A Similarity-Ranking Method on Semantic Computing for Providing Information-Services in Station-Concierge System

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Abstract

The prevalence of smartphones and wireless broadband networks have been progressing as a new Railway infomration environment. According to the spread of such devices and information technology, various types of information can be obtained from databases connected to the Internet. One scenario of obtaining such a wide variety of information resources is in the phase of user's transportation. This paper proposes an information provision system, named the Station Concierge System that matches the situation and intention of passengers. The purpose of this system is to estimate the needs of passengers like station staff or hotel concierge and to provide information resources that satisfy user's expectations dynamically. The most important module of the system is constructed based on a new information ranking method for passenger intention prediction and service recommendation. This method has three main features, which are (1) projecting a user to semantic vector space by using her current context, (2) predicting the intention of a user based on selecting a semantic vector subspace, and (3) ranking the services by a descending order of relevant scores to the user' intention. By comparing the predicted results of our method with those of two straightforward computation methods, the experimental studies show the effectiveness and efficiency of the proposed method. Using this system, users can obtain transit information and service map that dynamically matches their context.

Keywords: Context Awareness, Semantic Computing, Semantic Associative Search, Information Retrieval, Cyber-Physical system.

1. INTRODUCTION

The prevalence of smartphones and wireless broadband networks have been progressing as a new Railway infomration environment. According to the spread of such devices and information technology, various types of information can be obtained from databases connected to the Internet. One scenario of obtaining such a wide variety of information is when the users use transportation [1]. In general, information that passengers need are transfer guides, facility information, and tourist information, etc. but they are separately provided and managed by each service provider. Thus, passengers must look for information from each service provider contents and summarize/merge them. Obviously, this is a challenge in enhancing the convenience of transportation service [2]. One additional aspect to the challenge is the wide spreading diversity of passengers with increasing number of them needed special care such as tourists, baby carriage users, handicapped people, etc. and their respective demands. To address these challenges, JR East has provided smartphone users with the smartphone app "JR East App" [3] and has studied information services that reflect the needs of individual passengers by interactive communication [4]. With the available of information providing systems such as the JR East app, passengers can more easily obtain the information. Since the display of these systems is restricted to the displayable area, their screens are created for each category of information. Thus, the passengers struggle to find the information that they need from the vast amount of information. Also, the station map has become extremely complicated and difficult to comprehend and take advantages of. Despite the huge number of facilities in the complex structure, the Tokyo station which is one of the largest terminal stations in Japan is represented by few station maps. As a result, it is difficult for passengers to immediately find the facilities and shops they want from the station map. This is a factor interfering with the comfortable use of the station. To reduce the search information load, the systems that provide passengers with only desired information is necessary. Those systems must understand the situation and intent of the passenger such as a station attendant or hotel concierge. In this paper, we propose an information provision system with the function to estimate the needs from the context of the passengers, named the Station Concierge System that matches context such as their situation and intention. This system is one of the context aware systems that can obtain passenger's context by using touch panel display, smartphone, sensors, etc. Using this system, users can obtain the information and maps that dynamically matches their changing context. We also constructed a dynamic station map generation system using the proposed function and show the experiment results.

2. RELATED WORKS

The information that satisfies the needs of individual passengers must reflect the context that represents the dynamic/static situation and dynamic/static intention of the passenger [5]. Abowd et al. [6] states that "We define context as any information that can be used to characterize the situation of an entity, where an entity can be a person, place, or physical or computational object. We define context-awareness or context-aware computing as the use of context to provide task-relevant information and/or services to a user." Many information-providing systems that reflect the user context have been studied. For example, there is a study on the smartphone application search technique by using search keywords that represent the user status. Yano et al. [7] address the location, time and history of input keywords as a context to determine the search keywords. The applied search method in this study is based on tf-idf, which is used in document retrieval. However, this method requires an enormous amount of text data which are not always available. On the other hand, there is a vector space model that represents the similarities between the user contexts and contents. This approach does not require an enormous amount of data, but its result depends on the feature to be used in the vector space. Furthermore, information retrieval is studied to reflect the context in this vector space model [8, 9]. However, the problem with this approach is the possibility that the similarity evaluation value is significantly different because cannot understand user's needs from context.

To understand user's needs from context, the vector space model determines the information depending on the context [10]. In this method, the similarity of the information dynamically changes with the context of the user for the vector subspace selection. Hence, this method can have the higher ranking of information that matches the needs of the individual passenger, and the other can have a lower rank.

3. Information-ranking method

In this section, we present a new information-ranking method with the function to estimate the needs from the context of the individual passengers. Several information retrieval methods, such a straightforward method (vector space model) and SVD (Singular Value Decomposition), have been proposed. The essential difference is that our method provides the important function for semantic projections, which realizes the dynamic recognition of user's needs from their context. The mathematical model of meaning (MMM) [10] was proposed as the machinary with a function of semantic projection, and our method is applying the MMM to similarity calculations between user's contexts and services in railway-stations. Our method can dynamically change the information ranking according to the user's needs estimated using the user context. The user's needs are represented by a vector subspace determined according to the context. Originality of this research is

to realize the cyber physical system [11,12] in which the real space and the information space cooperate as follows.

- Based on information acquired from smartphones and sensors, guidance knowledge of station staff and static / dynamic situation / intention of passengers are projected to vector space.
- Determine the subspace of the vector space that expresses needs with the context vector representing the situation and intention of the passenger.
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4. SYSTEM DESIGN

Our Station Concierge System(Figure 1) realizes the following functions:

- Collect features of the information object (Station Crew Knowledge, web page, document, etc.) from various sources of information.
- Provide semantics to the information object.
- Obtain the context element of individual passengers.
- Provide semantics to the context of individual passengers.
- Compute the distance of the semantic of the information object with the user's context.
- Display information recommendations according to the computed distance of the information object.
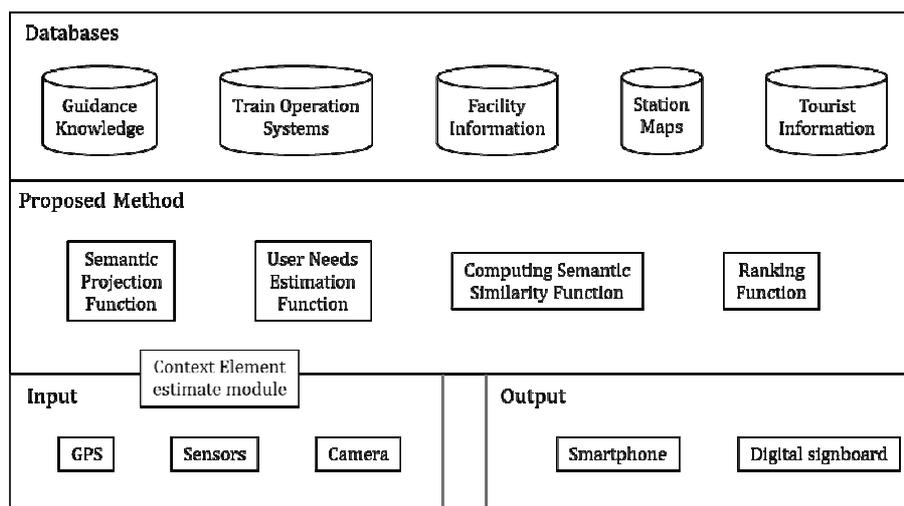
Figure 1. Over view of Station Concierge System

Our method obtains ranking the services which satisfied passengers. We classify the context of the passenger into the following four types: Static Situation (SS), Dynamic Situation (DS), Static Intention (SI), and Dynamic Intention (DI) [5]. The structure of the context is shown in Figure 2, and an example of a context is shown in Figure 3. Here, the context elements are SS_1, $\cdots$, SI_1, $\cdots$, DS_1, $\cdots$, DI_1, $\cdots$. In addition, the context is a set of context elements. The procedure of our method is shown in Figure 4.

	Situation	Intention
Static	$SS_1, \cdots$	$SI_1, \cdots$
Dynamic	$DS_1, \cdots$	$DI_1, \cdots$

Figure 2. Structure of a context

	Situation	Intention
Static	Age, Sex, Etc.	Hobby, Etc.
Dynamic	Time, Location, Etc.	Aim, Demand, Etc.

Figure 3. Example of a context
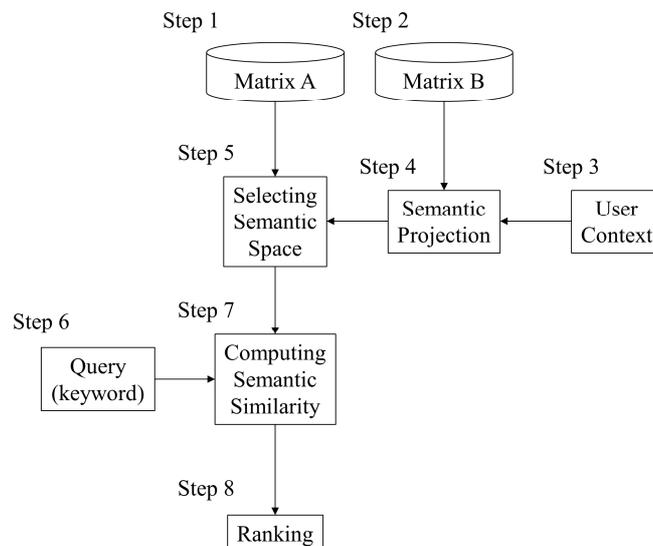
Figure 4. Procedure of the proposed method

4.1 Step 1: Providing Matrix *A* (semantic Space *M*)

Matrix *A* is provided as follows:

A set of ℓ station facility items (e.g., ticket counter, travel center, etc.) and m features that are used in the field of passenger service (e.g., station office, tourist office, etc.) is provided in the form of an $\ell \times$ m matrix *A* (Figure 5). In this example, the matrix represents several facilities that are used in the field of transportation. These facilities are characterized using fourteen features. If the facility provides the service, the matrix element is 1;

otherwise, it is 0. The facilities and features are shown in Table 1 and Table 2. Through this step, the vector space of station staff guidance knowledge is constructed.
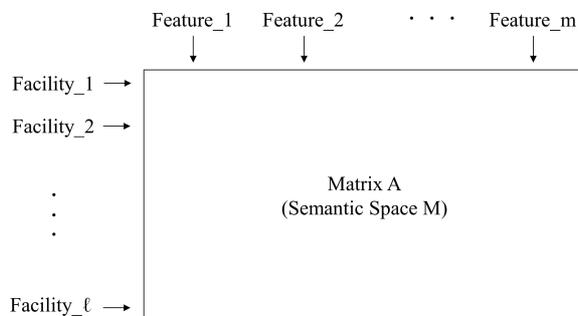
Figure 5. Structure of Matrix *A*

Table 1. Abbreviations of Facilities

Abbreviation	Facility
F1	Midori-No-Madoguchi (JR Ticket Office)
F2	View Plaza (Travel Center)
F3	Fare adjustment machine
F4	Ticket vending machine
F5	Ticket reserve machine (Shinkansen)
F6	Eki-Rent-A-Car (Car rental)
F7	Information Center
F8	ViewALTTE (ATM)
F9	VIEW GOLD LOUNGE (lounge)
F10	Ginnosuzu (Meeting Point)
F11	Waiting Room
F12	Nursing room
F13	View Square (Rest area)
F14	Taxi Stop
F15	Bus Stop
F16	Travel Service Center
F17	Hotel
F18	Wheelchair waiting area
F19	Dourin-Hiroba (Meeting Point)

Table 2. Abbreviations of Feature

Abbreviation	Feature
S1	Station office
S2	Bus
S3	Taxi
S4	Tourist office
S5	Convenience store
S6	ATM (Automatic Teller Machine)
S7	Credit card service
S8	Car rental
S9	Hotel
S10	Restaurant
S11	Bar
S12	Café
S13	Park
S14	Travel agency

We define the semantic space *M* as the span of the features in Table 2. This matrix expresses the space formed by the axes that represent the presence or absence of the service. Therefore, the facilities are represented as a vector of the semantic space *M* (Figure 6).
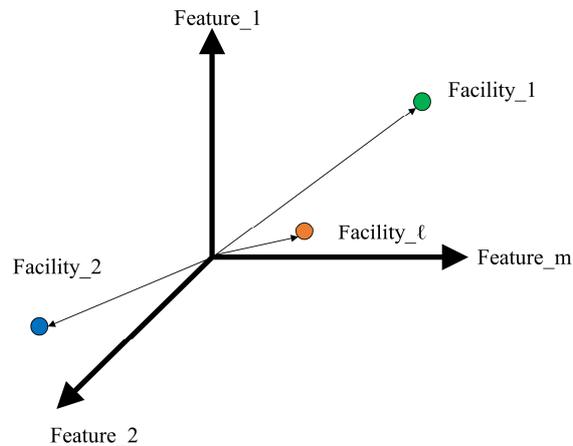
Figure 6. Semantic space *M*

4.2 Step 2: Providing Matrix *B*

Matrix *B* is provided as follows:

A set of m features and n context elements is provided in the form of an m × n matrix *B* (Figure 7). In this example, the matrix represents fourteen features that are used in the field of passenger service. These features are characterized by the elements of a passenger's context. If the context element needs the service, the matric element is 1; otherwise, it is 0. The features are identical to those in Step 1 (Table 2). The elements of passenger's context and matrix *B* are shown in Table3. Through this step, the vector space of passenger is constructed.
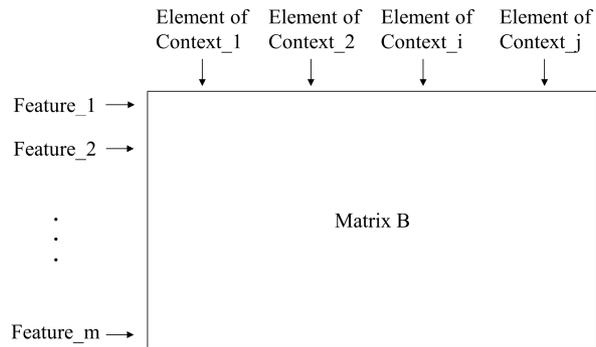
Figure 7. Structure of Matrix *B*

Table 3. Abbreviations of context elements

Abbreviation	Context element
C1	Use Tokyo as an entrance station
C2	Use an entrance station outside of Tokyo
C3	Have a commuter pass
C4	Do not have a commuter pass
C5	Use a credit card
C6	Do not use a credit card
C7	Have a high stored fare
C8	Have a low stored fare
C9	Use a mobile ticketing service
C10	Do not use a mobile ticketing service
C11	Frequent use of the Tokyo Station
C12	Infrequent use of the Tokyo Station
C13	Full age
C14	Are underage
C15	Are a worker
C16	Are not a worker

4.3 Step 3: Providing the Context

The elements of a passenger's context are provided by smartphones or wearable sensors. In addition, any elements that cannot be acquired from the user are enabled to protect the user privacy. In this paper, the context is an explicit input from the user interface, such as a button or a list in the smartphone or computer of the user.

4.4 Step 4: Semantic Projection

In this step, the context obtained in Step 3 is projected to Semantic Space *M*. In other words, this step projects passengers in physical space to cyberspace. First, we define matrix B' using the context in step 3 (Figure 8). Matrix B' is the m $\times$ n$'$ matrix; where n$'$ is the number of context elements in

step 3. Second, we compute the similarity of context vector v_{uc} and feature vector v_{feat_i} (Figure 9). v_{uc} and v_{feat_i} are given as follows:

$$v_{uc} = [x_1, \cdots, x_{n'} | \forall x = 1] \tag{1}$$

$$v_{feat\_i} \in V_{feat} = \left\{ v_{feat_i} \middle| i \in (1, \cdots, m) \right\} \tag{2}$$

$$v_{feat\_i} = [y_{i1}, \cdots, y_{ij}, \cdots, y_{in'} | i \in (1, \cdots, m), y_{ij} \in B'] \tag{3}$$
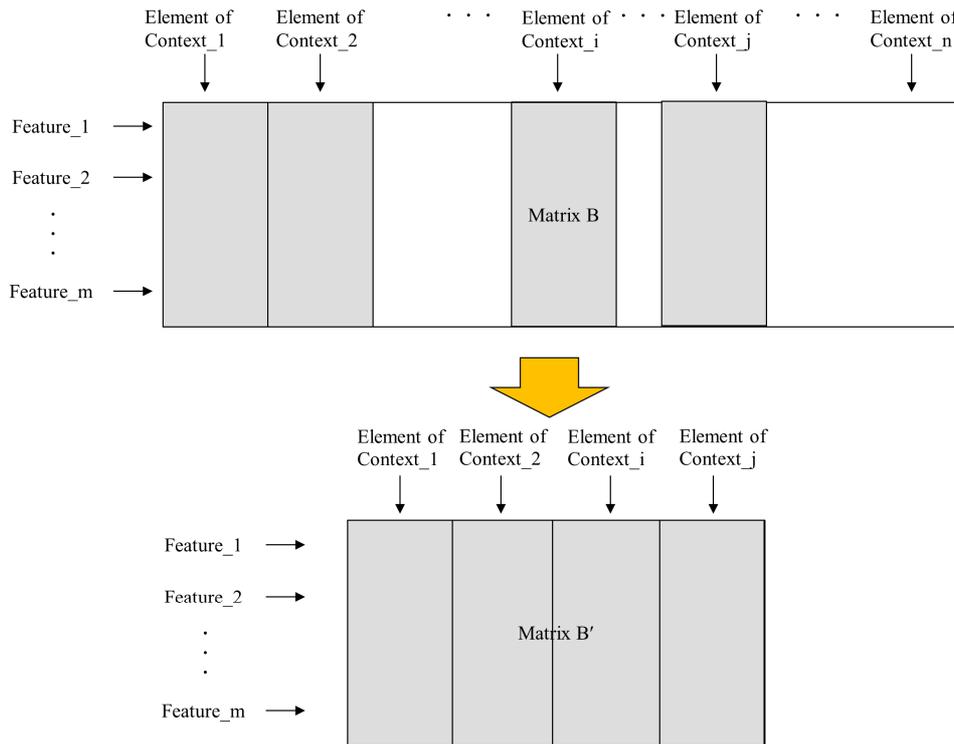
Figure 8. Structure of Matrix B′
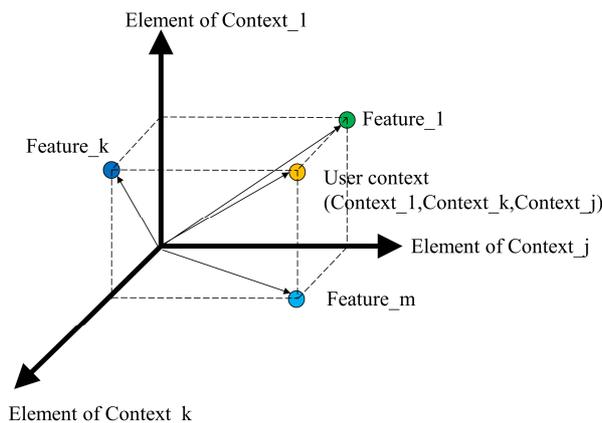
Figure 9. Similarity of the user context and features

The similarity of v_{uc} and v_{feat_i} is computed using the following equation (cosine similarity). The similarity score reflects the adaptation degree between the context and service.

$$sim_{uc \cdot feat\_i}\left(v_{uc}, v_{feat\_i}\right) = \frac{\vec{v}_{uc} \cdot \vec{v}_{feat\_i}}{|\vec{v}_{uc}| \times |\vec{v}_{feat\_i}|} \tag{4}$$

Thus, this step projects the context to a vector of Semantic Space **M** (Figure 10). We define the context vector cv as follows:

$$cv = \left\{sim_{uc \cdot feat\_1}\left(v_{uc}, v_{feat\_1}\right), \cdots, sim_{uc \cdot feat\_m}\left(v_{uc}, v_{feat\_m}\right)\right\} \tag{5}$$

$$\vec{vc} = \left\{sim_{uc \cdot feat\_1}(\vec{v}_{uc}, \vec{v}_{feat\_1}), sim_{uc \cdot feat\_k}(\vec{v}_{uc}, \vec{v}_{feat\_k}), sim_{uc \cdot feat\_m}(\vec{v}_{uc}, \vec{v}_{feat\_m})\right\}$$
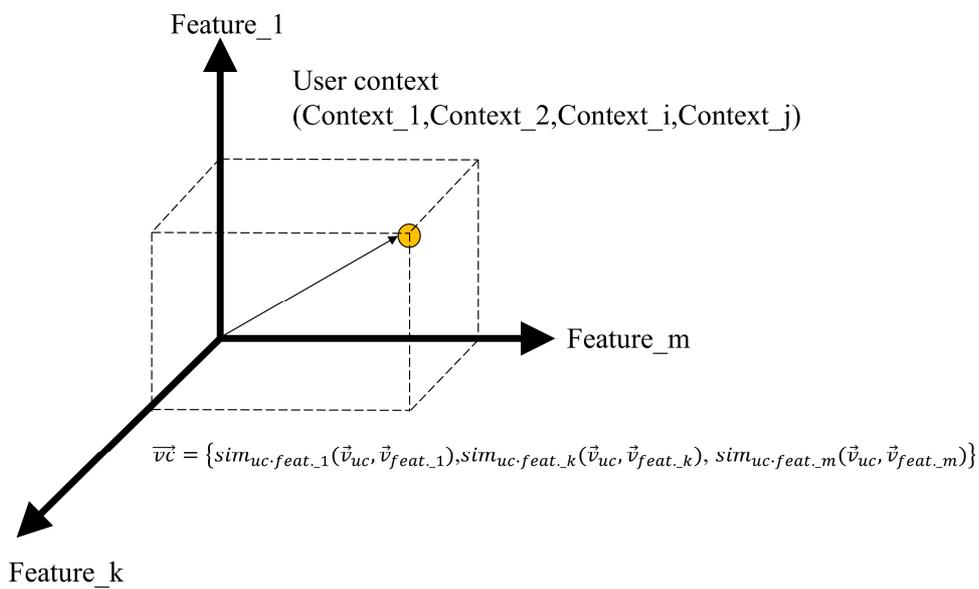
Figure 10. Context vector in Semantic Space M

4.5 Step 5: Selecting the Semantic Space

Partial space **M'** (semantic subspace) is selected by using features q_i, which are beyond similarity threshold ε to the context (Figure 11). Since this subspace is a space spanned by the axis of the service adapting to the context, this space expresses the needs of the user.

$$M' := span(q_1, q_2, \cdots q_i, \cdots, q_s) \tag{6}$$

$$where \ q_i \in Feature, sim_{uc \cdot feat\_i} \geq threshold \ \varepsilon$$

$$\vec{vc} = \{sim_{uc \cdot feat.\_1}(\vec{v}_{uc}, \vec{v}_{feat.\_1}), sim_{uc \cdot feat.\_k}(\vec{v}_{uc}, \vec{v}_{feat.\_k}), \ sim_{uc \cdot feat.\_m}(\vec{v}_{uc}, \vec{v}_{feat.\_m})\}$$

$$M' := \ span(q_1, q_2, \cdots, q_o)$$
$$where \ q_i \in Feature, sim_{uc \cdot feat.\_i} \geq threshold \ \varepsilon$$

Figure 11. Semantic subspace $\boldsymbol{M'}$
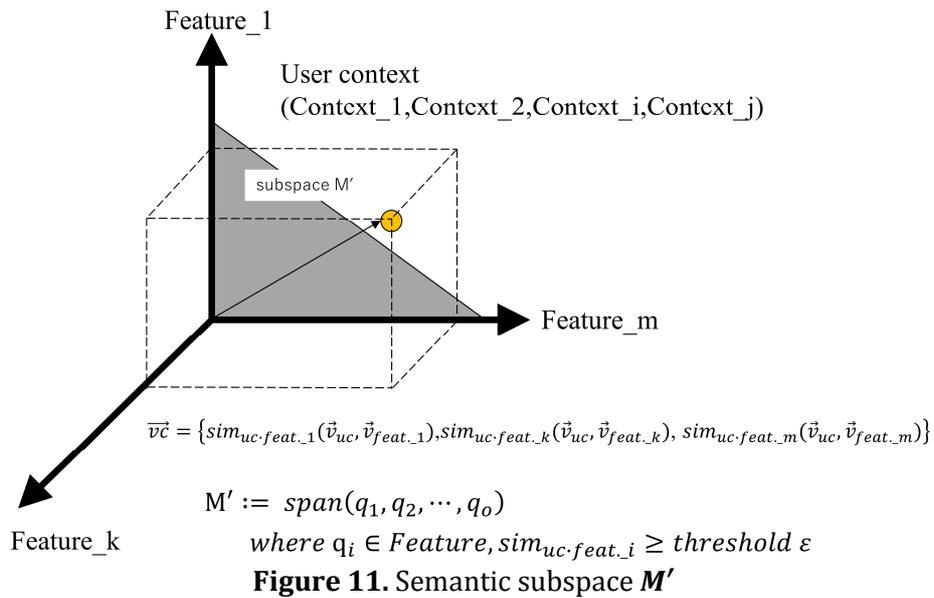
4.6 Step 6: Providing a Query (i.e., keyword)

The query is given by the user using a smartphone or other computer as a keyword of the station facility. Then, a query may be obtained using icons and checkboxes.

4.7 Step 7: Computing the Semantic Similarity

The similarity of the query vector and facility vector is computed as follows (cosine similarity) in semantic subspace $\boldsymbol{M'}$.

v_{query} and $v_{facility\_i}$ are given as follows:

$$\vec{v}_{query} \in V_{facility} = \left\{ \vec{v}_{facility\_i} \middle| i \in \{1, \cdots, l\} \right\} \tag{7}$$

$$\vec{v}_{facility\_i} = \left\{ y_{i1}, \cdots, y_{ij}, \cdots, y_{m} \middle| y_{ij} \in M' \right\} \tag{8}$$

The similarity of v_{query} and $v_{facility\_i}$ is computed as follows (cosine similarity) (Figure 12).

$$sim_{query \cdot facility_i}\left(\vec{v}_{query}, \vec{v}_{facility_i}\right) = \frac{\vec{v}_{query} \cdot \vec{v}_{facility\_i}}{|\vec{v}_{query}| \times |\vec{v}_{facility\_i}|} \tag{9}$$
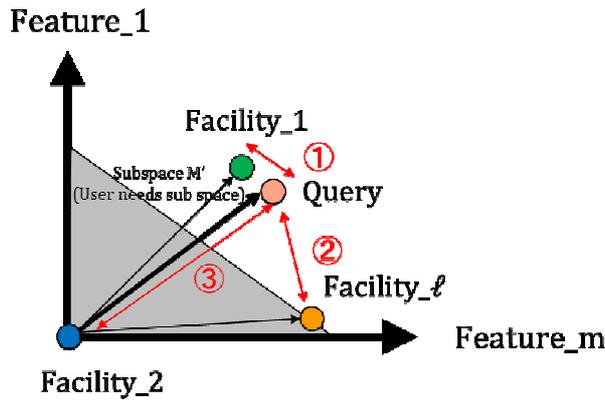
Figure 12. The degree of similarity between the facilities and the query

4.8 Step 8: Ranking

Our method ranks the facilities by the degree of similarity between the facilities and the query. The rankings are displayed on a smartphone display and information display. Figure 13 shows result display example. This example uses the station maps.

Figure 13. Visualization of a station in Display

5. EXPERIMENT AND ANALYSIS

The aim of this experiment is to confirm the change in facility rankings because of the differences in obtained context. An experimental system was implemented using Java and PostgreSQL according to the procedures in Chapter4. In addition, the context and queries were inputted from the program console. Threshold ε to select the semantic subspace was set to 0.8.

5.1 Experiment 1

This experiment aims to clearly show the difference between the existing method (straightforward computation method) and the study [8]. Figure 14 shows the computed degree of similarities in our method and the existing straightforward computation method.
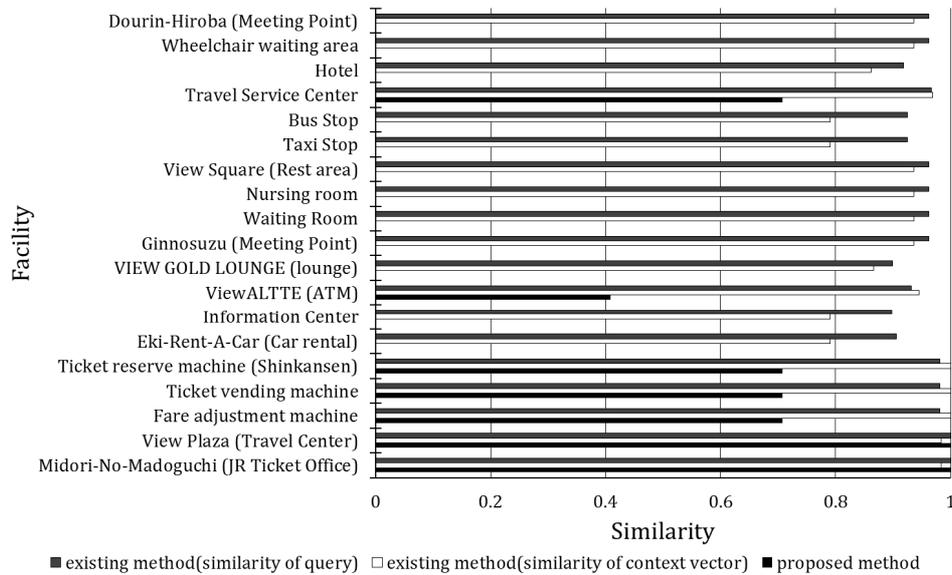
Figure 14. Degree of similarity of user's context to facilities
(Comparison of the proposed method with the existing methods)

Here, the query was set to F1: Midori-No-Madoguchi (JR Ticket Office), and the context using the proposed method was C1, C3, C5, C7, C9, C11, C13, and C15. In this experiment, the existing method (similarity of context vector) used matrix $\mathbf{C} = \mathbf{A} \times \mathbf{B}$, and the existing method (similarity of query) is using matrix $\mathbf{A}$. Here, Matrix $\mathbf{C}$ is the correlation matrix of context and facilities. (Figure 15)
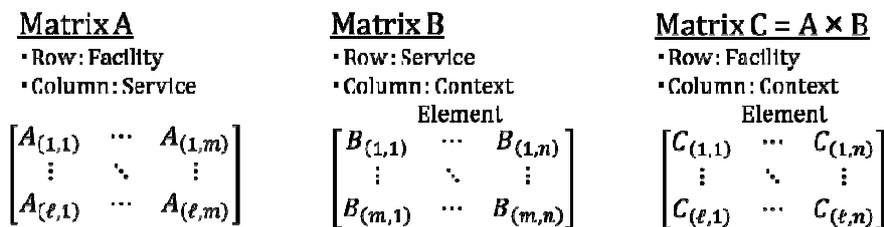
Figure 15. Definition of Matrix **A**, Matrix **B**, Matrix **C**

This experiment confirms the following hypothesis:

- The proposed method emphasizes the difference of the degree of similarity between facility and query.

5.2 Experiment 2

This experiment aims to confirm the change of the facility ranking using different queries. Here, the queries were set as follows: F1(Midori-No-Madoguchi (JR Ticket Office)), F2(View Plaza (Travel Center)), F9(VIEW GOLD LOUNGE (lounge)), F11(Waiting Room), F16(Travel Service Center) and the context was set as follows: C1, C3, C5, C7, C9, C11, C13, C15. Figure16 shows the computed degree of similarities in our proposed method. The similarities of the context vector and features are calculated as follows: S1:1.0, S2:0.79, S3:0.79, S4:0.79, S5:1.0, S6:0.87, S7:0.87, S8:0.79, S9:0.79, S10:0.87, S11:0.87, S12:0.87, S13:0.94, S14:1.0
Therefore, the result (Figure16) was obtained using a subspace spanned by S1, S5, S6, S7, S10, S11, S12, S13, and S14.
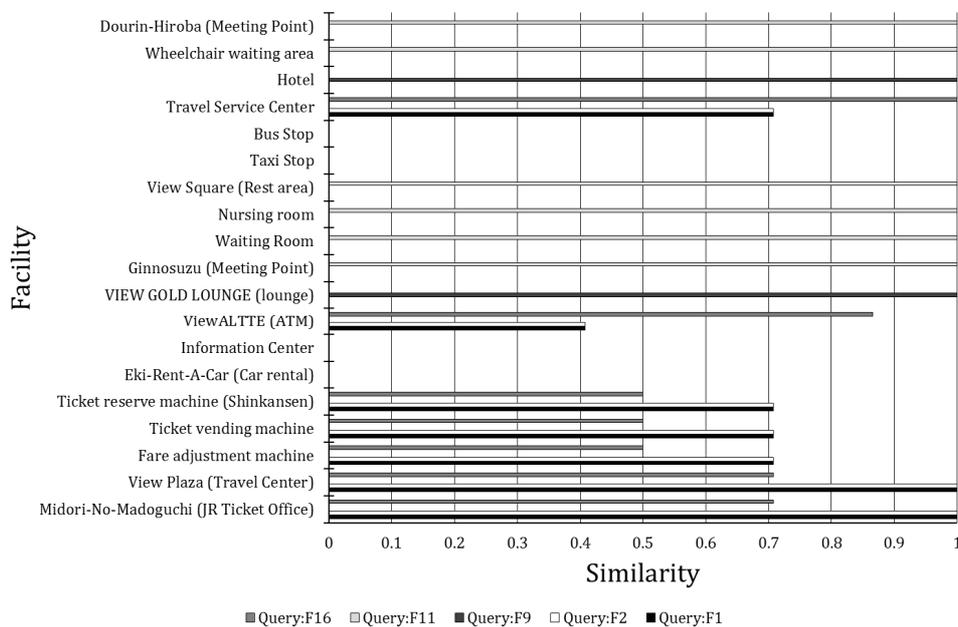
Figure 16. Degree of similarity between user's query and each facility (identical context)

This experiment confirms the following hypotheses.

- The similarity computation of the query and each facility with a selection of context is possible.
- The difference in degree of similarity is caused by the difference in query.
- The degree of similarity is identical for different queries.

The first and second results show that the search ranking may reflect the needs of the user. The third result shows that the relationship between the facility and the characteristics ($v_{facility\_i}$) remains unchanged.

5.3 Experiment 3

This experiment aims to confirm the change of the facility ranking using different contexts. Figure 17 shows the computed degree of similarities in our method. Here, the query was set to F1(Midori-No-Madoguchi(JR Ticket Office)), and the contexts were set as shown in Table 4. The similarities of the context vector and features were calculated as shown in Table 5 and Figure 18.
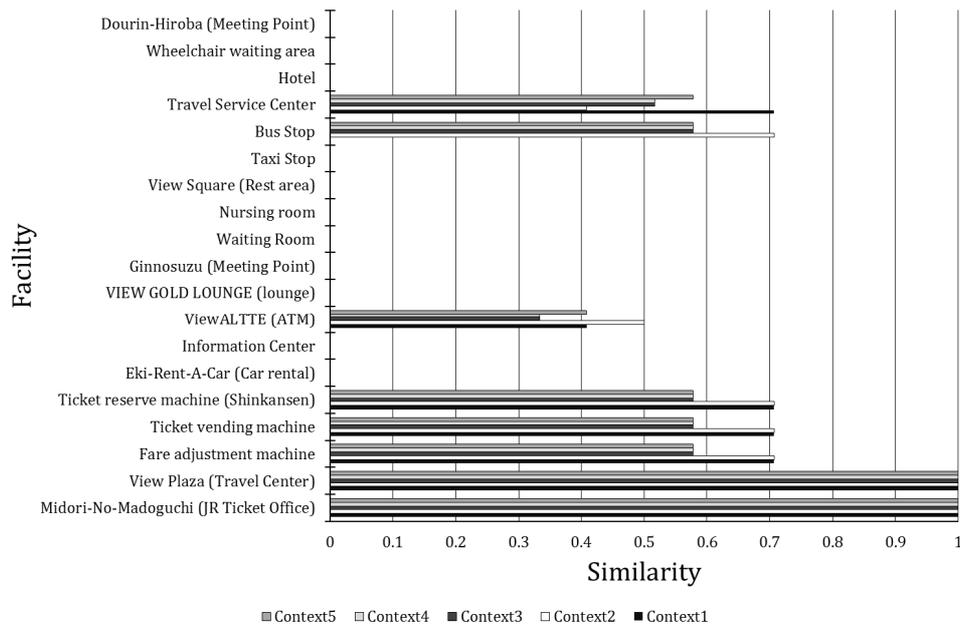
Figure 17. Degree of similarity between user's query and each facility (identical context)

Table 4. Combination of Contexts

Description of legend	Context
Context1	C1, C3, C5, C7, C9, C11, C13, C15
Context2	C2, C4, C6, C8, C10, C12, C14, C16
Context3	C13, C15
Context4	C1, C5, C8, C11, C13, C16
Context5	C1, C6, C7, C9, C13, C15

Table 5. Similarity of the context vector and features

Feature	Context1	Context2	Context3	Context4	Context5
S1	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
S2	0.79	**1.00**	**1.00**	**0.91**	**0.91**
S3	0.79	**1.00**	**1.00**	**0.91**	**0.91**
S4	0.79	**1.00**	**1.00**	**0.91**	**0.91**
S5	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
S6	**0.87**	**1.00**	**1.00**	**1.00**	**0.82**
S7	**0.87**	0.79	**1.00**	**0.91**	0.71
S8	0.79	**0.94**	**1.00**	**0.91**	**0.91**
S9	0.79	**0.94**	**1.00**	**0.91**	**0.91**
S10	**0.87**	**0.94**	**1.00**	**0.82**	**0.91**
S11	**0.87**	**0.87**	**1.00**	**0.82**	**0.91**
S12	**0.87**	**0.94**	**1.00**	**0.82**	**0.91**
S13	**0.94**	**1.00**	**1.00**	**0.91**	**1.00**
S14	**1.00**	0.61	**1.00**	**0.82**	**1.00**
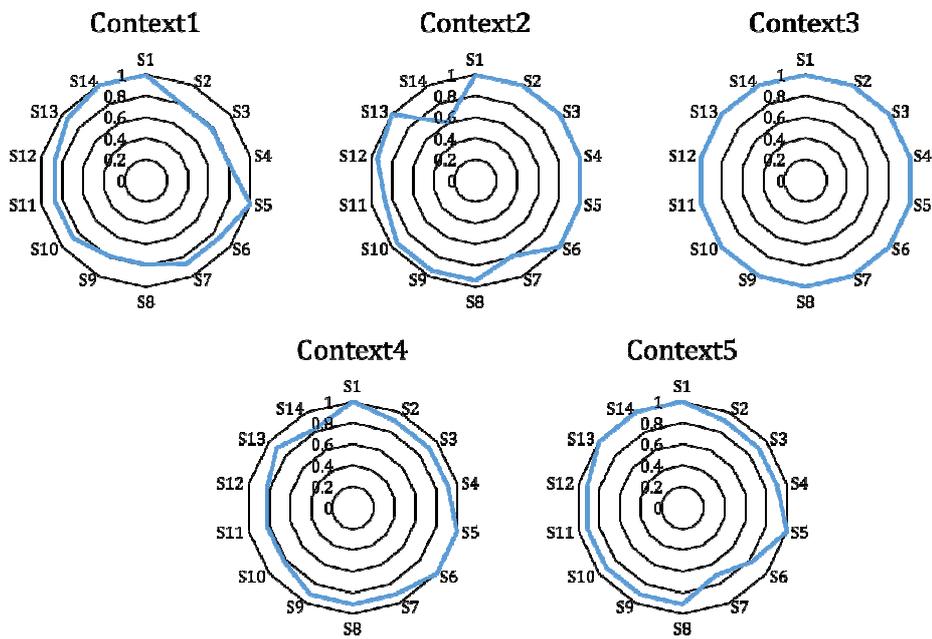
Figure 18. Similarity between the context vector and features

This experiment confirms the following hypotheses.

- The selected subspace changes with the difference in change of context.
- If there is no acquired context, the degree of similarity can still be calculated.
- With different contexts, different degrees of similarity are computed for each facility in the same query.
- Although differences in similarity may not appear with different contexts, differences may appear.

Similarly to Experiment 2, the first, second and third results show that the search ranking may reflect the needs of the user. The fourth result shows that the relationship between the facility and the characteristics ($v_{facility\_i}$) is unchanged although the context changes. When the cosine similarity of the semantic subspace was high, the degree of similarity of the query and facility in different contexts was almost the same. When the cosine similarity of the semantic subspace was not high, Degree of similarity of the query and facility in different contexts was somewhat lower(Table 6, Figure 19). However, as a result of calculating correlation coefficients between Similarity between Semantic subspaces and similarity between the facilities and the query, it was inferred that there is a strong correlation (Correlation coefficient: 0.971540686, n = 10).

Table 6. Semantic Subspace

Semantic Subspace	Axis of the Semantic Subspace (1:Selected axis, 0:Not Selected axis)													
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
Context1	1	0	0	0	1	1	1	0	0	1	1	1	1	1
Context2	1	1	1	1	1	1	0	1	1	1	1	1	1	0
Context3	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Context4	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Context5	1	1	1	1	1	1	0	1	1	1	1	1	1	1
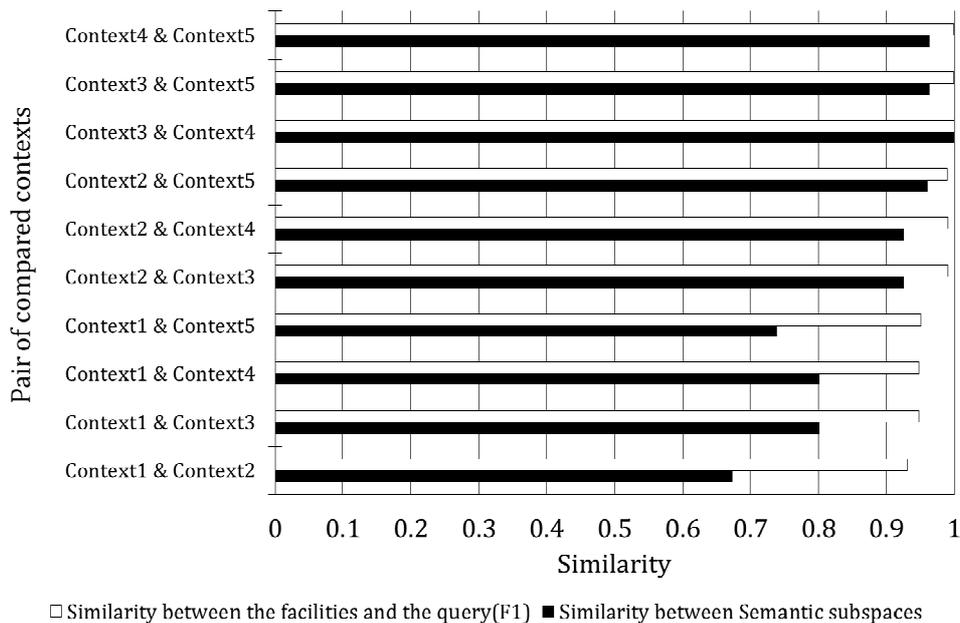
Figure 19. Degree of similarity of Semantic Subspace, the query and facility

6. DISCUSSION

The results of the experiment confirm the change of the degree of similarity because of the changed query and context. The experiments show the feasibility of providing information that matches the context of the user using our method. The difference in degree of similarity is not significant due to the difference in queries and contexts. This is because the value of each element of the matrix is 0 or 1, and the subspace selection result does not significantly change with the context. To increase the difference in degree of similarity due to the difference in the queries and context, we expect to incorporate a learning mechanism to change the values of the matrix and set the elements to use in the context.

7. CONCLUSION

In this paper, we have proposed an information provision system, the Station Concierge System, with the functions for estimating passenger's needs from their context. We have presented a new information-ranking method for passenger intention prediction and service recommendation. This system provides information resource that matches the passenger dynamic context and displays related facilities to the service passengers in a railway-station map. The method includes three main features: (1) predicting the intention of a user based on his/her current context, (2) selecting a subspace for the service recommendation, and (3) ranking the services based on the highest relevant order. By comparing our method with a straightforward computation method, the experimental study has shown the effectiveness and efficiency of the proposed method. The paper has also described the simplicity of our method compared to the existing subspace selection

methods. In our method, the information ranking dynamically changes in response to the user's context. Our system realizes facility-information provisions that matches to the contexts of passengers with the ability to learn accordance with the passenger's context. Furthermore, the following possibilities are realized:

- Extension of Passenger Meaning Subspace Using Similarity of Meaning Subspace
- Query-less context-based information provision

For the first, when there is a context element that cannot be obtained from the passenger, a semantic subspace similar to the semantic subspace obtained by the acquisition context element is set as the semantic subspace used in the proposed method. For the second, as shown in Figure5 and Figure10, the context vector can be expressed in the same vector space as the facility. Query-less information retrieval can also be realized by using the context vector and the vector similarity of the facility.

In our future study, we also promote our system in the following elements:

- Collect features of the information object (web page, document, etc.) from various sources of information.
- Provide semantics to the information object.
- Obtain the context element of individual passengers.
- Provide semantics to the context of individual passengers.
- Compute the distance of the semantic of the information object with the user's context.
- Display information recommendation according to the computed distance of the information object.

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REFERENCES

[1] Satoshi Fukada, Kazunari Moriuchi, **NTT Group Activities in Transportation × ICT**, NTT Technical Review, Report number: Vol. 14, No. 7, 2016.

[2] Yousuke Hidaka, **Development and Research of a system for providing integrated information of public transportation**, IPSJ SIG Technical Report, Report number: Vol.2014-MBL-73 No.8., 2014.

[3] Mikiko Sakamoto, **Technical Innovation in Railway Service: The JR East App**, JR East Technical Review, Report number: No. 28-Spring, 2014.

[4] Takeshi Nakagawa, **ICT-Based Information Services for Customers**, JR East Technical Review, Report number: No. 28-Spring, 2014.

[5] Kaoru Mori, Shuichi Kurabayashi, Naoiki Ishibashi, Yasushi Kiyoki, **An Active Information Delivery Method with Dynamic Computation of Users' Information in Mobile Computing Environments**, Proceedings of Data Engineering Workshop2004,1-A-04, 2004.

[6] Gregory D. Abowd, Anind K. Dey, Peter J. Brown, Nigel Davies, Mark Smith, Pete Steggles, **Towards a Better Understanding of Context and Context-Awareness**, First International Symposium on Handheld and Ubiquitous Computing(HUC'99) , Germany, pp. 304-307, 1999.

[7] Motoki Yano, Katsuhiko Kaji, Nobuo Kawaguchi, **App.Locky: Users' Context Collecting Platform for the Context-aware Service Recommendation**, Journal of Information Processing ,52(12) 3274-3288, 2011.

[8] Tomotaka Hayashi, Yoshihiro Kawahara, Hiroshi Tamura, Hiroyuki Morikawa, Tomonori Aoyama, **Design and Implementation of a Context-Aware Content Delivery Service Using Tiny Mobile Sensors**, IEICE technical report. Information networks 104(691), 149-154, 2005.

[9] Ryota Yabe, Shuichi Kurabayashi, Yasushi Kiyoki, **A META-LEVEL LOCATION-BASED INFORMATION PROVISION SYSTEM WITH PERSONAL-CONTEXT ANALYSIS MECHANISMS**, DEIM Forum2012,A5-5, 2012.

[10] Yasushi Kiyoki, Takashi Kitagawa,Takanari Hayama, **A metadatabase system for semantic image search by a mathematical model of meaning**, ACM SIGMOD Record, vol.23, no.4, pp.34-41, 1994.

[11] Siddhartha Kumar Khaitan, James D. McCalley, **Design Techniques and Applications of Cyberphysical Systems: A Survey**, IEEE SYSTEMS JOURNAL, VOL. 9, NO. 2, pp.350-365, JUNE 2015.

[12] Chalisa Veesommai, Yasushi Kiyoki, **The rSPA Processes of River Water-quality Analysis System for Critical Contaminate Detection, ClassificationMultiple-water-quality-parameter**,EMITTER International Journal of Engineering Technology Vol. 4, No. 1, pp.31-45,June 2016.