Informational Messages and Space Models Application in Smart Factory Concept

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Abstract

Smart Factory concept is considered to play one of the crucial roles in the Industry 4.0 paradigm development and evolution. The informational space model provides a wide spectrum of opportunities for developers to implement new informational interaction mechanisms within the Smart Factory system. In this paper, we propose the informational message and the basic information space models for Smart Factory networks. The informational messages model allows to ensure confidentiality of data transmitted between Smart Factory nodes. In addition, we implement Smart Factory network in a simulation environment, apply described informational interaction models, and analyze further viability of the developed approach.

Keywords

Smart Factory, Information Interaction, Informational Space

1. Introduction

Nowadays, increasing the manufactories' autonomy level becomes one of the crucial factors for successful competition on the market. Scientific communities are focused on the technologies development that allows to accelerate the production process and to decrease a human-related aspects' influence on it. Automated factories became a reality, but we still experiencing difficulties associated with planning processes. An individualized product and its adaptation to the market require an optimized time and resource consumption. The Smart Factory concept and factory as a cyber-physical system allows solving the majority of challenges that we are facing now. Smart Factory can be considered as a network of smart devices presented by robots, conveyors, transportation, and management system. However, another obstacle is the representation of smart devices and their communication in a mathematical way.

In this paper, we introduce a mathematically described Smart Factory system and its agents via a multi-agent approach. In Subsections 3.2-3.3 we introduce the concept of the Informational Space in Smart Factory and describe the approaches to represent it as a two-dimensional and three-dimensional spaces. Subsection 3.4 focuses on the packet structure of the messages transmitted in Smart Factory. As a main result, we introduce the developed software simulation environment that allows modeling the informational interaction in Smart Factory according to

Proceedings of the 12th Majorov International Conference on Software Engineering and Computer Systems, December 10–11, 2020, Online Saint Petersburg, Russia
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CEUR Workshop Proceedings (CEUR-WS.org)
CEUR-WS.org/Vol-2893/short_3.pdf

the proposed specification. The functional structure and abilities of the simulator are presented in Section 4.

2. Related Work

Nowadays the smart factory is represented as a fully connected and flexible system [1] that uses constant information and adapts it for new technological requests. Supply manufacturing chains transform from a static sequence to a dynamic one that uses 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, proactivity, agile.

Systems that combine the informational level (the level of computing and communication) and the physical level are related to cyber-physical systems (CPS). CPS are engineering systems whose operations are controlled, coordinated, and integrated by the computing core [2]. Since the level of physical devices and the network level (set of informational elements) are integrated, the Smart Factory system can be considered as a CPS. Cyber-components of the system include components responsible for performing calculations, implementing algorithms, and transmitting data over a network. The physical component of such a system is determined by "analog" elements, other physical systems, and the environment itself. The use of CPS in the manufacturing sector allows increasing the production process efficiency due to the full integration of computing devices with enterprise mechanisms [3].

The Smart Factory's functional structure and the sequencing production process mechanism are well-studied topics [4]. The autonomous manufacturing physical side is researched, partially implemented and simulated by various scientific communities [5]. The concept of the Industrial Internet of Things (IIoT) is widely used as the basis to organize the factory elements' interaction with the use of IIoT routing protocols [6, 7]. However, the Smart Factory mathematical concept formalization has not been proposed yet, as well as the interaction and communication models for the Smart Factory elements.

3. Information Interaction in the Framework of Smart Factory

3.1. Mathematical Description of the Smart Factory

We consider Smart Factory as a structure $< A, I, R, Pr >$. The elements of this structure are the sets of Smart Factory objects: agents-robots set A, informational space set I, resources set R, products set Pr. It is assumed that the Informational Space is a result of a function $I = f(A)$. This assumption means that the set of informational messages (informational space) is formed during the robots' communication process. Due to the specific features described in [3], Smart Factory can be described as a multi-agent system. The agents can be represented as agents-robots (further - agents) of the set A. These agents are autonomous and perform specific tasks to achieve the common system goal. In this case, agents assemble the products using the information space I as a communication channel.

The set of agents is represented as $A = \{(a_1|q_1), (a_2|q_2), \ldots, (a_n|q_n)\}$, where q is a particular agent's access level to the Informational Space messages. The resource set can be described as $R = \{r_1, r_2, \ldots, r_s\}$, the set of Smart Factory products as $Pr = \{pr_1, pr_2, \ldots, pr_v, \}$. Production process can be described as a function $f = (A_i, F_i, R_i, I, t) + \phi_i$ where A_i, F_i, R_i are some subsets of the agents' set, functions and resources (A, F, R, respectively) are involved in this product assembling; I is the informational messages set; t is the time spent on the production process, ϕ_i presents other features that have an impact on production process.

3.2. The Structure of the Informational Space

We introduce informational space as a structure $< I, D >$ where I is a set of elementary informational messages $I = \{i_1, i_2, \ldots, i_l\}$ and D is a set of the access parameters for the corresponding messages of the set I, $D = \{d_1, d_2, \ldots, d_l\}, 0 \leq d_k \leq 1$. The parameter d_k can be calculated in the following ways.

- The message was sent by the agent to itself. In this case, the access parameter is calculated as $d_k = q_{sender}$, where q_{sender} is the access level of the sender agent.
- The message was sent to another agent. The sender can specify the d_k parameter value and, in this case, it cannot be greater than the access level of the sender. In another case, the parameter value may be calculated automatically as $d_k = min(q_{sender}, q_{receiver})$, where q_{sender} is the access level of the sender, $q_{receiver}$ is the access level of the receiver.
- In case the informational message receiver is represented as a set of all agents in the system (e.g. broadcasting mode), the access parameter value is taken as the minimum possible value of the access level of all agents: $d_k = min(q_1, q_2, \ldots, q_n)$.

3.3. Informational Space Representation Approaches

For analysis purposes, the described informational space can be represented as a two- or three-dimensional space.

A three-dimensional representation of the informational space is given by the coordinates a, b and t, and is illustrated in Fig. 1. The axis a illustrates the agents sending informational messages, the axis b represents the agents receiving informational messages, the t axis portrays the time. Considering this informational space representation, the following assumptions are introduced:

- on the axis a and b the agents are displayed discretely;
- the axes of the sender and receiver agents are limited by a_n-th agent, where n is the ID number of the last agent in the system, and the identifier has the highest value;
- the time is a discrete value;
- the time value $t = 0$ is the initial system operation time moment;
- the transmission time tends to zero, $t_{transmission \to 0}$, therefore the time of sending and the time of informational message receiving are considered as equal: $t_{send} = t_{receive}$.

These assumptions allow finding any transmitted message in case of the known time of its transmission and the IDs of the sender or receiver agent. Types of informational messages are introduced below.

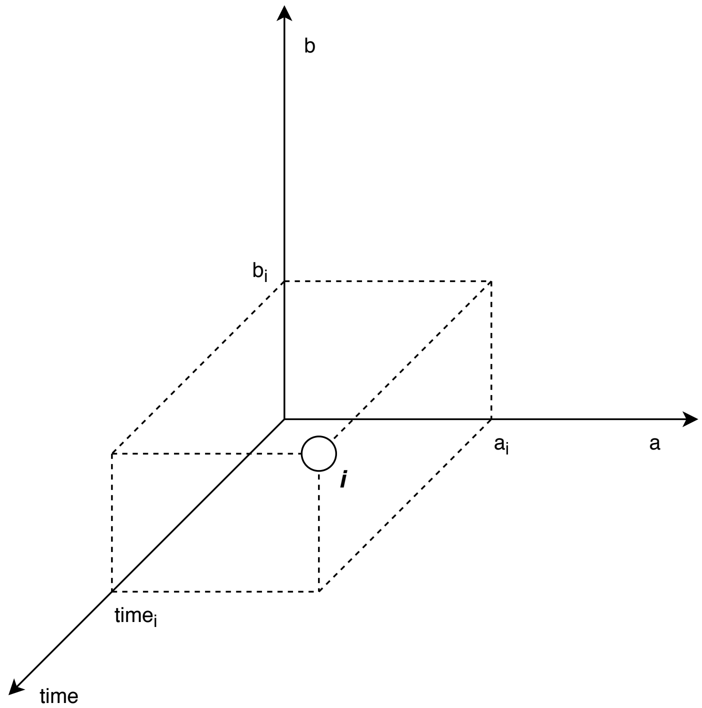

Figure 1: Three-dimensional representation of the Informational Space.

- $b = a_{sender}$. In this case, the agent sent the message to itself. The type of the mes-sage is "the agent's own message", it can be a report of the accomplished work. The set of these messages is represented as I_{own};
- $b \in [1, a_{sender} - 1] \cup [a_{sender} + 1, n]$. The messages of this type indicate interactions between agents a and b. The set of the messages passed between agents a and b is described as $I_{interaction}$;
- $b = a_n$. These messages are broadcasted to all agents since this identifier value is an all instruction. All the agents with $q_k \geq d$ have access to such messages. These messages are defined by the set I_{all}.

At the same time, only the sender and the receiver agents, whose identifiers are specified when sending the message, have access to this informational message. Agents should have the minimum required access level of q. This requirement was described earlier.

Informational space is considered as a set of informational messages' subsets, grouped by messages current position following the specified identifier of the receiver agent, and can be described by equation (1).

$$I = I_{all} \cup I_{interactions} \cup I_{own} \tag{1}$$

The visualization of the informational space in this form is presented in Fig. 2.

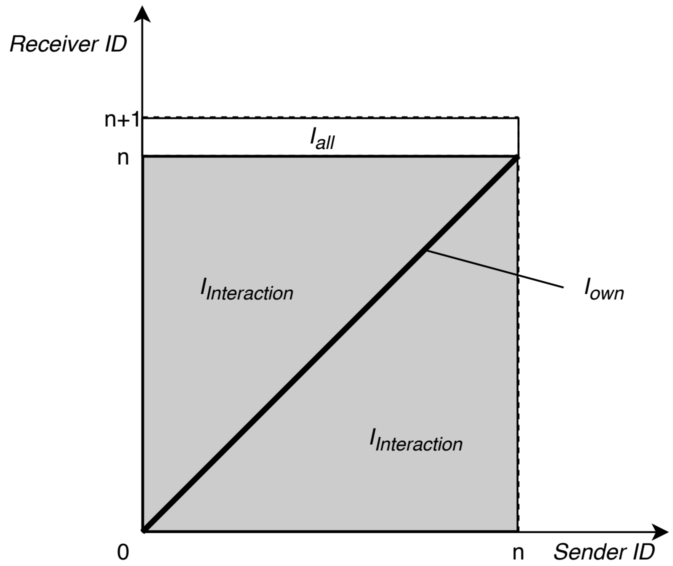

Figure 2: Two-dimensional representation of the Informational Space.

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

Figure 3: The structure of the informational message.

3.4. The Informational Message Structure

We assume that informational message has a packet structure. The structure of the message is presented in Figure 3. The message frame is divided into fields, each of them carries a certain type of data about agents and the message itself. The fields are described as follows:

1. "a" is the ID of the sender agent;
2. "b" is the ID of the receiver agent;
3. "d" is the access parameter of the message;
4. "$time$" is the message sending time. According to the introduced assumption, the time of sending and the time of receiving a message are considered equal;
5. "$type$" is the informational message type. The field contains the information on a subset to which the message belongs (according to equation (1));
6. "$info$" is the informational message content;
7. "DS" is the sender agent digital signature, used as a basic measure to ensure data dissemination process security.

4. Simulation

4.1. Simulator Description

To model the informational interaction between agents in a Smart Factory we developed a custom software simulator using Python 3 programming language and the IDE PyCharm Edu 2019.3.2 environment. Python was chosen as the main tool by the reason that it provides free public libraries for developing function-oriented programs, working with different file formats, and allows to obtain and analyze statistics. As the basis, *csv – File Reading and writing* and *matplotlib* libraries were used. The first one allows to parse *.csv format files and modify it, the second was used to generate statistical plots. All basic operations conducted in the informational space were described by particular functions.

All agents introduced in Section 3 are described by csv-format strings. The first field contains the agent's ID, the second - agent's access level. The informational space is also presented as a csv-format file, where each string is a particular informational message that consists of the field described in Subsection 3.4. The realization of an agents' list and the informational space is conditioned by the need to have the access to the concrete fields and the easy use of the *.csv format.

As the Python language uses Global Interpreter Lock (GIL) and allows the only thread to manage the Python interpreter, it is impossible to implement a multi-thread paradigm. To overcome this limitation, we developed a simulator of information interaction as the console program providing the interface to perform informational space operations on behalf of the Smart Factory agents during an infinite main cycle.

4.2. Available actions in the simulator

The developed simulator provides the following functions:

- To transmit the informational message from agent a to agent b. Sender and receiver IDs and the message access parameter have to be entered manually. Otherwise, *auto* mode can be chosen. The program writes the message to the related csv-format file.
- Message generation. A particular number of messages can be generated manually (with randomly chosen agents' IDs and the content) and written to the informational space.
- Message search. The message search with the use of known interacted agents' IDs and the time when the message was sent can be performed manually. In this case, the condition when the access level must be higher than the access parameter is not considered, as we assume that this action is performed manually.

It is also possible to perform operations from the side of the agent directly. The operator needs to call the corresponding function and choose an ID of the desired agent. The following functions are accessible in this mode:

- reading chosen messages. This option is similar to "Message search" function described earlier, but the access condition is mandatory. In this case, the agent does not have access rights to the message, and cannot read it;

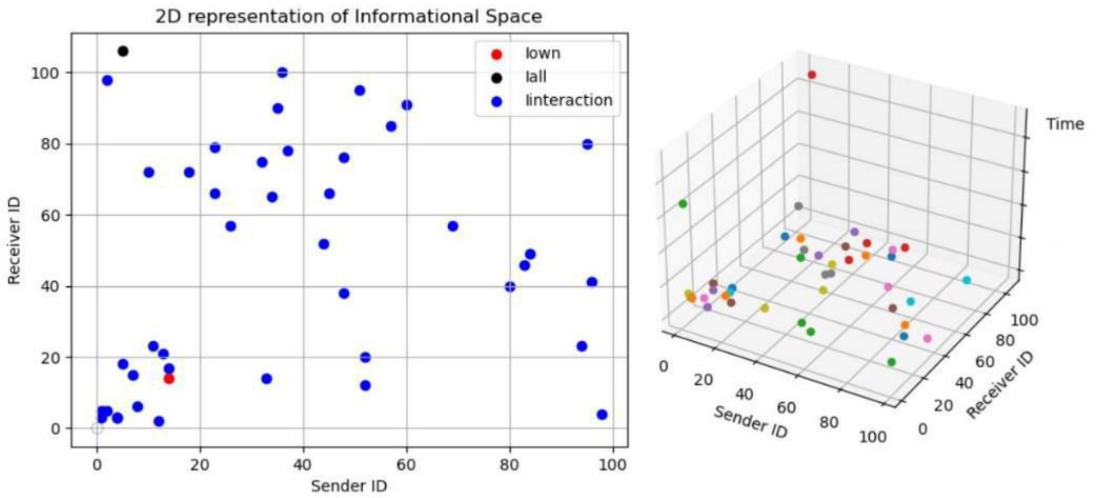

Figure 4: The two- and three-dimensional representations of the informational spaces generated by the simulator.

- send a message. This function is similar to the function described earlier.

The scalability of the system is provided by a function that adds new agents with the chosen access level. The added agent and its access level are written to the csv-file. Statistics and plots generating functions include the possibility of building two- and three-dimensional spaces. An example of plots generated by these functions is illustrated in Fig. 4.

In the current moment, the mechanism of a digital signature is not yet implemented in the simulator. The main difficulty of the implementation is to develop the mechanism for storing private and public keys and their use by the agents.

4.3. Results

The developed simulator demo-test showed that the model described in Section 3 is viable, and it is possible to implement it in production systems or digital twins of Smart Factory. The proposed interaction model provides basic measures to protect data and increase the information security level. The accuracy and efficiency of the model have not verified yet, as in this paper we were focused on the models' formalization and demonstration of their implementation in a software simulation environment possibility. In the next step, we will outline efficiency and security metrics, provide experiments design, and conduct an empirical study to assess the proposed mechanisms via a developed software simulator.

5. Conclusion

The Smart Factory is considered to be a vital part of Industry 4.0 development and evolution. At the current moment, it is treated as a fully autonomous and self-organized manufacturing system that aimed to reduce the human factor influence on the production process. It brings a wide list of topics to be discussed. The rapid development of the Smart Factory concept arises the need to provide safe and secure interaction among system elements. To address this issue, in the present paper we proposed an informational space concept that allows implementing our developed model of the informational messages for communication among Smart Factory elements. The informational interaction custom software simulator was developed, the results showed that the presented interaction concept is viable and can be implemented in practice.

In further work, we plan to analyze simulation results on communication speed and security and assess the approach information security aspects.

Acknowledgments

This paper is supported by the Government of Russian Federation (grant 08-08).

References

[1] R. Burke, A. Mussomeli, S. Laaper, M. Hartigan, B. Sniderman, The smart factory-responsive, adaptive, connected manufacturing. deloitte insights, 2017.

[2] R. Rajkumar, I. Lee, L. Sha, J. Stankovic, Cyber-physical systems: the next computing revolution, in: Design automation conference, IEEE, 2010, pp. 731–736.

[3] B. Pozdneev, M. Sutyagin, I. Kupriyanenko, V. Tikhomirova, A. Levchenko, New horizons of standardization in the age of digital education and manufacturing, Vestn. Mosk. Gos. Tekhnol. Univ., Stankin (2015) 35.

[4] S. Wang, J. Wan, D. Zhang, D. Li, C. Zhang, Towards smart factory for industry 4.0: a self-organized multi-agent system with big data based feedback and coordination, Computer Networks 101 (2016) 158–168.

[5] R. Harrison, D. Vera, B. Ahmad, Engineering the smart factory, Chinese Journal of Mechanical Engineering 29 (2016) 1046–1051.

[6] A. Chehri, G. Jeon, Routing protocol in the industrial internet of things for smart factory monitoring, in: Innovation in Medicine and Healthcare Systems, and Multimedia, Springer, 2019, pp. 505–515.

[7] J. Jang, E.-J. Kim, Survey on industrial wireless network technologies for smart factory, Journal of Platform Technology 4 (2016) 3–10.