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UI Design Method for Visualizing Sensor Data to Enhance User Understanding

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***Abstract*—To create knowledge from data, it is important to understand the characteristics and meaning of data, but the degree of understanding differs depending on the person's ability and knowledge. If there is a method that can visualize not only its values but also its characteristics and meaning, it could decrease the dependence on the user's abilities and knowledge. This paper presents a study on a method to incorporate such design in the software development process. In particular, a design of a user interface of the software for museum curators to analyze data of museum visitors is presented and analyzed. The data contains various characteristics, such as technical limitations of sensor performance, installation locations, measurement range, and frequency. The methods used to communicate them are presented and their effects are evaluated through user evaluation.**

Keywords—Human-Computer-Interaction, Knowledge Acquisition, Experience Design

I. Introduction

Understanding data and discovering information is an important part of the knowledge-creation process. However, understanding data is difficult unless you are an expert in data analysis. For the democratization of data, there is a movement to realize collaboration between data analysis experts and non-data analysts [1]. Then, if there is an interface that promotes a correct understanding of data, everyone will have the same opportunity to create knowledge. Various studies have already been conducted on user interface design guidelines as a means to realize better user experience [6]. However, the goal of these design guidelines is to enhance usability, and specific guidelines that are useful in developing software for a particular purpose are not considered enough.

One of the problems in data analysis is data uncertainty. Several approaches have been proposed to call them dirty data and to remove them [2], but to understand the data correctly, it is effective to express the uncertainty itself instead of removing it. Research on methods to express data uncertainty has been carried out in various fields. According to Deitrick et al., there are both explicit and implicit uncertainties. Attempts have been made to recognize it [3]. However, explicit uncertainty visualization is rarely mentioned. Liu et al., in the field of deep learning, use a method to recognize the meaning and ambiguity of the data as it is by converting the data into color gradation when expressing the driving behavior of a car [4]. However, this is only a means for experimentation and no mention is made of their effectiveness.

In this study, a method for explicitly and implicitly expressing different uncertainty of data is presented. The method is based on modeling the various characteristics of data where uncertainty is one of them. The visualization also includes user interactions to aid data exploration and understanding.

II. Method

The focus of the design is to reflect the conditions in which data is measured and to display them in the visualizations that the users see. To perform this study, the proposed design was adopted in the development of a software, called “Kurate”, to support curators' understanding of visitor behavior/activities at a museum. A total of eleven sensors were installed on the museum exhibit floor. Each sensor can measure the number of people and their locations as well as numerous environmental conditions including temperature, luminosity, and noise level. In this study, the data of the number of people was only used. The purpose of the software is to visualize data collected by these sensors so that the curators can browse them and obtain new knowledge to gain insights to improve the visitor experience.

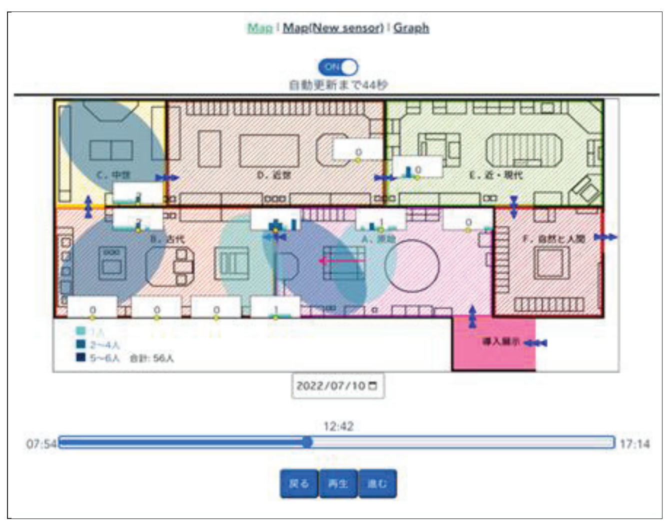

Fig. 1. Map visualization within Kurate

A. Sensor limitations and visualization

The locations of the sensor are depicted in Fig.1 which is a screenshot of the "map view" of the software. On the screen, a map of the exhibit floor is shown in the middle. There are 6 exhibit areas labeled from A to F and colored in different backgrounds (hashing). The location of each sensor corresponds to the small yellow circle associated with a white rectangle box. In total, there are 11 sensors. Sensor placement is confined by various local limitations so that their positions are not evenly spaced and do not cover the whole exhibit floor. While these limitations are not favorable to the measurements, it serves as a good example for visualizing irregular and uncertain data.

The map view displays the detected number of people and their locations. Each sensor computes the number of people by performing object detection on an image captured by an onboard camera using Yolo v3 and counts the number of objects classified as "person". While the detection accuracy is rather high, there is a certain possibility of miss-detections and the data should always be treated as such. The data is measured in real-time and the view is updated immediately but the view can also show accumulated data within the day.

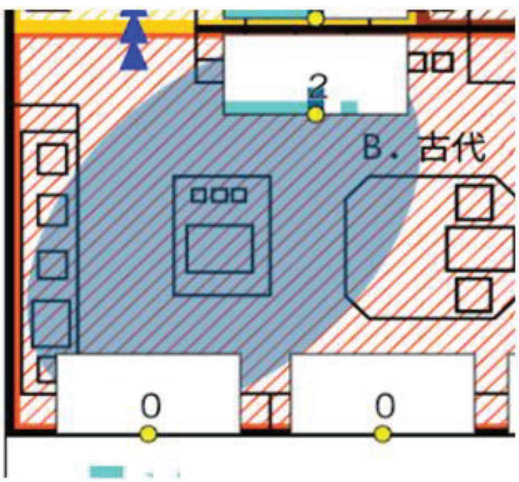

Fig. 2. Example of a sensor at the top detecting 2 visitors in the oval region

Each sensor has a limited measurement range. Fig.2 depicts an example of the range of a sensor that is visualized as an ellipse. In this example, the sensor is placed at the center of the white rectangle shown at the top of the figure, and pointing to the left bottom. There are two more sensors visible, both on the bottom edge of the figure as shown by the additional white rectangles but there are no associated ellipses since the detected number of people is zero. Thus, in total, this means that there are two people in the area covered by these three sensors and that these people are in a position that is only detected by the sensor at the top.

In the map, each ellipse is colored in three colors corresponding to a range of the number of people. Considering the accuracy of the measurement by Yolo, as described above, expressing the number of people by color gradation is better instead of numbers.

Along with the elliptical display, a bar graph is also displayed inside the white rectangle. The number of viewers detected by that sensor is shown in chronological order by the height of bars, with the center showing the currently displayed time, the left side showing the past, and the right side showing the future. The value of the current number of people is also directly shown above in the center. While the ellipses tend to be rendered only for a short time since they represent instant values, the bar chart is intended to provide information on the trend for a longer time scale.

B. Inferring visitor behavior

By observing the measured data over time, it becomes possible to understand the flow of the visitor. For example, in Fig.3, the visitors seem to have transitioned from the bottom right area to the bottom left and then to the top left area. The arrows drawn in the figure display the movement to adjacent areas as inferred by the increase/decrease in the measured data. At the museum for which this system was developed, the route for viewing the artifacts is not restricted and allows visitors to view freely, so arrows are sometimes drawn in both directions. In Fig.3, it can be interpreted that the viewers who were in the lower left area in the figure returned to the lower right area, and the number of people in the lower right increased.

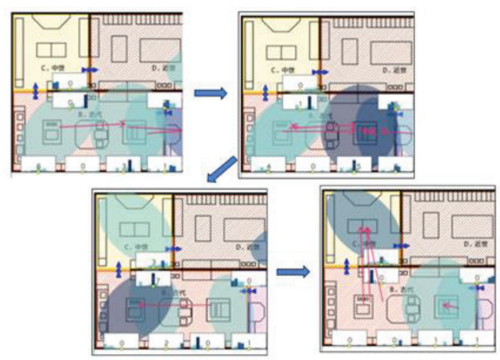

Fig. 3. The flow of visitors detected over time

When the same ellipse continues to be displayed, it can be interpreted that the visitors have stopped in that area. On the opposite, the area where the ellipse flickers intensely could mean that the viewer is passing by. For example, Fig.4 depicts a case in which the viewer is standing still in the area on the left, while the visitor is passing by in the area on the right.

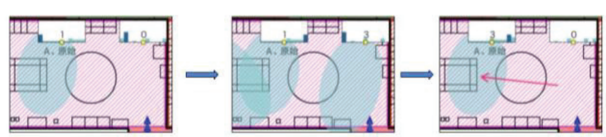

Fig. 4. Visualizing stationary and passing visitors

C. Exploring data

The slide bar at the bottom can be used to select data for a certain time to display. Users can also change the date by clicking the calendar at the top of the slide bar. Changing the display time and/or date helps users explore the data to build their understanding and analyze visitor behavior. It is also possible to play back the data to see an animated rendering using the three buttons below the slide bar.

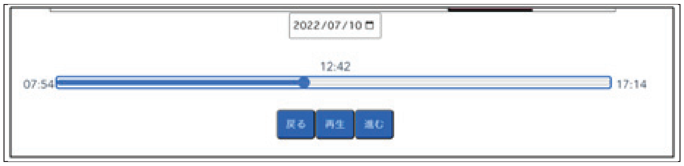

Fig. 5. Slide bar to change the displayed time

Furthermore, a “graph view” is designed to provide an additional perspective to the data. The graph view can be opened by the tab at the top of the page. In the graph view, in addition to the number of people, data of other measurements such as temperature, humidity, and noise can be viewed as line graphs. The map and graph views, even viewing the same data on the number of people, are expected to supplement each other. Fig 6 is the line plot for the number of people for a certain date as measured by the 11 sensors. The graphs are better at showing an overall trend of visitors throughout the day, the existence of peaks, similarities, and differences among different sensor locations, etc.

Fig. 6. Graph view for the number of people

III. Evaluation

In the previous section, the design and intentions of the visualization were described, but here we evaluate the actual effects based on the actual data. The evaluation is based on data collected approximately one year after the installation in the museum.

A. Visualization of multiple detections

Fig.7 shows a state in which 3 sensors are possibly sensing the same set of people. In this example, the top sensor is detecting one person, the bottom right sensor is detecting one person, and the bottom left sensor is detecting two people. Technically, it is not clear if the same people are being detected by the sensors or not. This is an example of uncertainty or ambiguity that is inherent to the data. Since this design intends to communicate this fact to the user, three ellipses are rendered on top of each other. The overlapping of the ellipses denotes the area where the sensors overlap and expresses the possibility that multiple sensors may be detecting the same visitor.

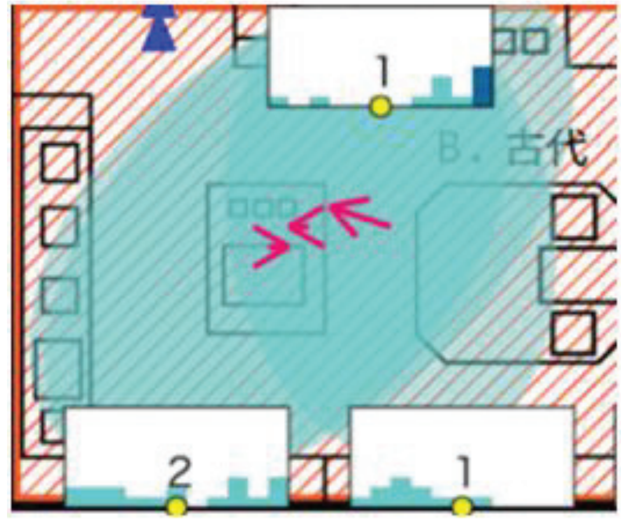

Fig. 7. Visualization of multiple sensors possibly sensing the same visitor

B. Visualization of crowded situations

Fig.8 shows the transition of successive time displays for a certain period with many numbers of people being detected. During this period, the number of visitors is large, and it can be seen that there are multiple visitors in each area. This is a typical case for a group visit and the design is successful in visualizing crowded areas. As shown in the figure, it is especially successful in explaining the movement of visitors between the exhibit areas (A to F). In contrast, this design does not provide much information at a more detailed level such as crowded places within an area. However, this is a limitation of the current sensors that rely on object detection from one camera which does not provide depth information. Rather than providing an error-prone estimation of visitor positions from such unreliable data, the design focuses on visualizing the limitations by just providing the total number of people detected in the elliptical region. To fill this gap in data detail, the system does provide another view that provides visualization of the visitor positions even within the sensor sensing area based on another technique that is not discussed in this paper.

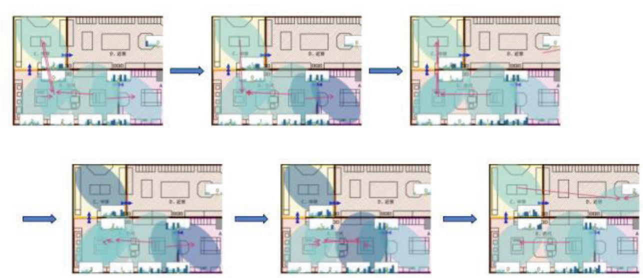

Fig. 8. Visualization of crowding.

IV. Experiment

As an experiment to evaluate the design by the target users, several curators of the Fukushima Museum were asked to use the software and provide feedback in form of a questionnaire. The experimental procedure was carried out in three steps.

Step 1. Participants were familiarized with the software by following the instructions of a self-conducted tutorial
Step 2. Participants used the software
Step 3. Participants filled out a questionnaire

The contents of the questionnaire are as follows

Q1. Did you understand that visitors outside the sensor's range cannot be measured?
Q2. Did you understand that the total number of people may be displayed higher than the actual number where the sensors have overlapping measurement ranges?
Q3. Was this app useful to know the trends of visitors?
Q4. Can you trust the information displayed by the software?
Q5. Can you accept the information displayed by the software?
Q6. Was the information displayed by the software easy to understand?
Q7. Did the information displayed by the software help you understand the data?
Q8. Are there any data you wish to be provided in addition?
Q9. Are there any additional functions you wish to be provided?
Q10. Please provide any other comments or opinions.
Q11. How long did you use this software?
Q12. When you look for information, do you value difficult but accurate information or less accurate but easy-to-understand information?
Q13. What is the self-evaluation of your skills in reading graphs?
Q14. Which type of explanation would you prefer, logical or emotional explanations?

V. RESULT

The total number of participants was 4. Table 1 shows the results of the questionnaire, excluding Q8, Q9, and Q10. For Q4, Q5, Q6, and Q7, results were scored as 1 for "disagree", 2 for “somewhat disagree”, 3 for “somewhat agree”, and 4 for “agree”.

TABLE I. RESULT OF QUESTIONNAIRE

Question No.	Subject			
	S1	*S2*	*S3*	*S4*
Q1	Yes	Yes	Yes	Yes
Q2	No	No	-	Yes
Q3	Yes	Yes	Yes	Yes
Q4	4	3	4	3
Q5	3	3	3	3
Q6	3	3	3	3
Q7	3	3	3	-
Q11	~30min	1~2h	1~2h	1~2h
Q12	Accurate	Easy to understand	Accurate	Accurate
Q13	Bad	Not bad but don’t like	Not bad but don’t like	Not bad but don’t like
Q14	Logical	Logical	Logical	Both

VI. DISCUSSION

A major goal of our design was to express the constraints and characteristics of data as they are and to have users understand them. From the answer to Q1, it was found that the measurement range of the sensor was communicated to the user. However, the answer to Q2 did not seem to give much consideration to sensor overlapping. This shows that the current visualization itself is not enough in communicating this characteristic and requires improvement.

Presenting the data as it is, rather than simply summarizing it, was expected to increase the sense of trust and satisfaction in the data. From the answers to Q4 and Q5, it can be said that there were also those effects.

In the results of Q6, everyone answered: “somewhat agree”. In Q12 and Q13, we asked what the person emphasized when researching and how to read the graph, and got different answers for each. In particular, some people answered that they were not good at reading graphs. It can be said that it was easy to understand the information displayed by this software regardless of the user's personality or strengths.

VII. CONCLUSION

A design of software to visualize the constraints and limitations of sensor data as much as possible to improve user trust and the quality of their knowledge creation. The developed software was tested with data collected at a museum and tested by curators for understanding user behavior. As result, the proposed visualizations were overall useful. However, the visualization of possibly overlapping detection results was not effective as intended.

In general, observing data by various display methods and exploring them while switching viewpoints leads to a deeper understanding of the data. In the field of education as well, attempts are being made to provide a place for students to independently explore their interests as a way to encourage learning and understanding [5]. The proposed method has few interactions that allow users to focus on the data they want to see. It is possible to help the user understand the data by realizing an interaction that allows users to dig deeper into the data they are interested in, such as selecting whether to display it or displaying more detailed data.

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