

In the first case we used parameters a, b and $time$ to introduce a three-dimensional space (Figure 2). The axis a is the axis of agents sending informational messages, axis b is the axis of agents receiving informational messages, axis $time$ is the time axis. The number of agents is limited, n is the last agent's ID, the axes a and b are limited by agents a_n, b_n.

To introduce the informational space, the following assumptions were proposed:

- all the agents are discretely displayed on the following axis;
- *time* is considered as a discrete value;
- Messages transmission time tends to zero. This assumption allows to find the particular message in the space.

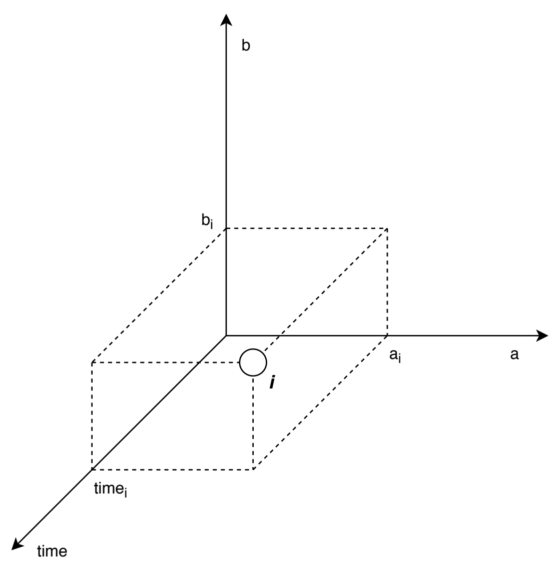

Fig. 2. Three-dimensional representation of the informational space.

When the agent-sender transmits the message, it specifies the parameter b as the ID of the agent-receiver. There are three scenarios how the parameter could be specified:

1. $b = 0$. If the parameter b is 0, it means that agent sent the message to itself. The type of the message is “own agent’s message” and it is a work report. The set of such messages is a set I_{own};
2. $b = (\overline{1, n})$. The messages of this class indicate the interaction between agents a and b. The set of the messages transmitting between agents is a set $I_{interaction}$;
3. $b = n{+}1,\ b = all$. This messages are broadcasting to all agents. All the agents satisfying the condition $q \geq d$ have an access to them. These messages are placed to the set I_{all}.

According to these parameters, we consider the information space as a set of subsets of information messages grouped by their current location:

$$I = I_{all} \cup I_{interaction} \cup I_{own}$$

The visualization of the informational space divided by clusters is shown in the Figure 3.

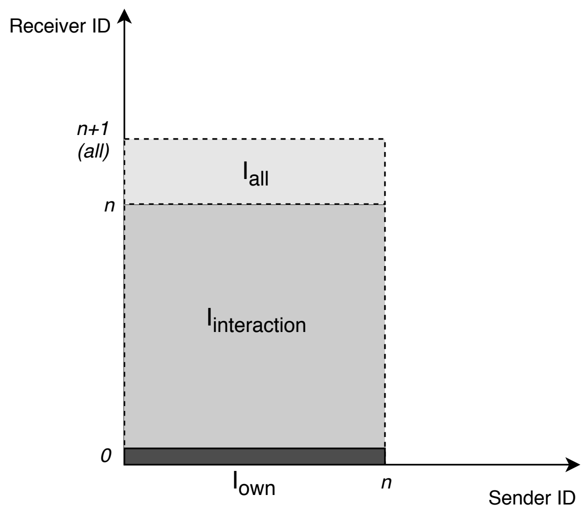

Fig. 3. The informational space divided by clusters.

4.3 Messages Transmitting

Basically, the process of informational messages' transmitting includes the sequential creation of an informational message, digital signature, sending to the communication channel (informational space), sending a message from the communication channel to the receiver and checking the digital signature by the receiver agent.

4.4 Possible Actions with Messages

Here we describe the actions, which agents could perform on messages.

1. Reading. All agents possessing sufficient access rights have rights to read messages from the I_{all} cluster. Reading messages from the $I_{interaction}$ and I_{own} is performed by the receiver-agents and sender-agents for the first case, and by sender-agents for the second case.
2. Writing. It is possible to generate a message once only, rewriting an existing message is impossible.

3. Exploit. The agents who have rights to read the informational message have the rights to exploit the data contained in these messages. It is understood that the messages are intended for a specific group of agents in the factory system.

5 General Case of Informational Channel

Due to the fact that the process of informational messages' transmitting is a process that includes the sequential creation of an informational message, digital signature, sending to the communication channel (informational space), sending a message from the communication channel to the receiver, and checking the digital signature, we propose the informational space as a middle point in the process of informational messages transmitting. It serves to record informational messages in the permanent memory of the system. After receiving the message by the information space, the following basic attributes are assigned to it:

- the time of creating a memory cell to store it (transmission time);
- sender-agent, receiver-agent IDs;
- access level parameter.

Digital signature and its validation are mandatory steps in the process of information exchange due to the fact that the possibility of the attack is not excluded.

Any of the agents involved in the process of messages transmission can refer to them for the purpose of reading or exploit using the recording time of the message and the identification number of the interlocutor-agent as parameters for the search.

6 Properties of Informational Messages

- Theoretical properties of informational messages:
  1. Informational messages (IM) are discrete in time and space.
  2. Nonadditiveness. Adding IM to existing ones does not increase the total amount of information by the amount of added information.
  3. Nonassociativeness. Let $f_1(I) = h(i_1 + \ldots + i_n)$ is the first function algorithm to be executed by the agent, $f_2(I) = h(i_n + \ldots + i_1)$ is the second function algorithm, and the functions differ only in the order of summation of certain informational messages, then $f_1(I) \neq f_2(I)$ by definition of determinacy of algorithms inside the factory system.
  4. Obsolescence of IM. The data contained in IM may lose their relevance after a certain time.
  5. Non-disappearance of IM. As part of the work, the authors introduce the assumption that a message placed in informational space cannot be deleted.

6. The invariability of information in time. Similar to property 5, an informational message in the space cannot be changed by the sender-agent, the receiver-agent, or the third-party agent.
7. Independence of the representation of informational messages for various agents, syntactically and semantically.
8. The pragmatic value of informational messages depends on the class to which the agent belongs.
9. Non-equivalence of the value and usefulness of the information contained in the IM (consequence of property 8).

– Physical properties of informational messages:
1. Memorability. Due to the fact that the messages transmitted by agents are recorded in the information space, these messages are linked to the transmission time, therefore, they are also remembered physically.
2. Transferability. Informational messages are transmitted via communication channels within the factory system.
3. From property 2 follows the ability of the IM to be copied. Let t_{copy} be the point in time at which the message will be copied, then, according to (1):
$$i(t_{copy}, i(t_k)) = i(t_k) = i(t_{copy}), t_k \leq t_{copy} \tag{1}$$
4. Reproducibility. In the ideal case, the copied message is syntactically identical to the original (reproduced) message. In real systems, there is a possibility of copying errors.

Let a discrete message $i(l, X)$ be transmitted, where l is the length of the information message, $l \in N, X = \{(x_1|p_1), (x_2|p_2), \ldots, (x_n|p_n)\}$ - is the set of available symbols of the alphabet with the length n and the corresponding error probabilities of recording the letter is p, $0 \neq p \neq 1$. To be considered that a writing error has occurred, the number of incorrectly written characters of the message must be more than or equal to the number m. Message characters are written independently of each other. Then the probability of writing a message is calculated by (2):

$$P_{error} = \sum_{k=m}^{l} P_k \tag{2}$$

7 Conclusion

The rapid development of the Smart Manufacturing concept arises the need to provide safe and secure interaction among system elements.To address this issue, in the present paper we proposed information space concept which allows to implement our developed model of the informational messages for communication among Smart Factory elements.

Due to the implementation of digital signature and access parameters to the informational space, the new structure of informational messages help to ensure confidentiality of informational interaction. In further work we plan to develop information interaction simulator and analyze the results of simulation on speed and security in the presence of the intruder of the information security.

References

1. Burke, R., Mussomeli, A., Laaper, S., Hartigan, M., Sniderman, B.: The smart factory.(2017). URL: http://www. smartfactory-owl. de/index. php/en/industry-4-0
2. Giustozzi, F., Saunier, J., Zanni-Merk, C.: Context modeling for industry 4.0: An ontology-based proposal. Procedia Computer Science **126**, 675–684 (2018)
3. Komoto, H., Kondoh, S., Furukawa, Y., Sawada, H.: A simulation framework to analyze information flows in a smart factory with focus on run-time adaptability of machine tools. Procedia CIRP **81**, 334–339 (2019)
4. Osterrieder, P., Budde, L., Friedli, T.: The smart factory as a key construct of industry 4.0: A systematic literature review. International Journal of Production Economics (2019)
5. Wan, J., Li, J., Imran, M., Li, D., et al.: A blockchain-based solution for enhancing security and privacy in smart factory. IEEE Transactions on Industrial Informatics (2019)