Methods and Models for Building an Interface for Digital Information Infrastructure Smart Gallery

Stanislav Simeonov[1], Ekaterina Gospodinova[2][0000-0001-9083-7135]

[1] "Prof. Dr. Assen Zlatarov" University, 8010, Burgas, Bulgaria,
[2] Technical University of Sofia, 8800, Sliven, Bulgaria,
st_sim@yahoo.com, ekaterina_gospodinova@tu-sofia.bg

Abstract. This paper aims to demonstrate some solutions of a new method for constructing modal interfaces for information structure of a smart Gallery, which allows using the context-oriented calculations and subject-oriented knowledge base to offer the user the most suitable interface, based on available resources, situations, context, preferences and constraints. The developed foundations are based on subject-oriented knowledge bases.

Keywords: Multimodal Interface, Smart Gallery, Exhibitions, Digital Resources, Cultural Heritage.

1 Introduction

Digital technologies are introducing new solutions for existence of cultural heritage knowledge the modern state. In Bulgaria are developed, in one degree or another, all major aspects of European type artistic life. A number of exhibitions, monuments and a museum of history and culture have been created. Users could get information about them using a smartphone, tablet or computer, or choose the object of interest from home (Genova, I., 2012).

The analysis of existing systems shows that it is difficult to build an intelligent system (IS) based on interfaces, containing only one modality (e.g., graphics, text, voice). For different users of the system, in different situations, interfaces containing different modalities will be convenient. The same user located in different places (e.g., home, public transport, public place) using devices such as smartphone, tablet, consumer computer (PC) or the same device, but with different characteristics, different interfaces will be preferred. In addition, in many situations it would be more convenient and effective to use not one modality but a combination of modalities. For example, for a user who is in front of a monument, voice and graphic modalities will be convenient, and for a user who is in a gallery or museum - text and voice. Thus it is necessary to develop methods for building multimodal interaction for the information infrastructure, based on the context, situation, preferences and limitations of users and user statistics (Bui, V., Brandt, P., Liu, H., Basten, T. & Lukkien, J., 2016).

Digital Presentation and Preservation of Cultural and Scientific Heritage. Conference Proceedings. Vol. 12, Sofia, Bulgaria: Institute of Mathematics and Informatics – BAS, 2022. ISSN: 1314-4006, eISSN: 2535-0366

A method has been developed that allows the interface to be customized based on previous user choices, taking into account available resources, situation, context and user role. It is applicable to urban services. The interface is developed on the basis of a method that executes and uses connected intelligent objects.

The research methodology includes the use of set theory, first-order predicate logic, semantic technologies, as well as methods for planning and processing experimental results. For the application of the method, software engineering methods and technologies for building web services have been applied (Ambrosino, G., Boero, J., Nelson, M., 2020).

2 Research and Development of a Mechanism for Adaption and Selection of an Appropriate Interface

Data types can be defined for each group: user data (user preferences and restrictions, skill level), device data (device type, device characteristics, traffic characteristics), object data (museum, monument, work of art). Based on them, models of the user, the device and the object have been developed. A set of context parameters (IP address, GPRS, etc.) determine the situation in which the user finds themselves (Boccardo, P., Arneodo, F. & Botta, D., 2019).

Based on contextual data models, different situations can be considered: according to the location of users; they are on the move or at rest and how busy their hands are. It is necessary to look at the same contextual data differently for each situation. For example, the dark time of day is important if the user is moving, but does not affect the choice of the appropriate interface if the user is at home. Based on this data, an algorithm for selecting an appropriate modality or combination of modalities is described (1),

$$\mathrm{M}_m = \begin{bmatrix} w_{11}^m & \cdots & w_{1m}^m \\ \vdots & \ddots & \vdots \\ w_{N_m^1}^m & \cdots & w_{N_m}^m \end{bmatrix} \quad (1)$$

where m is the type of context matrix, w is a coefficient reflecting the influence of the context rule on the choice of modality i, M_m is the context matrix of context m, N is the number of modalities, N_m is the number of context rules of context m.

Each row of the M_m context matrix describes how the context rule influences the choice of modality.

$$\begin{cases} w^m > 0, recommended \\ w^m < 0, not\ recommended \\ w^m = 0, no\ effect \end{cases} \quad (2)$$

At the summation stage, the selection and summation of the coefficients for the fulfilled context rules for each modality is performed. The sums of all coefficients for each modality ($\mathrm{lSU}M_d^i$) are then calculated.

$$\mathrm{lSU}M_d^i = \sum_{c \in C^B} B_{ci} + \sum_{c \in C^S} S_{ci} + \sum_{c \in C^R} R_{ci} \ , \quad (3)$$

where i is a modality, c is a context rule, d is a direction (receive/send), B_{ci} is a basic matrix, S_{ci} is a situation matrix, R_{ci} is a role matrix, C^R is a set of active context rules in the role matrix, C^B is a set of active context rules in the base matrix, C^S is a set of active context rules in the situation matrix.

At the next stage, the sums of the coefficients for each combination of modalities are calculated ISUM_d^i in accordance with the templates (t). A template is a predefined set of modalities (e.g., graphics, audio, audio and graphics). In addition, depending on the direction of data transfer d: from user to system or from system to user, a different set of models is used, as the receiving and transmitting interactions may differ from each other,

$$\mathrm{MSUM}_d^i = \frac{\sum_{i \in l_d^t} \mathrm{ISUM}_d^i}{N_d^t}, \tag{4}$$

where i is the modality, d is the direction (receive/send), t is the pattern, MSUM_d^i is the sum of the modality coefficients i, i_d is the set of modalities in the template, N_d is the number of modalities in the modality set (i_d).

To customize the interface, it is necessary to calculate MSUM_d^i, where consumer statistics are also taken into account - previous choices of combinations of modalities in the same situation and context. To do this, a feedback mechanism has been developed σ_d^t, which allows the consumer's previous choices to be taken into account, gradually increasing the amount received when re-choices are made. To ensure that the template is raised in the first place, it is necessary to calculate the maximum amount MSUM_d^{max} from the templates and multiply by the old feedback factor:

$$\sigma_d^t = \log_{10} N_{Cu}, \tag{5}$$

where t is the modality combination pattern, d is the direction (receive/send), N_{Cu} is the number of pattern choices in a given context and situation and σ_d^t is the feedback factor,

$$\mathrm{MSU}M_{dpersonalized}^t = \mathrm{MSU}M_d^t + \mathrm{MSU}M_d^{max} . \sigma_d^t, \tag{6}$$

where d is direction, t is a template of combined modality, MSUM_d^{max} is the maximum sum of the modal coefficients of all templates, MSUM_d^t is the sum of the modal coefficients of the template, σ_d^t is feedback coefficient (Hanif, M.S.; Aono, M., 2019).

At the last stage, the probability that each combination of modalities is appropriate for the user is calculated based on the context, the situation, the user data, the user statistics. Calculation of the probability that a combination will suit the user based on the context, situation and user data is obtained as follows: the sum of the coefficients for each $\mathrm{MSU}M_{dpersonalized}^t$ template in question divided by the sum of the MSUM_{total}MSUM coefficients total and multiplied by 100,

$$MSUM_{dtotal} = \sum_{t \in M_d} \mathrm{MSU}M_{dpersonalized}^i, \tag{7}$$

where d is a direction, t is a template of combined modality, M_d is the sum of all templates of directions, $MSUM_{dtotal}$is the sum of the coefficients of all templates,

$$P_{dpersonalized}^t = \frac{\mathrm{MSU}M_{dpersonalized}^t}{\mathrm{MSU}M_{dtotal}} . 100, \tag{8}$$

where $P_{dpersonalized}^t$ is the probability of submitting a template by a user, $\mathrm{MSU}M_{dtotal}$ is sum of coefficients of all templates, $\mathrm{MSU}M_{dpersonalized}^t$ is sum of coefficients taking into account the user's previous choices (Castano, S.; Ferrara, A.; Montanelli S., 2018).

The result of the algorithm is a list, each element of which is a related value: the type of template and the probability of selection in percent. The resulting list is then sorted by probability and then used to arrange the proposed options for combinations of modalities in the user application menu.

3 Development and Research of a Mechanism for Adaptation and Selection of an Appropriate Modal Interface. Algorithm for Modality Selection

Based on the user, device, and environment models, the following algorithm for selecting an appropriate modality or combination of modalities is described.

1. User authorization. After authorization, the algorithm is customized based on a set of rules. The role of the user, preferences (e.g., graphical interface preference) and user limitations (e.g., hearing limitations) are defined .

2. Obtaining the context of the algorithm: device parameters (e.g., GPRS, battery charge, screen resolution, wi-fi network parameters, speed and cost of traffic) and environment (e.g., lighting, temperature, humidity, precipitation).

3. Based on the analysis of the context, in accordance with the algorithm, the situation in which he finds himself is determined (Adomavicius G., 2019).

4. Is being created rule tables using contextual data for user, device and environment.

5. Based on the analysis of the context, situation, user data and user statistics, the system sends a set of the most appropriate combinations of modalities. For each proposed combination of modalities, the probability that this combination will suit the user in a given context and situation is also shown, taking into account the statistics for him (Hanif M.S.; Aono M., 2019).

6. The user selects the interface that suits him best and sends a request for information. If the probability of one of the combinations of modalities is greater than 60% and the user selects it, he is offered a value as a threshold, after which he will be invited for confirmation.

7. Processing the modal interface request and generating a response to the user.

The calculation of modalities or combinations of modalities suitable for sending a response to the user is performed according to the descriptive algorithm, but using templates for receiving a message. The type of data requested is also taken into account when sending. An additional matrix of message types (M_{ci}) is used for this:

$$MSUM_d^i = \sum_{c\in c^B} B_{ci} + \sum_{c\in C^S} S_{ci} + \sum_{c\in C^R} R_{ci} + \sum_{c\in C^M} M_{ci} \quad (9)$$

where i is the modality, d is the direction (receive / send), c is the context rule, B_{ci} is the base matrix, S_{ci} is the situation matrix, R_{ci} is the role matrix, Mci is the communication matrix, C^R is the set of active context rules in the role matrix, C^B is a set of active context rules in the base matrix, C^S is a set of active context rules in the situation matrix, C^M is a set of active context rules in the communication matrix.

The implementation of the algorithm follows:

8. Sending a response to the user from the modal interface;

9. The user evaluates the usability and efficiency of the interface;

10. The modal interface receives and processes user statistics.

The result of the algorithm is a list, each element of which is a related value: the type of template and the probability of selection in percent. The resulting list is then sorted by probability and then used to arrange the proposed options for combinations of modalities in the user application menu.

Based on the analysis of the context, situation, user data and user statistics, the interface sends the user a set of the most appropriate combinations of modalities. For each proposed combination of modalities, the probability that this combination will suit the user in a given context and situation is also shown, taking into account user statistics.

Contextual matrices are used to illustrate the algorithm. In general, there are three context matrices (M_m): role matrix (R_{ci}), situation matrix (S_{ci}) and base matrix (B_{ci}), which contain context rules: C^R, C^S, C^B, respectively. A context rule is a set of coefficients {w} for receiving and sending a message for each modality corresponding to a context parameter (for example, light level or device battery charge).

The developed database of services is based on user, device and environment models developed within the mechanism for adaptation and selection of appropriate modalities, methods for determining situations based on contextual data and a set of rules or a combination of modalities based on of context and situation (Honkola, J.; Laine H.; Brown R.; Tyrkko O., 2020).

The developed system consists of three parts: subject area of data collection, situations and coefficients. Such partitioning allows data to be transferred to different services by connecting the appropriate system to the subject area. The coefficients for selecting an appropriate modality or combination of modalities based on context and situation are within the method.

The result of the algorithm is a list, each element of which is a related value: the type of template and the probability of selection in percent. The resulting list is then sorted by probability and then used to arrange the proposed options for combinations of modalities in the user application menu.

Contextual matrices are used to illustrate the algorithm. In general, there are three context matrices (M_m): role matrix (R_{ci}), situation matrix (S_{ci}) and base matrix (B_{ci}), which contain context rules: C^R, C^S, C^B, respectively. A context rule is a set of coefficients {w} for receiving and sending a message for each modality corresponding to a context parameter (for example, light level or device battery charge) (Zhelyazkov Y, 2019).

4 Method for Building a Multimodal Interface for Information System

Taking into account the descriptive algorithm, the concept of a distributed information system for information exchange with multimodal support interfaces can be built. applications for communication and access to objects of art, culture and historical heritage will increase the efficiency and convenience of human-digital device interaction (Carminati B.; Ferrari E.; Heatherly R.; Kantarcioglu M.; Thuraisingham B., 2021). The user should be offered the most appropriate interface for him based on the situation (for example, the user is viewing a work of art or wants to visit a museum with a specific theme), context (contextual data about the exhibit, such as sculpture, painting), contextual data about device (e.g., device type, battery charge), preferences and limitations (blind, deaf), digital device type and statistics. In order to report statistics, there must be a mechanism that allows you to independently select an interface from a set of the most appropriate interfaces calculated by the system. To improve ergonomic performance, the system must gradually adapt to the needs and preferences of the user and in situations and contexts where the user often uses the system, automatically provide the most appropriate interface without user intervention (Liuha, P., Lappeteläine A.; Soininen J.P., 2020).

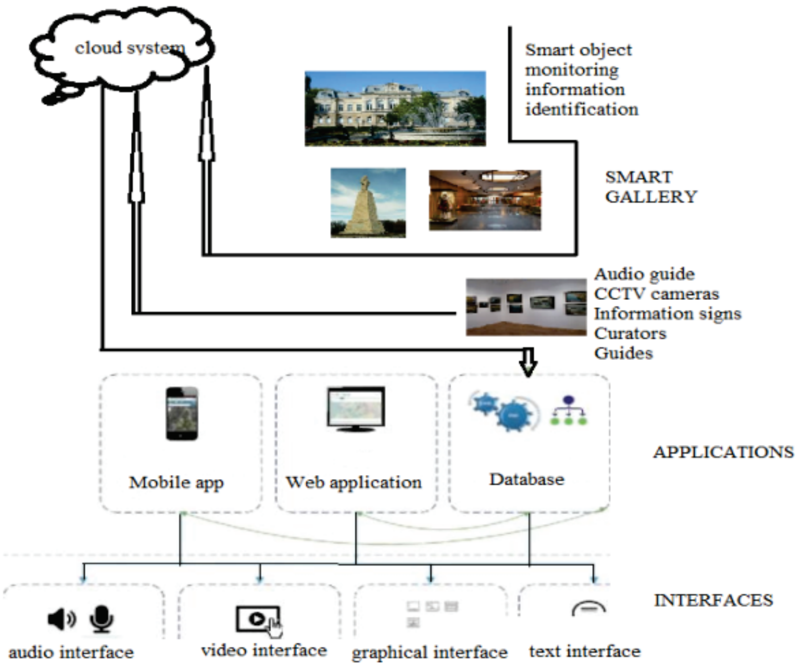

Fig. 1. The concept of building a distributed environment

The method for constructing an information system is divided into three components: resources of the physical environment, resources of the information environment and resources of the social environment (Fig. 1).

Figure 2 shows the requirements for the architecture of a distributed modal system developed to implement the method of building a modal interface for Smart City infrastructure. Each resource can interact directly with other resources in its category and indirectly through the relevant services in the service interaction space - with resources of any origin, which includes the development of a scenario model to describe such interaction.

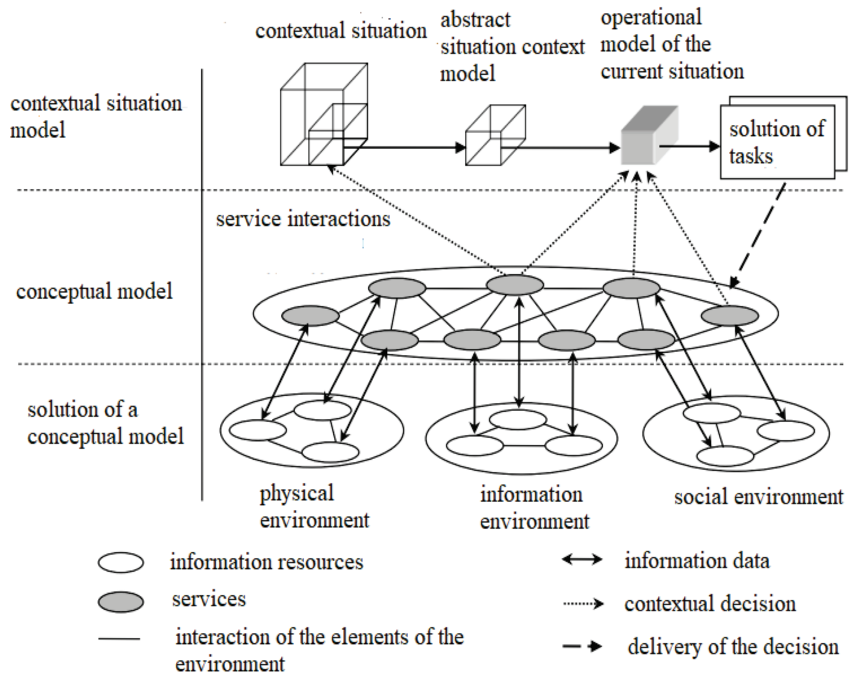

Fig. 2. General scheme of service oriented approach

5 Implementation of the Method for Building a Modal Interface for Intelligent Distributed Information System

Web applications can be developed in CMS Plone. Graphic and textual modalities have been implemented for the web applications of the dispatchers, the citizens and the city administration. Mobile application developed in Xamarin, C#. Graphic, text, audio modalities, as well as combined audio + text, graphics + text, audio + graphics + text have been implemented for the mobile applications of the driver and the utility worker.

The experimental study of the developed IS MI consists of preliminary tests of the prototype MI IS. 12 users participated. In the course of experimental research, two systems based on the method of constructing MI were compared: a system without decision support; a system containing only a graphical interface. The performance of the MI customization mechanism is assessed on the basis of several (4 to 10) passages from the user script. It turned out that 10 repetitive passages from the script, ie situations with the same contextual data from the user of a given role, are enough to customize IS MI. The number of errors made by users is calculated. Compared to such a system without decision support, fewer mistakes are made. The presence of a negative emotional reaction of the users, which is understood as stress or confusion, is assessed. Such a system.

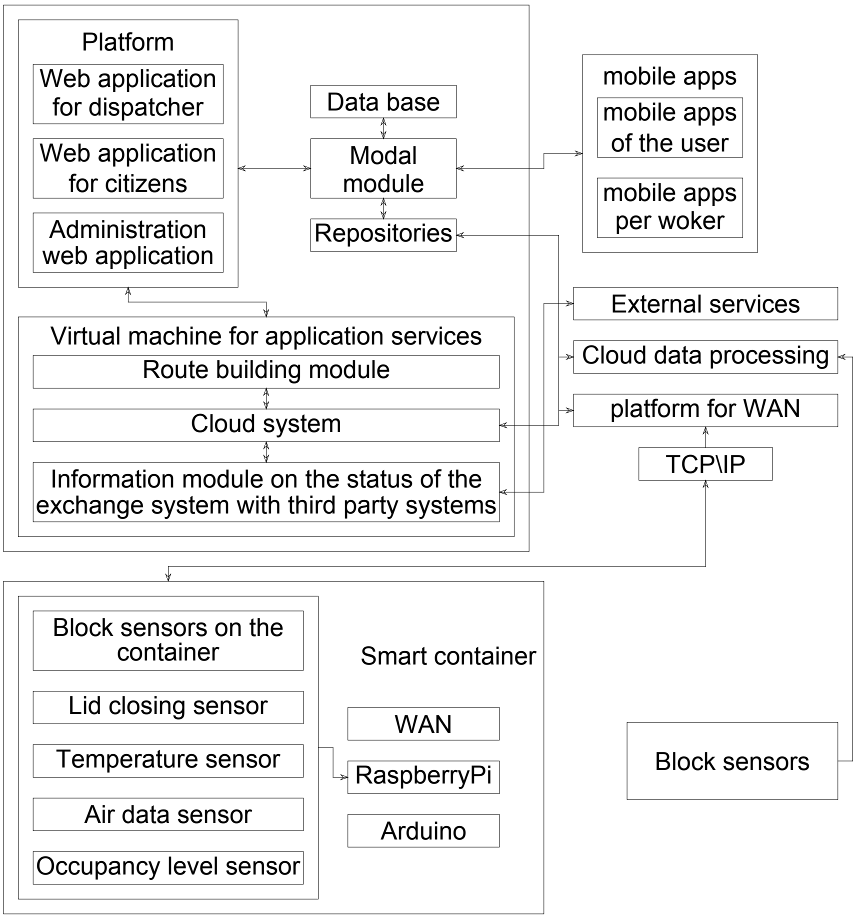

Fig. 3. Shows the architecture of the test configuration of the distributed IIS using MI

6 Conclusions

The developed concept consists of three parts: subject area, concept for situations and coefficients. Such division of parts allows transfer of the developed database to different services related to the respective subject area. To without decision support is preferable. An analysis of consumer ratings is also performed. Experimental studies show the workability of the method for designing MI and improving the ergonomic characteristics thanks to the developed method. Further research should be carried out in the field of expanding the set of rules describing situations and the corresponding expansion of the knowledge base.

This field has great potential for innovations especially in the current situation of active imposition of e-devices, e-literacy, and e-content. The focus will be in the research and exploitation of new or emerging technologies, smart world, environments and devices for the development of innovative products, tools, applications, and services for creative digital content production, usage and management. The aims are to transform and customize the valuable parts of mankind's cultural and historical ancestry into digital assets, whose integration and reuse through research-lead methods has high commercial and noncommercial potential for learning and cultural institutions, tourism, creative and media industries.

Acknowledgements.

This research was funded by the European Regional Development Fund through the Operational Program "Science and Education for Smart Growth" under contract UNITe No BG05M2OP001–1.001–0004 (2018–2023).

References

Adomavicius, G. (2019). Context-aware recommender systems. *AI Magazine, vol. 32(3)*, pp. 67–80.

Ambrosino, G., Boero, J., Nelson, M. (2020). Infomobility Systems and sustainable transport services. *ENEA*.

Boccardo, P., Arneodo, F. & Botta, D. (2019). Application of geomatic techniques in infomobility and intelligent transport systems. *European Journal of Remote Sensing*(vol. 47, Issue 1), pp. 95-115.

Bui, V., Brandt, P., Liu, H., Basten, T. & Lukkien, J. (2016). Semantic Interoperability in Body Area Sensor Networks and Applications. *9th International Conference on Body Area Networks*, (pp. pp. 210-216). Great Britain.

Carminati, B., Ferrari, E., Heatherly, R., Kantarcioglu, M. & Thuraisingham, B. (2021). Semantic web-based social network access control. *Comp. & Security*(vol. 30, issues 2–3), pp. 108–115.

Castano, S., Ferrara, A. & Montanelli, S. (2018). H-Match: an Algorithm for Dynamically Matching Ontologies in Peer-based Systems. *Proc. of the 1st VLDB Int. Workshop on Semantic Web and Databases.*

Genova, I. (2012). *Possible History of Bulgarian Art ISBN 978-954-92416-31.* Sofia: Sofia City Art Gallery.

Hanif, M.S. & Aono, M. (2019). An efficient and scalable algorithm for segmented alignment of ontologies of arbitrary size. *Journal of Web Semantics., Elsevier, Vol. 7*(no. 4), pp. 344-356.

Honkola, J., Laine, H., Brown, R. & Tyrkko O. (2020). Smart-M3 Information Sharing Platform. *Proceedingsof the IEEE Symp. Computers and Communications (ISCC'10)*, (pp. pp. 1041-1046).

Liuha, P., Lappeteläine, A. & Soininen, J.P. (2020). Smart Objects for Intelligent Applications. *ARTEMIS magazine*, pp. 27-29.

Zhelyazkov, Y. (2019). Survey and analysis of the influence of electromagnetic interference on transmission parameters of twisted pair cables used in the construction of communication networks. *Announcements of union of scientists – Sliven, volume 34*(1).

Received: June 04, 2022
Reviewed: July 04, 2022
Finally Accepted: July 07, 2022