System Architecture Analysis with Network Index in MBSE Approach -Application to Smart Interactive Service with Digital Health Modeling-

Toshiya Kaihara, Nobutada Fujii, Daisuke Kokuryo, Mizuki Harada

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Toshiya Kaihara, Nobutada Fujii, Daisuke Kokuryo, and Mizuki Harada

Graduate School of System Informatics, Kobe University,
1-1 Rokkodai-Cho, Nada, Kobe, Hyogo 657-8501, Japan
kaihara@kobe-u.ac.jp, nfujii@phoenix.kobe-u.ac.jp,
kokuryo@port.kobe-u.ac.jp, mizuki@kaede.cs.kobe-u.ac.jp

Abstract. In recent years, systems have become large scale and complex due to the development of Internet of Things(IoT). Therefore, it becomes difficult to understand the influence of component specification changes that occur during the system development stage. Thus we focus on Model-Based Systems Engineering(MBSE), which is capable of expressing hierarchical structure and overviewing information. In this paper, we propose a method for analyzing the influence on the smart interactive service with digital health modeling caused by changes in system elements using index of network theory. As a conclusion, we clarified the degree of influence on the whole system caused by changing the specification of each component with using eigenvector centrality, which is one of the network indices.

Keywords: Model-Based Systems Engineering(MBSE) · SysML · network theory · architecture analysis

1 Introduction

In recent years, the realization of Cyber Physical Systems(CPS) accompanying the development of Internet of Things(IoT) technology has increased the number of systems connecting between different fields. As a result, the scale and complexity of the system are even more problematic than before. In the development stage of a system, the specifications of components in the system change due to factors such as changes in the business environment and system environment, mistakes and changes in the definition of requirements. In addition, the specification change influences not only the target component but also the components related to the target. Then, it cause frequent revise processes, which greatly influence the cost and schedule of the whole system development[1]. As

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a result, it is necessary to analyze the influence by considering the propagation range of the influence due to the change of system specification. In order to consider the range of influence propagation, it is important to clearly understand the relationships and effects in large scale and complex systems. We focused on Model-Based Systems Engineering(MBSE), which has features such as the ability to represent the hierarchical structure of systems and explain multiple causal relationships[2]. MBSE is an approach that focuses on the creation and utilization of models, and achieves tha overall optimization of the system, taking into account the diverse values that span multiple disciplines. There is an approach similar to MBSE called Model Driven Architecture (MDA). MDA is an approach to design, development, and implementation in software development using graphical models. And it focuses on the transformation of the model[3]. The common point with MBSE is to use a model. On the other hand, MDA is an approach mainly considered for software, and is not suitable for use at a high abstraction stage including software and hardware. Therefore we use MBSE rather than MDA.

There are related work of change influence analysis. First, there is a scenario-based software architecture modifiability analysis method called Architecture-Level Modifiability Analysis(ALMA)[4]. They define a change scenario for software, rank the impact of the scenario on a five-level scale, and interpret the results to gain strength against changes in the software architecture. Second, there is also an Enterprise Architecture Modifiablity Analysis Method (EA-MAM) as a method for scenario-based changeability evaluation for enterprise architectures[5]. This was considered as an adaptation of Software Architecture Analysis Method (SAAM) to enterprise architecture. As for the influence analysis of changes related to model-based systems engineering, change propagation prediction using design structure matrix (DSM) exists[6]. By using DSM, it is possible to identify the relevant component for the case of change. As described above, there are few studies that evaluate the degree of influence of the element change of each element of the system on the system architecture including software and hardware.

In this paper, we propose a method for analyzing the influence on the smart interactive service with digital health modeling caused by changes in system elements using eigenvector centrality, one of the network indices.

2 Target System

In this paper, we target the smart interactive service with digital health modeling, one of the projects of JST-Mirai Program[7]. In order to reduce medical and nursing care costs in hyperaging society, it is necessary to provide services to manage health and exercise for each individual. The smart interactive service with digital health modeling aims to realize an innovative multi-side platform type smart interactive service that provides quantification of health degree by modeling health, behavioral change based on disease prediction and individual optimal exercise and lifestyle prescription. Fig. 1 shows a conceptual diagram of smart interactive service with digital health modeling.

The smart interactive service with digital health modeling consists of the following subsystems.

- **Digital dummy system**
  System that simulates the operation of each system using a digital body model that is completely personalized for each user
- **Home health care system**
  System that maintains and improves user health in households by proposing livingfitness designed as exercises with daily activities based on motion simulations of user activities using digital body model
- **Health checkup and Physical fitness diagnosis system**
  System that maintains and improves user health by cosulting exercise, meal and sleep based on medical checkup and physical fitness diagnosis informations
- **Care welfare system**
  System that maintains and improves user health by navigating usage settings suitable for user based on simulations of usage situation of nursing care equipment using digital body model
- **Smart sports service system**
  System that maintains and improves user health by advising support suitable for user, such as assisting sports, correcting forms, and training care using digital body model
- **Digital Smart Factory**
  Factory that operates mass customization of various products such as sports products, nursing care equipment, and health-related equipment that are completely customized for each user by using digital body model

In this paper, we target Home health care system, a subsystem of smart interactive service with digital health modeling, for modification influence analysis.

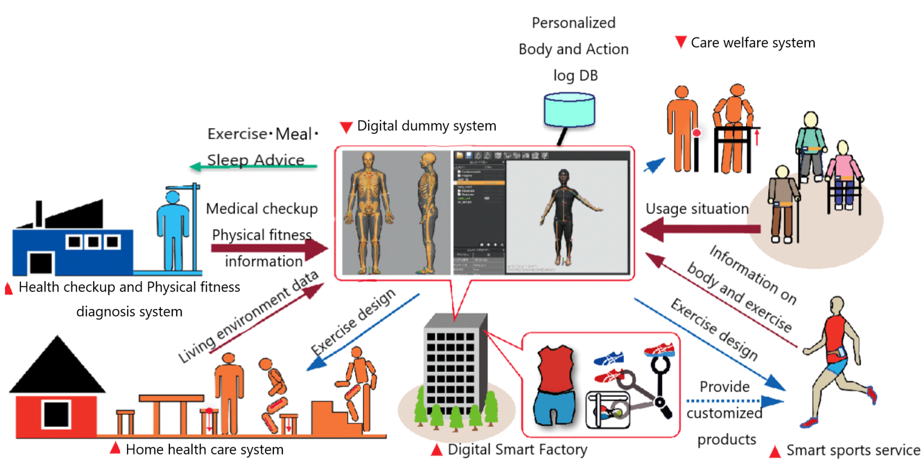

Fig. 1. Smart interactive service with digital health modeling

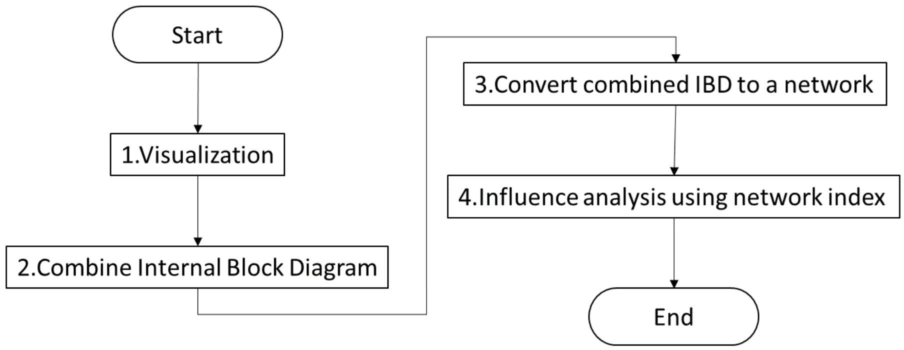

Fig. 2. Flowchart for influence analysis

3 Proposed Influence Analysis Method

We propose a method to analyze the influence of changing system elements of a system with complicated system specifications. Modifying a system element influences other elements that connect to it. In other words, it is necessary to clarify the connection relations of system elements and then perform influence analysis using the connection relations. Therefore, the connection relationship of system elements is clarified by visualizing the system specifications based on the idea of MBSE. At that time, the connection relationship between the systems is clarified by using an Internal Block Diagram (IBD) which is a diagram of the System Modeling Language (SysML). SysML is a general-purpose graphical modeling language that supports the analysis, specification, design, verification, and validation of complex systems[8]. IBD is a diagram that describes the interconnection among the parts of a block that is a component of the system and represents the internal structure of the block. Then, in the analysis of influence, eigenvector centrality, which is one of the indices of network theory, is used in order to consider an index that can consider the chain of changes such as the change caused by the influences of changes. In order to use the index, the connection relation between the systems shown in IBD is converted into a network. Fig. 2 shows a flowchart for influence analysis.

3.1 Step1: Visualization

The system specifications of the target system are visualized based on the dual vee model in Systems Engineering using SysML diagrams. Dual vee model is composed of “architecture vee” which represents the decomposition of the target system and “entity vee” which represents the development process of the system elements. It uses Use case diagram, Sequence diagram, Block definition diagram, Internal block diagram and Requirement diagram, which belong to SysML diagrams. As a result, the relationship between the operation scenario of the system and the external system, the required functions, the components that realize the functions, the relationships among the components, and the requirements of the system are clarified.

3.2 Step2: Combine Internal Block Diagram

In Sect. 3.1, an IBD is created for each subsystem. In the influence analysis, it is necessary to consider the influence of the change based on the relationship of the whole system. Therefore, the IBD created for each subsystem are combined to create one combined internal block diagram representing the entire target system.

3.3 Step3: Convert combined IBD to a network

We convert the combined internal block diagram created in Sect. 3.2 to a network structure. The part in the combined internal block diagram is converted into a node in the network, and the connector path is converted into an edge. If there is a connector path to the external system of the target system, the external system is also a node. A part is an element that constitutes a system, and a connecter path is a line that indicates the existence of an interaction between two connected parts. Therefore, the network created in this section represents the relationships between the components of the system.

3.4 Step4: Influence analysis using network index

The network created in Sect. 3.3 is analyzed using network indices. In this paper, we focus on eigenvector centrality among network indices. Since the centrality of eigenvectors takes into account the centrality of adjacent nodes, we believe that it is possible to take into account the chain of changes, such as the secondary changes created by the influence of changes.

Eigenvector centrality Eigenvector centrality is an index that increases the centrality of nodes connected to nodes of higher degree[9].

$$C_{ev}(i) = \frac{1}{\lambda}\sum_{j=1}^{n} a_{ij} C_{ev}(j) \tag{1}$$

$$C^{*}_{ev}(i) = \frac{C_{ev}(i)}{\max\{C_{ev}(k)\}, (k = 1, 2, \cdots, N)} \tag{2}$$

- $C_{ev}(i)$: Eigenvector centrality of node i
- $C^{*}_{ev}(i)$: Normalized eigenvector centrality of node i
- a_{ij} : Components of the adjacency matrix $\mathbf{A}$ of the network
- λ : Maximum eigenvalue of adjacency matrix $\mathbf{A}$
- n : Total number of nodes in network $(n = 1, 2, \cdots N)$

4 Result of Influence Analysis

According to the flowchart shown in Fig. 2, we analyze the influence of changing the components of the home health care system. In this paper, we show the network obtained in Step3 in Fig.3 and the result of the influence analysis of Step4 in Table 2.

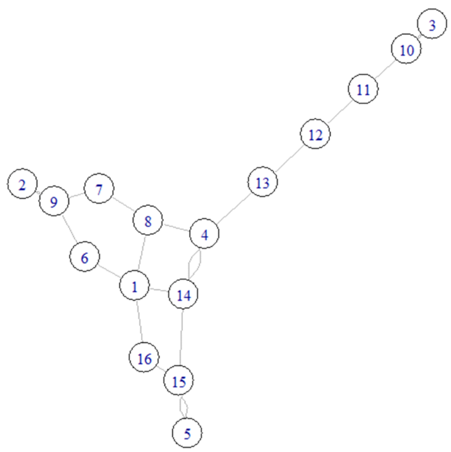

Fig. 3. Network

Table 1. Node name

Label	Name
1	Terminal
2	Living environment
3	User
4	Database
5	Digital dummy system
6	Sensor identification unit
7	Spatial recognition unit
8	Furniture detection unit
9	Near infrared camera
10	Visible light camera
11	Skeletal estimation unit
12	Motion classification unit
13	Personal identification unit
14	Calculation exercise unit
15	Creation exercise unit
16	Optimisation unit

Fig. 3 is a network obtained by converting the combined internal block diagram of the target system. Table 1 shows the relationship between node labels and names of system compornents before conversion. Ternimal, Living environment, User, Database, Digital dummy system of label 1 to label 5 in Table 1 are external systems of the target system. We calculated the centrality of the eigenvectors of all nodes in the network shown in Fig. 3, and analyzed the influence of changing the components of the system. Table 2 shows the calculation results of eigenvector centrality. The eigenvector centrality is normalized to a maximum value of 1. From Table 2, the node with the higtest eigenvector centrality is node 14, which is Calculation exercise unit. The degree of node 14 is 4, which is large in this network. Similarly, the degree of the node connected to node 14 is also 4. From these facts, it was confirmed that the eigenvector centrality became large. Calculation exercise unit(node 14) is a unit that calculates the amount of exercise required to maintain the user's health. If you change the data used to calculate in the Calculation exercise unit, the Database(node 4) which is the data storage must be influenced. Similarly, the Personal identification unit(node 13) and the Motion classification unit(node 12) could be influenced because they are data acquisition units. A change is also required for the Creation exercise unit(node 15), which uses the calculated amount of exercise. Thus, it is considered that the change of the node having the large eigenvector centrality such as the node 14 has a large influence on other nodes.

Table 2. Eigenvector centrality

Node	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Degree	4	2	2	4	2	2	2	3	4	3	2	2	2	4	4	2
C^*_{ev}	0.725	0.181	0.012	0.894	0.447	0.314	0.271	0.584	0.292	0.020	0.039	0.108	0.310	1.000	0.724	0.448

5 Conclusion

In this paper, we analyzed the influence of changing system elements using the network in MBSE for the smart interactive service with digital health modeling. By converting IBD of SysML into a network and using the eigenvector centrality, the degree of influence on the entire system due to component change for each system compornent could be clarified. As a result, it becomes possible to identify the system elements at an early stage, for which the cost of modification will increase. It can also used to verify the strength of changes to system specifications.

In future work, it is necessary to analyze not only the connection relation of the system but also various factors by using the relation of other diagrams of SysML.

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