ISSN 2229-5518

Visualization Approach to Effective Decision Making on Hydrological Data

Faudziah Ahmad, Khairul Bariah Ahmad, Azliza Othman

Abstract— Temporal data is by nature arranged according to the sequence of time where the order of the data is very significant. Thus in order to visualize a temporal data, the order of the data has to be preserve that will show certain trends or temporal patterns. Most visualization technique however uses technical visual representation such as bar chart and line graph. This approach is suitable and can be easily comprehended only by technical users. In order to reduce the learning curve in understanding the prototype develop and facilitate decision making, metaphor based visualization approach was used for representing temporal hydrological data. To evaluate the correct of decision making similarity test was conducted by using data mining approach, specifically incorporating case-based reasoning. The test case or new data was compared with the case extracted from previous operation data and the case closely was examined by exploring the detailed data. Results were evaluated through usability testing and similarity testing. The prototype was demonstrated to a group of users specifically three DID staff involved with the dam operation directly and indirectly. The feedbacks received from the users are positive where the interface objects used took a short time for them to learn and understand due to the familiarity of the representation. One look at the map, it will give them the overall picture of the situation patterns of the dam water level and rainfall around the catchments area according to the time frame chosen. The metaphorical representation based visualization is used as a basis to represent temporal and multi-variate data using icon based technique and colour code to enhance interface usability and usefulness. This type of representation can be easily understood by a non-expert from the domain. The visualization actually assists users in the process of decision-making by representing the patterns in form close to the mental model of a user by using metaphor. This help speed up data exploration thus decision-making process. In critical situation speed and accuracy is vital in the decision making process.

Index Terms— Temporal, Visualization, Hydrology Data, Decision making.

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1 Introduction

Visualizing hydrological data is an effective way to capture unnatural patterns or trends that may lead to destruction to human lives. In critical decision making such as releasing dam water to prevent dam outburst, timeliness and accuracy of decision is most important [8]. A slight mistake in decision will cause catastrophic event that can harm public safety and properties. One critical problem faced by dams is unexpected sediment or silt that deposit below the dams and causes dams to lose their total water capacity. For example, Timah Tasoh Dam, which is located at the north of Malaysia, can store up to 40 million cubic meters when it started operation in 1992. After 14 years of operation, the current total storage capacity in Timah Tasuh Dam is less than 40 million cubic meters at the normal pool. The dam gate operation guideline used 14 years ago, thus needs to be adjusted to suit the new situation. The new situation also requires the dam engineer to manually recalculate the rainfall and water level at the dam before they can make a decision on opening or closing a gate. Miscalculation by the dam engineer could cause inaccurate decision which may lead to tragedies such as loss of human life and property.

In the case where a new engineer takes over the task, decision making is riskier as the person is lack of experience and do not fully understand the dam operation procedures.

The integration of visualization and data mining is one way to improve understanding and facilitate decision making [5, 13, 3, 19]. This is because visualizing abstract data amplifies cognition and makes data more inference and understandable [13, 2, 4, 16]. The advantage of visualization is that it is intuitive, does not call for understanding of complex mathematical, statistical formulas or algorithm, capable of being understood by non-expert users, and can handle very large volume of data with huge amount of information. Visualization of temporal data causes certain issues such as how to present continuous data, how to show the order of data sequentially, and how to produce visualization that can be understood by non-experts.

According to [10], a metaphor framework for visualization will promote meaningfulness due to familiarity and at the same time promote an understandable mental model for non-experts. Information visualization that closely resembles the mental model of the users can help reduce the learning curve of users in using the system by providing graphics that are familiar to them and their surroundings. User ori-

- *Faudziah Ahmad is currently lecturing masters program (MSc(IT)) at Universiti Utara Malaysia, Malaysia, PH-6049284788.*
- *E-mail: fudz@uum.edu.my*
Khairul Bariah Ahmad is currently lecturing degree program in IT at Universiti Utara Malaysia, Malaysia, PH-6049284616.
E-mail: kbariah@uum.edu.my
Azliza Othman is currently lecturing lecturing degree program in IT at Universiti Utara Malaysia, Malaysia, PH-6049284647.
E-mail: azliza@uum.edu.my

ISSN 2229-5518

ented design was proposed for visualization graphics. User involvement in the early design stage is crucial in order to obtain suggestions and feedbacks that are meaningful. This paper presents a metaphor based visualization approach for temporal hydrological data. It particularly describes the process of visualizing data and visualizing patterns, and presents two methods to evaluate visualization prototype.

In temporal data, time and sequence are two most important aspects of data that must be closely monitored. Storing and processing a time based data must preserve the natural order of data so that no information loss is experienced. Retrieving and indexing records according to the time sequence is main task in managing temporal data. From temporal data, trends and temporal patterns can be extracted to give an insight of certain knowledge [8]. However, the point of change in a temporal data is an important piece of information that needs to be detected as prompt and accurate detection will help to reduce delay in decision making [18]. Visualization of temporal data can assist user in recognizing trends, patterns and detecting change. This is because users are able to choose the time range to look for trends and patterns visually. The temporal information presented visually is much easier to comprehend that just looking at a series of numbers and with the support of automatic computation, information can be effectively understood [3].

In terms of decision making, information visualization and visual data mining can deal with large data sizes. Information visualization deals with how to visually present information and makes data more inference and understandable [4]. Visual data mining is a collection of interactive reflective methods that support exploration of data sets by dynamically adjusting parameters to see how they affect the information being presented. In the last few years, several efforts have been made to integrate visualization and data mining [17, 6, 14, 3]. The integration was meant to increase the effectiveness of visualization process. Visual data mining technique have proven to be of high value in exploratory data analysis and they also have high potential for exploring large databases.

Successful visualization system has to be built to satisfy universal-usability for diverse users regardless of their backgrounds or technical disadvantages. Such system though necessary becomes a huge challenge for developers. [12] stated that development process requires higher software development skills, complex requirements, tedious development process, and understanding and integrating mental models. Mental model aspect has been seen to be investigated in visualization research in various ways. [1] and [5] studied on human perception and claimed that human perception through the visual representation capable of straightforwardly identify the data relationships when it is 2 or 3 dimensional but for multivariate data, it is very difficult to identify the relationships manually. [11] and [7] reported that manual visual data exploration is time consuming and may produce incorrect conclusion when certain tasks takes too much time. For example, finding the right parameter is very tedious and sometimes is almost impossible.

[5] investigated the ability of certain human to understand what the visualization shows and to perceive the identified pattern into meaningful hypothesis. His results showed that different peoples perceive differently due to dissimilar background and domain knowledge. He suggested an integration of established technique such as machine learning and statistical because the automatic and visual data mining exploration combination utilize the human intuitive cognitive skills and computer efficiency. This integration will permit speedy and efficient detection of interesting pattern and trend in data.

2 APPROACH VISUALIZING HYDROLOGICAL DATA

The approach consisted of five main steps: task analysis, data characterization, display mapping, prototyping, and evaluation. The task analysis is a process of observation and interviewing end users and is intended to understand how users currently accomplish their tasks. Data characterization is a process of characterizing data attributes to be used in the display mapping step. Sample of data are first transformed to a data table. Rows represent particular cases and columns are features of the case. The display mapping process maps data into visual structure based on text, color and icon. A prototype is developed to show how visual representations can be used to discover patterns in hydrological data and make decisions based on the patterns. The effectiveness of the decision making based on the visualization system is evaluated for usability and similarity. Figure 1 shows the entry and exit criteria for each step

STEPS	**ENTRY CRITERIA**	**EXIT CRITERIA**
1. Task analysis	- User goals - Previous related work	- Task list -Sample data
2. Data characterization	- Task list -Sample data -Current methods -User requirements	-Data types -Data priorities -Data sources
3.Display	- Task list	-User oriented

ISSN 2229-5518

mapping	-Sample data -Current methods -User requirements -Data types -Data priorities -Data sources	design
4. Prototyping	-Design -Sample data	-Prototype -Platform limitations
5. Evaluation	-User oriented design	-Evaluated by experts -Compare with actual previous situation -Recommended improvements

Figure 1: Steps for the approach

3 RESULTS

Results for each step described in section two are presented.

Task Analysis

An interview was conducted with the dam technician of Timah Tasoh Dam situated in Perlis, a state at the North of Malaysia. The aim was to seek information regarding the management of day to day reservoir operation. Data and users' requirements were collected from the Drainage and Irrigation Department (DID), a government unit that is responsible on the reservoir operation management. The data consists of hydrology information such as rainfall measurements at six stations and reservoir's water level. The interview was transcribed and a list of user tasks in sequential order was produced.

Data Characterization

The hydrology data used in this study are temporal data sets that contain dynamic data. These data changes in time continuously and are constantly updated. The changes are sequential in a successive time frame and can be a regular or unpredictable event. It has special characteristics. An event *e* at time current time, t_n , is influenced by previous event *e* at time t_{n-i} where *n-i +1* is the previous number of time index. Thus, an event can be represented as Equation 1.

$$e_{t_{n+1}} = e_{t_n} + e_{t_{n-i}} \qquad (1)$$

which means that future event is the effect of previous events occurred in the time index. Hence event $e_{t_{n+1}} = e_{t_n} + e_{t_{n-i}}$ indicates a temporal pattern. As shown in Equation 1, the event is temporally continuous that implies the sequential ordering is important and cannot be randomized. The study uses multivariate data that includes two types of data: daily rainfall measurement and reservoir water level. The rainfall causes water level at the reservoir to rise but the rise will occur after some delay. Equation 2 shows the formula:

$$w_t = w_{t-1} + \sum_{i=1}^{k} \alpha\, r_{i,t-d} \qquad \text{for } k \geq 0 \qquad (2)$$

where *w* is the water level at time *t* , *r* is the rainfall at *k* number of collecting stations, *d* is delay and ∝ some constant number. Delay *d* represents a timeframe where a rainfall *r* has influence on water level *w* after some time. The time delay here gives important information to the domain expert and will be used for making decision to release or not to release excess water from the reservoir through the spillway gate openings.

Based on the information above, a visual temporal encodings is created to ensure that it can be reflected by the movement of change to a particular visual structure property over time.

The exit criteria of this step are types, priorities and sources of the data that will be used in the display mapping step. This step focuses on describing the mapping of data attributes (from the data characterization step) to a display artifact. A visual metaphor is used to produce a display mapping. It includes concepts of movement, animation, rhythms and cycles [12]. The mapping is then represented to a design artifact by creating a set of storyboards. The storyboard will be used to design user interfaces.

Display Mapping

Colour codes proposed by the Drainage and Irrigation Department (DID), Malaysia has been used to indicate water levels in rivers and reservoir. Green stands for *Normal* situation, yellow for *Alert*, orange for *Warning* and red for *Danger*. These colors are only applicable for the Timah Tasoh dam. Figure 4.1 shows the information regarding the colors used.

Water Level	Normal	Alert	Warning	Danger
Measurement/m	≤29.0	≤29.4	≤29.6	>29.6
Colour Code				

Figure 4.1: Colour Code for Water Level

A map surrounding the dam was used to indicate the upstream and downstream area especially the location of the rainfall stations and incoming river flow.

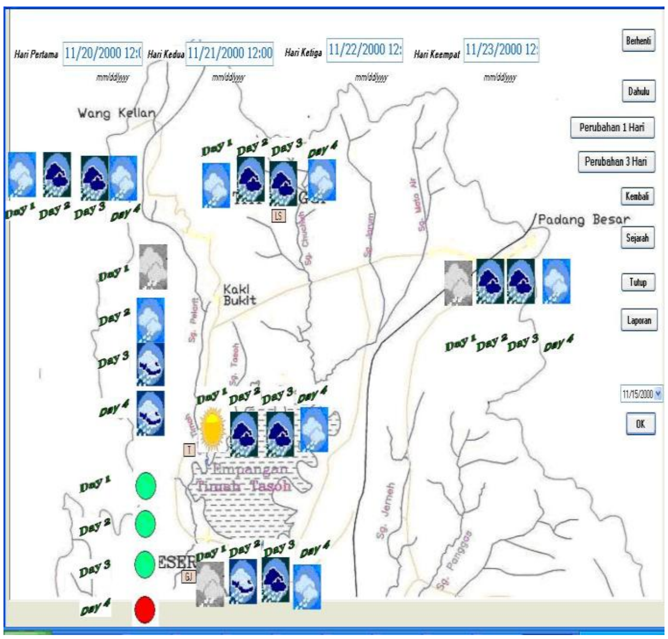
Based on discussion with the dam technician, icons were used to represent the rainfall measurement. Commonly used icons were chosen to represent data values that falls into several categories. The icons chosen are based on small images commonly used by the Meteorological Department, Malaysia and the Malaysian news telecast. No Rain is represented by , Light rain, moderate rain and heavy rain are shown with , , . Very heavy rain is represented with 

ISSN 2229-5518

Representations used such as colour codes, map, and icons are objects that are familiar to users and thus can be associated with user's mental model.

Prototyping

Prototyping is the product development phase. It involves transforming the specified design from the previous step into an application. As mentioned earlier, icons were used to show trends of rainfall and dam water level. A user can select the time frame (*n-i+1*) as shown in representation Equation 1. A user can choose a minimum of two days and up to a



maximum of seven days.

The minimum and maximum days allocated are due to the limitation of the standard computer screen. Figure 4.3 illustrates an example of the screen shot. that shows a four days trend in rainfall and reservoir water level data. The event at day 4 is influenced by event at day 1, 2 and 3. The rainfall around the catchments area at day 1, 2 and 3 caused a significant water rises at the reservoir as indicated by the red circle in the map. The icon displays actual data (shown by the date indicator) that was used in a real operation of the Timah Tasoh dam.

Evaluation

Usability test was used to evaluate the prototype. The prototype was demonstrated to a group of experts. These experts include three DID staffs involved with the dam operation directly and indirectly. The experts evaluated the prototype by walking through their daily routine tasks with the system. This evaluation technique is known as *cognitive walkthroughs* [9]. During the walkthrough, a usability test was used to evaluate the performance of the application in terms of ease of use and ease of learning goals that were laid out in the goal setting task. The overall feedback was positive. Users found that visualization through representations based on users' mental model made them easy to remember thus speed up their process of learning.

Similarity test involves testing and training a selected temporal dataset. The dataset was partitioned into two sets, training and testing. Case-based reasoning was used to check for similarity search on cases in the training set with cases in the testing set. The similarity search process was transformed into a visualization mode for the user to explore and examine. The user can compare the test case or new data with the case-based extracted from the previous operation data. Users can examine the cases closely by exploring the detailed data. Thus, user decision-making can be facilitated by visualization of cases, similarity search and detailed examination.

5 Discussion and Conclusion

Metaphor based visualization approach for hydrological data: The focus of the study is on the process of transforming hydrological data into visual data and making decision based on patterns produced.

As mentioned earlier in the paper, currently the process of deciding to open or close the Timah Tasoh Dam is conducted following written procedures established by DID. As the capacity of the dam changes due to deposits settlement at the bottom of the dam, recalculations by a dam engineer is made to adjust to the new situation. Thus, the recalculated data and other information can only be understood by the dam engineer himself.

The issue is "what if a new engineer takes over the job – can he immediately understands the process and able to make correct decisions?" or "can he understands the figures?". Making correct decisions is crucial in critical situations such as dam water reaching critical level. In such cases, several decisions is needed on opening or closing (i) "how many" gates, (ii) "which" gate(s), and (iii) "when".

A correct decision can save lives and properties in the surrounding area. A metaphor-based approach for visualizing hydrological data has been designed to facilitate a dam engineer or related field worker to make a decision in opening or closing a dam. The approach consists of five main steps task analysis, data categorization, display mapping, prototyping and evaluation.

Visualization of temporal data and patterns: The metaphor-based approach focuses on how information is interpreted from changes over time. The visualization representation process is being done in the display mapping step.

In the display mapping step, visualization of the temporal data and visualization of temporal patterns are constructed. Visualizing temporal data aims to make data more inference and understandable [4] while visualization of patterns include uncovering patterns and trends in the hydrological data. [7] and [1] mentioned that the basic of visualization technique is to represent the data into certain visual form that human being can directly interact with the data to gain insight from the pattern recognition and then to come out with hypotheses.

Here, mental models concepts are applied to identify visual forms or objects that could relate to the hydrological data. Discussion with users and observations confirms selected objects/ representations. Specific icons representing water level, and rainfall measurement that is familiar in context with users were chosen for the user interface. Visualization of patterns is representation of data changes.

For Timah Tasoh, changes are represented with colour codes. Water levels categories are represented by three colours, green, yellow and red. Green shows *Normal* situation, yellow means *Alert*, orange is *Warning* and red represents *Danger*. The colours have been chosen as these are standard colours that have been used world widely on hydrological data. The icons and colour codes were chosen to represent the data values according to the category that has already been used by DID. The icon chosen is based on small images commonly used by the Meteorological Department, Malaysia and Malaysian news telecast. This fact supports familiarity of the icons and can be associated with users' mental model.

The approach is seen to be an advantage as the current technical representation has been argued to be understood only by technical experts. In this study, a user oriented approach has been used to perform task analysis such as decision-making process, identifying a suitable metaphor that is familiar to the users. The aim is to reduce the learning curve in understanding the system or prototype developed. A map (Figure 4.3) gives the user an overall picture of the situation or known as "patterns" of dam water level and rainfall around the catchments area according to various time frames.

Evaluation: The prototype produced is a metaphor based approach. It is meant to show the feasibility of integrating visualization and data mining to facilitate decision making on hydrological data. The usability of the prototype has been analyzed in terms of usability and similarity. The usability test has been conducted based on *cognitive walkthroughs* [9]. Users have been observed to understand the visual representations and visual patterns displayed. The results indicate that the use of user-oriented approach to identify suitable representations produces satisfaction and speeds up understanding process. The incorporation of mental models in visualizing patterns produces positive effects on decision making process and inferences. The finding provides important clues for system designers.

Similarity test was conducted to evaluate the correctness of decision making. The test was conducted using data mining approach, specifically incorporating CBR. The approach was inspired by [0] in which his exploration on integrating machine learning, statistics, data mining and visualization with human intuitive cognitive skills and computer skills produce positive results. This integration resulted speedy and efficient detection of interesting pattern and trend in data. The visualization made on the similarity test process produces an easy checking mechanism. A user can compare the test case or new data with the case extracted from previous operation data. Users can examine the cases closely by exploring the detailed data. Thus, user decision-making can be facilitated and enhanced by visualization of cases, similarity search and detailed examination.

Visualizing hydrological data is one way to facilitate decision making. The visualization process has been conducted through a set of steps. The display mapping is the step that handles the visualization representation tasks, visualization of temporal data and visualization of temporal patterns. Machine learning and data mining are integrated with the visualized data to manage decision making. Results were evaluated through usability testing and similarity testing. Visualization when applied to hydrological data has been found to facilitate users in the process of decision-making. This because through metaphors, that is representing patterns in the form that is close to the users' mental model, improves understanding, speeds up data extraction and thus enhance decision-making process. In critical situation such as flood relieves, speed and accuracy is vital in the decision making process. Thus, visualized hydrological data can help technician in making correct and efficient decision in a short time. Among the problems faced during research is to understand the mental model of the technical people and decision-makers involved. However through the task analysis, user observation and walkthrough, adjustments in the application have been made.

ACKNOWLEDGMENT

The authors wish to thank the Malaysian Government for providing funds to support the research.

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