AN INTERACTIVE DATA VISUALIZATION SYSTEM FOR FLOOD WARNINGS IN TAIWAN

Er-Xuan Sung, Meng-Han Tsai & Shih-Chung Kang
Department of Civil Engineering, National Taiwan University, Taiwan

ABSTRACT: *This paper reports on the development of an Interactive Data Visualization System (IDVS) for flood warnings. Information from multiple sources, such as precipitation, geographical conditions, and the alert threshold, is collected in the system. Users of the system are able to manipulate the information to enhance their understanding of the flood potential. This can help them make timely and correct decisions. We develop four interactive functions: (1) Datatip, (2) Dashboard, (3) Data brushing, and (4) Dynamic queries. A Datatip displays all related data of a particular point or an area when the mouse hovers over. A Dashboard comprises multiple views, allowing users to manipulate and compare the information. The Data brushing function highlights the selected dataset in other views when users choose specific information in which they would like to gain deeper insight. The Dynamic query function provides a scroll bar for users to explore information by dragging the slider. By integrating the four functions, the system provides users with dynamic exploration and intuitive operation. We use data collected from a flood occurring in Taiwan on 10th June 2012 to validate our system. The results show that the IDVS can effectively help integrate decision-making information in real time. The interaction between related information provides users with insightful and versatile views, which can enhance decision-making.*

KEYWORDS: *data visualization, interactive interface, flood informatics, disaster mitigation.*

1. INTRODUCTION

Global climate change has caused the climate to tend to extremes in recent years. Using Taiwan as an example, Typhoon Morakot, formed on 5th August 2009, produced an hourly precipitation exceeding 50 millimeters at two stations for 24 hours. Moreover, it broke the record of the maximum daily accumulated precipitation, 1403 millimeters. Typhoon Megi, formed on 21th October 2010 caused a record-breaking hourly precipitation and daily accumulated precipitation at Su'ao station, 181.5 millimeters and 939.5 millimeters respectively. During Typhoon Nanmadol, formed on 27th August 2011 the hourly precipitation at Kenting station, 122 millimeters, broke the record made by Typhoon Morakot. Floods are often the result of those huge precipitations, causing countless roads and farms in Taiwan inundated with floodwater. Therefore, we should pay more attention to flood prevention and response.

Early warning is described as the process of detecting a possible threat using forecasting models and decision makers. Before taking any action, the decision makers must identify the possible threat (Boin *et al.*, 2005). The emergency response teams in some flood prone areas have designed their own standard procedure which provides early warning for natural disasters. For instance, the Environment Agency and the Meteorological Office in UK launched a service named Extreme Rainfall Alert (ERA) (Flood Forecasting Center, 2010). The service is based on the average 1-in-30 year storm rainfall-intensity thresholds. When the national rainfall threshold for severe urban flood is exceeded, the service will provide a warning for surface water flooding. The Hydrologic Research Center (HRC) in San Diego, California of USA has developed a Flash Flood Guidance System (FFGS) that can be used as a diagnostic tool by disaster management agencies to detect flash floods (WMO, 2007). At National Meteorological and Hydrologic Services (NMHS), the same system has also been integrated into its operation along with other available data, system, tools and local knowledge to aid in determining the risk of flash flood. In the Netherlands, the Royal Dutch Meteorological Institute (KNMI) sends the rainfall risk profile consisting of different rainfall volume events as a warning message to the local districts for further analysis. When one or more risk profiles are expected to occur, an early warning will be issued (NUWCReN, 2012). The flood alert system in Marseilles, France links rainfall intensities to locally relevant flooding thresholds for floods of different estimated return periods (Deshons, 2002). The system has defined four levels of alert in accordance with rainfall intensity and accumulated rainfall. In the research of Hurford *et al.* in 2012, his research team discovered that recording flood event data would facilitate a more accurate analysis after conducting several case studies. However, the influence of using rainfall-runoff models as addressed above to predict flood potential is limited since the

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computation of the model is too time-consuming to make timely decision for flood warnings. In addition, the accuracy of precipitations forecast needs to be improved. Hence, there are still many challenges to establish real-time flood warning with current technologies.

2. FLOOD WARNINGS PROCEDURE IN TAIWAN

Authorities in Taiwan have formulated two regulations, the "Disaster Prevention and Response Act" and the "Central Emergency Operation Center Operating Guidelines", for disaster early warnings. The research center for Weather Climate and Disaster Research (WCDR) at National Taiwan University (NTU) serves as a technical support of disaster preventions and responses to Taiwan Governments. Therefore, we interviewed two experts working in WCDR to understand the operating procedures for flood warnings. The overall procedure is illustrated in Fig. 1. The following paragraphs describe the components of the procedure.

1. *Field*:

There are three kinds of critical information - precipitation, alert threshold, and geographical conditions - generated by the monitoring system, the subject experts' analysis, and the statistical data, respectively, that is collected and saved in the database belonging to the WCDR.

Precipitation: Precipitation is an essential factor widely used in the meteorological field to forecast weather. According to the "Disaster Prevention and Protection Act", the Water Resources Agency of the Ministry of Economic Affairs is responsible for implementing different levels of response when the precipitation reaches three kinds of threshold. Three levels of rainfall - heavy rain, extremely heavy rain, and extremely torrential rain - have been defined based on the 24-hour accumulated precipitation in certain regions, reaching 130 millimeters, 200 millimeters, and 350 millimeters, respectively. If the 24-hour accumulated precipitation of a certain area is more than one of the latter two conditions, the experts will hold a meeting to discuss whether it is necessary to set up a CEOC.

Alert threshold: Each precipitation station has its own alert thresholds, with two different levels depending on the severity of the flood warning, level 1 alert and level 2 alert, defined by The Disaster Prevention Information Service Network of the Water Resources Agency. Level 1 Alert is established if it is continuing to rain in the flood warning area, then there may already be flooding at easy-to-flood villages and roads. If it is continuing to rain in the flood warning area, then there may be flooding at easy-to-flood villages and roads in three hours, which defines level 2 alert. In addition, alert is divided into five types: hourly precipitation, 3-hour accumulated precipitation, 6-hour accumulated precipitation, 12-hour accumulated precipitation, and 24-hour accumulated precipitation. These alert thresholds are formulated based on the experience of past flood events, the data of high flood potential districts, and the data of each rain station and its affected areas. For example, the data of 24-hour accumulated precipitation is obtained by summing the number of precipitations in the previous 24 hours. Based on the date of past flooding events, the experts can calculate the minimum precipitation value that causes flooding at each rain station, which defines the threshold of level 1 alert. Once level 1 alert is determined, level 2 alert can be defined by subtracting 10~50 millimeters from the value of level 1 alert. If necessary, both levels can be revised according to the records of future flood events. If any type of precipitation reaches its own defined alert threshold at a certain station, then a flood warning will be issued in the alert-affected areas.

Geographical conditions: Different geographical conditions may affect the flood potential. For example, the capability of pumping and drainage facilities in different areas leads to different probabilities of flooding. Meanwhile, the loading of Rainwater Drainage Systems (RDS) in different administrative regions is another indicator of flood potential. Other factors, such as low-lying areas and a full tide, may cause severe flooding.

2. *Office*:

After a certain area suffers rain and the precipitation reach the alert threshold, experts in the WCDR, the data analyzers, must monitor the weather conditions continually and analyze related data extracted from the database, such as precipitation, to judge flood potential. As soon as the precipitation satisfies the conditions of setting up a CEOC, the experts will hold meetings to aggregate relevant information to find the solution to the flood and then make reports to the executive for final decision-making. The workflow will be repeated until the flood potential drops to its lowest. The research scope is shown in Fig. 1 (frame A). This begins with the data analyzers extracting their required data from the database, followed by analysis and judgment, and then a meeting and decision-making.

The particular process regarding data gathering, which is represented by the red arrow inside frame A, will be discussed later in section 4.1.

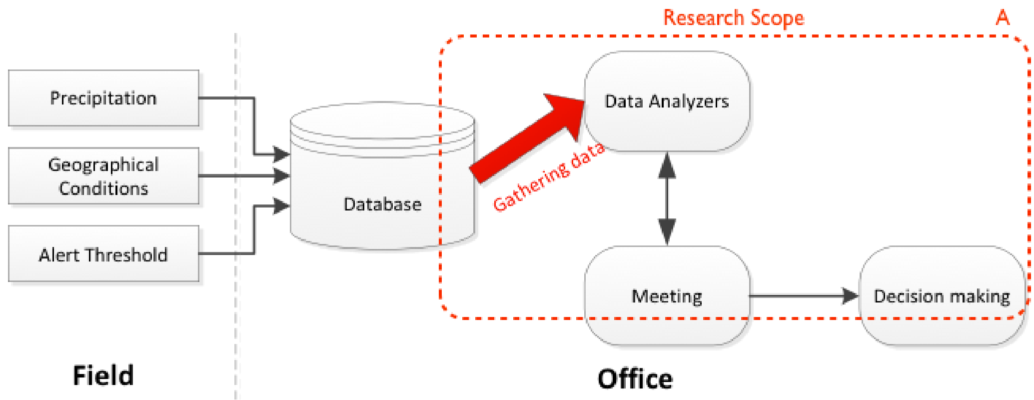

Fig. 1: Empirical model of flood warnings procedure in Taiwan.

3. DATA VISUALIZATION

Many investigators have attempted to help users extract useful information from the available data. The amount of data and information has rapidly increased over the last decade. The better-educated processes and procedures have also become quite complicated. Shneiderman (1986) mentioned that the time required by the human perceptual system to understand knowledge is less than that of the cognitive system, and that the human visual system is the fastest among the perceptual systems. The research of Crapo *et al*. (2000) indicated that humans are able to make judgments when observing a number of visual characteristics (including movement, color, size, orientation, *etc*.) without any conscious effort. Human brains depend on short-term memory and long-term memory to process the received perceptual task. Card *et al*. (1983) pointed out that images can more easily trigger the perceptual system to understand things than normal text and numbers, which aids short-term memory to a certain extent. Moreover, short-term memory can develop into a part of the long-term memory. Visualization can provide an intuitive understanding of complex data (Johansson *et al*., 2010). Utilizing visualization technology to present large amounts of data and information as images can transfer some of the work of information processing from the cognitive system to the perceptual system. Hence, the rate at which the human brain can absorb knowledge is accelerated. Visual technologies contribute to various stages of better-educated processes, providing researchers with a variety of different angles to observe the data. They can discover new knowledge by identifying possible spatial connections and the characteristic patterns in a multi-dimensional database. The man-machine interface (also known as a user interface) has made a revolutionary change in many fields, and has improved communication between the data and the end-user. Because human beings can quickly understand a visual representation of how different entities are connected and their relative positions, interface designers can take advantage of this feature to transfer some messages from cognitive systems to perceptual system (Shneiderman, 1994).

Different available visualization techniques conveying different levels of understanding are of use in different situations. In other words, visualization techniques make huge and complicated amounts of information intelligible. The common visualization techniques are divided into three categories: data visualization, information visualization, and interactivity (Khan & Khan, 2011). Data visualization is the study of the visual representation of data, which means information that has been abstracted in some schematic form, including attributes or variables for the units of information. In contrast, information visualization concentrates on the creation of approaches for presenting abstract information in intuitive ways (Thomas and Cook, 2005). Interactive visual representations of information—the basic purpose of visualization—can exploit a human's perceptual and cognitive capabilities for problem solving (Colin Ware, 2004). The goal is that a user can easily understand and interpret a huge amount of complex information.

4. RESEARCH OBJECTIVES

The objective of this research is to develop an interactive data visualization system (IDVS) that can assist experts in exploring the multi-dimensional data of a flood. To achieve this objective, we would like to develop a system that can deal with the large amount of data and provide users with an intuitive operating interface so that they can concentrate on analyzing and judging data of the latest situation and return it to the central decision-making unit. To increase the efficiency of data analysis and judgment, the system needs to reduce the time they take to explore the data. A user interface that can simultaneously present a variety of information and allow users intuitive operation can improve the performance of the flood warning. Because the flood data and geographical conditions come from different sources, the system needs to integrate them in order to obtain the best visual performance.

5. THE INTERACTIVE DATA VISUALIZATION SYSTEM

In this research, we developed an interactive data visualization system (IDVS) to help users make crucial decisions. Huge amounts of disaster-related data, which are of different types and stored in various formats, are generated from different sources. The decision makers also can use IDVS to make accurate judgments based on huge sets of disaster-related multi-dimensional data.

5.1 Gathering data

In order to present such data in more efficient ways, we divided the date into two categories in the IDVS: rainfall-related data and geographic data.

Rainfall-related data: The rainfall-related data include precipitation station numbers, recorded date and time, hourly precipitation, and accumulated precipitation in the previous 3, 6, 12, and 24 hours. The precipitation data are raw data generated by automatic precipitation monitors belonging to the Central Weather Bureau (CWB). We gathered the data source from existing databases of CWB by using SQL Server Integration Services (SSIS) platform.

Geographic data: The geographic data are collected within three different files and from different resources, including the positions of Taiwan's precipitation stations, the alert threshold based on different precipitation stations in Taiwan and the alert-affected area, and both the boundaries of Taiwan's administrative regions and Taiwan's townships. The file containing the positions of Taiwan's precipitation stations, provided by the Water Resources Agency in CSV format, comprises each precipitation station's name, longitude, and latitude. The file containing alert thresholds based on different precipitation stations in Taiwan and the alert-affected area, provided by the Water Resources Agency in CSV format, comprises each precipitation station's name, its administrative region's name, the town's name, the affected areas' names, the level 1 alert of flood warning at each station, and the level 2 alert of flood warning at each station. The file containing the boundaries of Taiwan's administrative regions and Taiwan's townships, provided by the Institute of Transportation of the Ministry of Transportation and Communications, contains TWD97 data in SHP format. The polygons representing the boundaries of Taiwan's towns are produced by inputting the package from the gathered prime data into the IDVS. Then we create an Excel file, a requirement of the package, comprising each town's serial number, each administrative region's name, and each town's name.

Finally, we converted the three CSV file formats to XLS, the same as the latter file. In this way, we can integrate the three different files. Thus, we inputted a single file composed of three spreadsheets into the IDVS.

5.2 Functions of the IDVS

In order to assist users in exploring this complicated data in more efficient ways, we develop the following four visual interactive functions:

Datatip: Datatips are tooltips showing data values or enumerations when a mouse hovers over a point, area, label, *etc*. Users can roll over various points within a graphic while the data associated with those points appears immediately in the datatip.

Dashboard: Dashboards provide a collection of multiple visual components fitted entirely on a single computer screen, including the most information needed to achieve one or more objectives, so that the information can be monitored at a glance. Interactive exploration, combined with appropriate visual representations using colors, size, and shape, can amplify human cognition and enhance information understanding.

Data brushing: If two or more views make up a dashboard, then, whenever a user selects a set of data points or just a point or area in one view, the selected dataset, point, or area in the other views will also be highlighted in real time.

Dynamic queries: Dynamic queries provide easy-to-use standard controls, such as sliders and checkboxes, to filter the data set immediately and interactively when users adjust those controls and the results appear on the display.

5.3 System architecture

The overall composition of IDVS is illustrated in Fig. 2. It has a two-layer structure comprising a user interface layer and a data layer. The blocks represent the major components or functions in both layers. The arrows between each layer represent the direction of communication or the flow of data. The user interface layer provides users with functions to directly manipulate and interact with each view in a dashboard, which can present the results in a visual way. The data layer consists of four components. There are two kinds of database, historical and real-time. In this paper, we extract precipitation data from historical database which was collected during a flood event from 10th June to 16th June 2012 (called the 610 flood). The data processor is responsible for extracting data from the database and satisfies the demand of view table; and the view table generates elements in the dashboard. During the user phase, users can manipulate elements in the dashboard directly and obtain synchronous feedback visually.

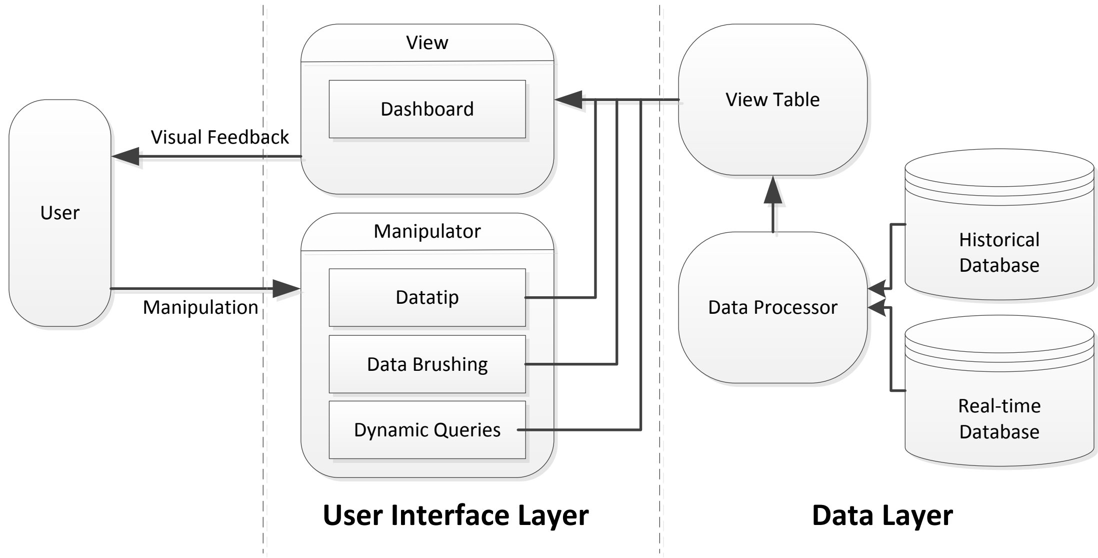

Fig. 2: The two-layer structure of the IDVS.

5.4 Displaying information in the IDVS

In the past, experts from different fields first collected the relevant data and continued monitoring the latest conditions in order to prevent human lives and property from being threatened when there is a flood potential. In this research, the IDVS is designed to display three kinds of information within a dashboard: precipitation, geographical conditions, and alert threshold. The IDVS provides an intuitively operated interface so that users can make timely decisions. Fig. 3 shows the user interface of the IDVS. The upper-left-side window (Frame A) shows the distribution of the precipitation stations that reach certain level of flood warning. The lower-left-side window (Frame C) lists the towns that already have a high level of flood potential. The center window (Frame D) displays the distribution of those towns with high flood potentials. The following paragraphs describe each display of the IDVS separately.

Precipitation: Precipitation is a critical indicator when judging flood potential. Once the 24-hour accumulated precipitation exceeds the threshold of extremely heavy rain, the experts would inform the authorities concerned about holding a meeting to discuss the set-up of a CEOC. As shown in Fig. 3 (Frame A), the circles represent the stations' rainfalls during the hourly time interval, at 8:00 pm on 12th June 2012, and the 1-, 3-, 6-, 12-, and 24-hour accumulated precipitation of each station is proportional to the radius of those circles.

Alert threshold: This research uses two different colors to represent the alert status of each precipitation station: the orange spots represent the 24-hour accumulated precipitations reaching the threshold set up by the CEOC, and the blue represents one that reaches level 1 or level 2 alert of flood warning, but has not reached the threshold of the CEOC set-up.

Geographical conditions: According to experience, the same flooding situation may occur when both the same precipitation and geographical conditions of a previous flood are satisfied. Thus, the Water Resources Agency has designated alert-affected areas based on each precipitation station's location. The dashboard in Fig. 3 shows the situation on 12th June 2012 at 8:00 pm. As shown in Fig. 3 (Frame B), we can see that there are 73 towns that reach extreme torrential rain, 350 millimeters. Fig. 3 (Frame C) lists the alert-affected towns' names in detail, and Fig. 3 (Frame D) shows the distribution of those towns. In this way, users can realize the flood potential situation with direct visual feedback. Experts may also make judgments based on the high flood potential regions. The khaki-colored belt areas in Fig. 4 (Frame A) represent the high flood potential regions in Taiwan. Hence, when the regions with flood potential (the orange areas in Fig. 4 (Frame A)) overlap with the high flood potential regions, the probability of a flood occurring is greatly increased.

5.5 Interaction functions in the IDVS

Datatips: As shown in Fig. 6, some detailed data, such as precipitations, a station's name, and the warning areas' names, are displayed in a tooltip when users place the mouse over the desired station. In the past, we had to manually match this data between different Excel sheets and then list them in a table. Thus, the use of the datatip function obviously helps users to get required information more efficiently than before.

Dashboard: As shown in Fig. 3, the use of the dashboard maximizes the performance of the IDVS. Unlike the traditional approach, which can only show those views on a static display, users can interact and compare the flood-related information simultaneously within different displays on a single screen. In some circumstances, users need to gain a deeper insight to understand the trend of rainfall over a certain time interval. Hence, we designed a function that allows the user to browse the precipitation hyetograph of a certain station. As shown in Fig. 5, the subview of dashboard is displayed when users select a circle representing a certain precipitation station in Fig. 3 (Frame A). Frame A1 highlights the station's position on a map of Taiwan, while Frame A2 highlights the bar representing the precipitation measured by the station on 12th June 2012 at 1:00 am.

Data brushing: As shown in Fig. 7, when users select an element in the lower-left-side window, other relevant elements of that selected element in other displays will be highlighted. For example, when an alert-affected town's name is selected, the source precipitations in the upper-left-side display, and the alert-affected area's location in the right-hand-side display will be highlighted. Thus, users can rapidly learn the absolute positions of those affected areas.

Dynamic queries: In this research, we designed two scroll bars for dynamic queries function. The first bar allows users to adjust the 24-hour accumulated precipitation. As shown in Fig. 3 (Frame E), when users increase the threshold of 24-hour accumulated precipitation by scrolling the slider while keep the dates and time as the same, the number of precipitation stations reaching the threshold decreases. For example, when adjusting the value from 200 to 350, users can find out that within the same date, under which threshold will have the requirements of the set-up by CEOC, as shown in Fig. 8. The other scroll bar allows users to adjust dates and times. As shown in Fig. 3 (Frame F), when dragging the slider of the scroll bar from left to right, users can browse the changes in the precipitation distribution by hour. For example, when dragging the time slider from 10th June 2012 at 3:00 pm to 12th June 2012 at 3:00 pm, users can learn that the number of warned towns rose from 5 to 25 and also see the changes of orange polygons' numbers, as shown in Fig. 8.

6. COMPARISON BETWEEN EXISTING AND IDVS PROCEDURES

We chose data from the flood beginning on 10th June 2012 (called the 610 flood) in Taiwan to implement our system. We make two comparisons between the existing procedure and the IDVS procedure. The first is to compare the information rendering approach and the second is to compare the efficiency of decision-making.

In the existing flood warnings procedure, the rendering of information has limited interaction with users so that they can only make judgments based on reading paper reports back and forth repeatedly. Moreover, the experts present their own viewpoints individually based on different sources, so that it is difficult for them to reach a consensus. The current procedure lacks an integrated platform for experts to communicate, so the procedure for making judgments to decision making takes a long time.

By using the IDVS to deal with flood warnings, users can intuitively make judgments by interacting with information in the user interface. The IDVS has integrated flood-related information so that it can improve the efficiency of communication and accelerate the procedure from making judgments to decision making.

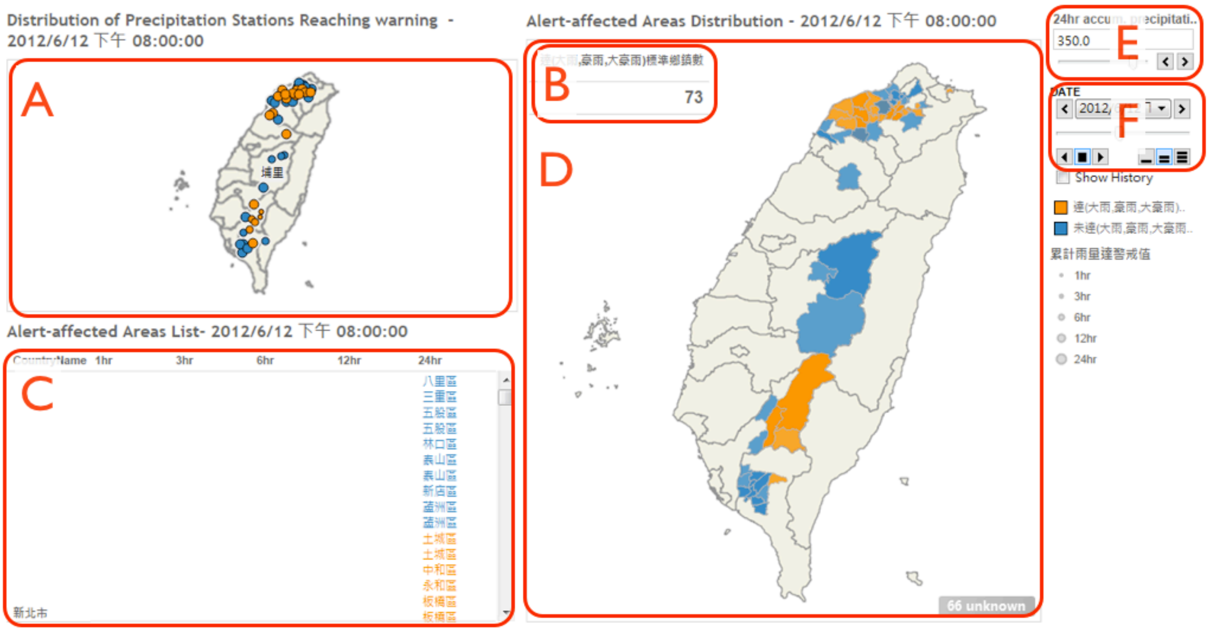

Fig. 3: Dashboard: Distribution of precipitation stations having reached level of flood warning.

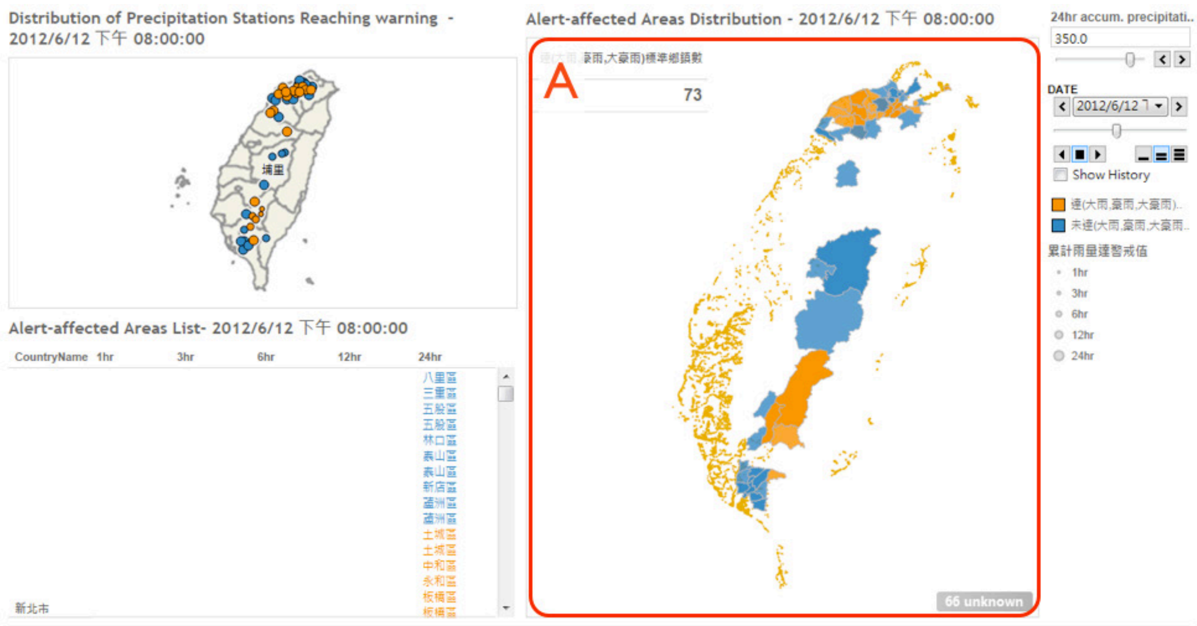

Fig. 4: Dashboard: the high flood potential regions.

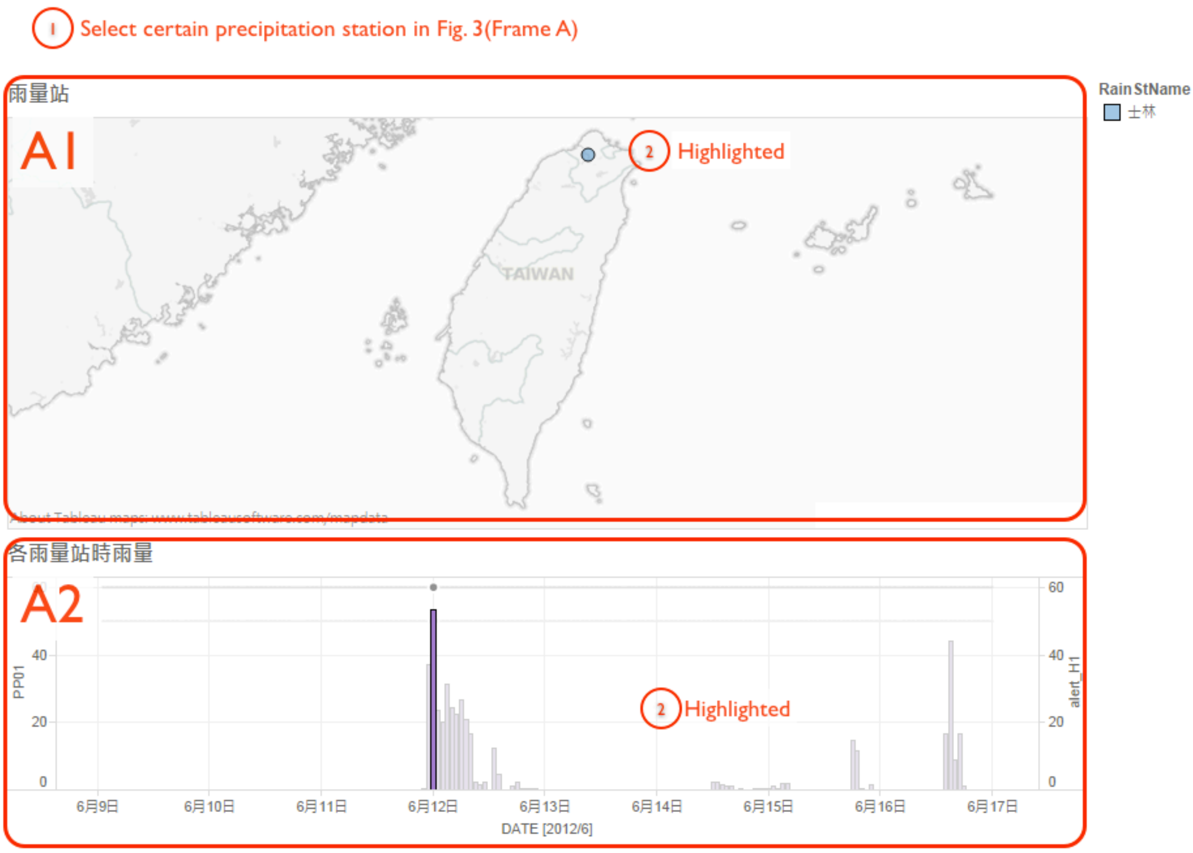

Fig. 5: Subview of the dashboard: the location and hourly precipitation hyetograph of a station.

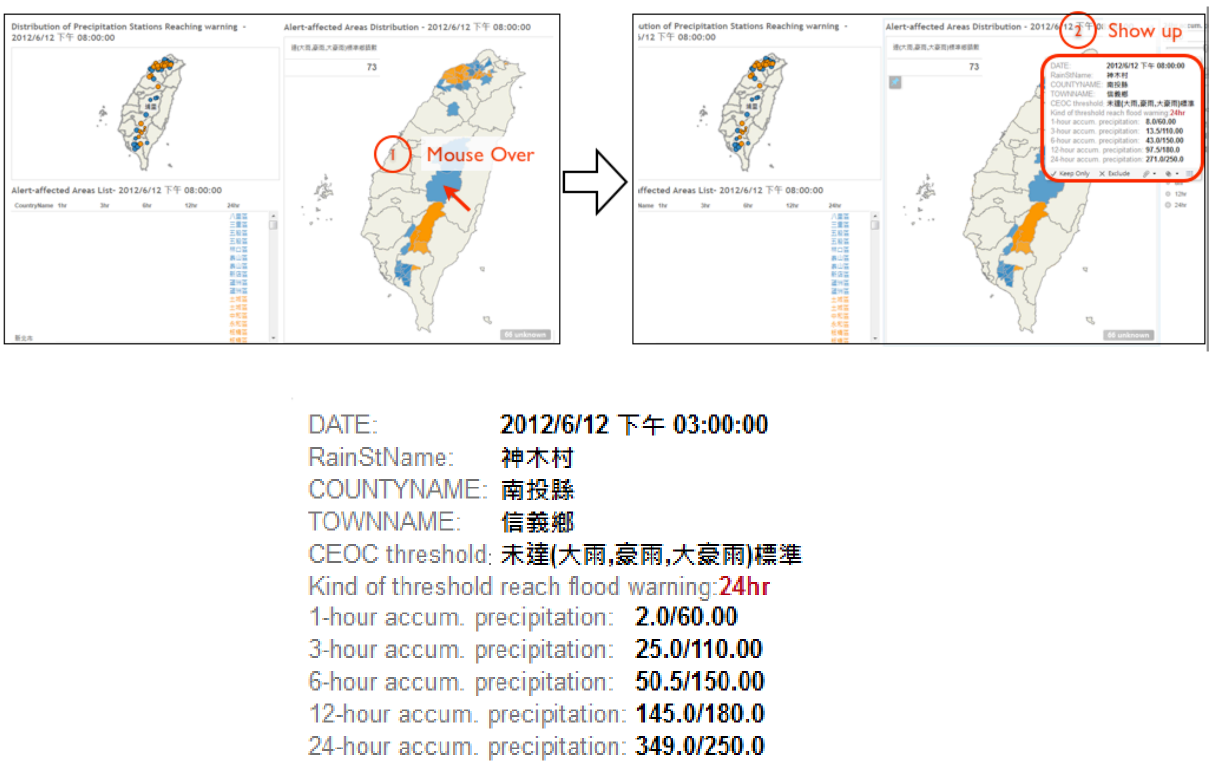

Fig. 6: (Top) The Datatip function and (bottom) datatip box

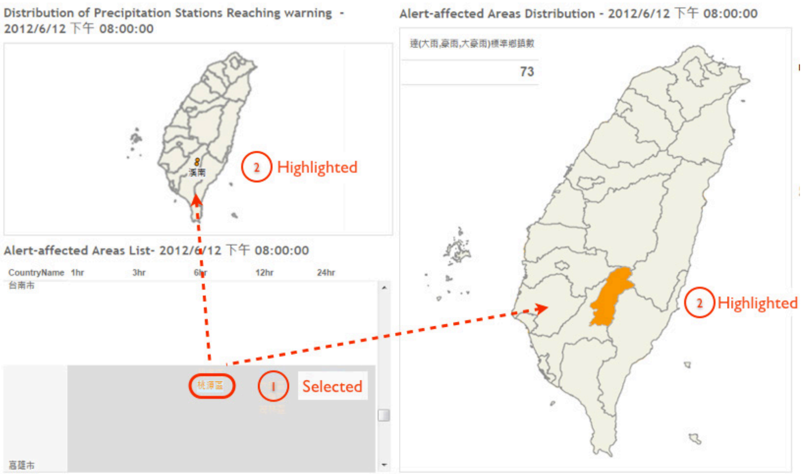

Fig. 7: The Data brushing function.

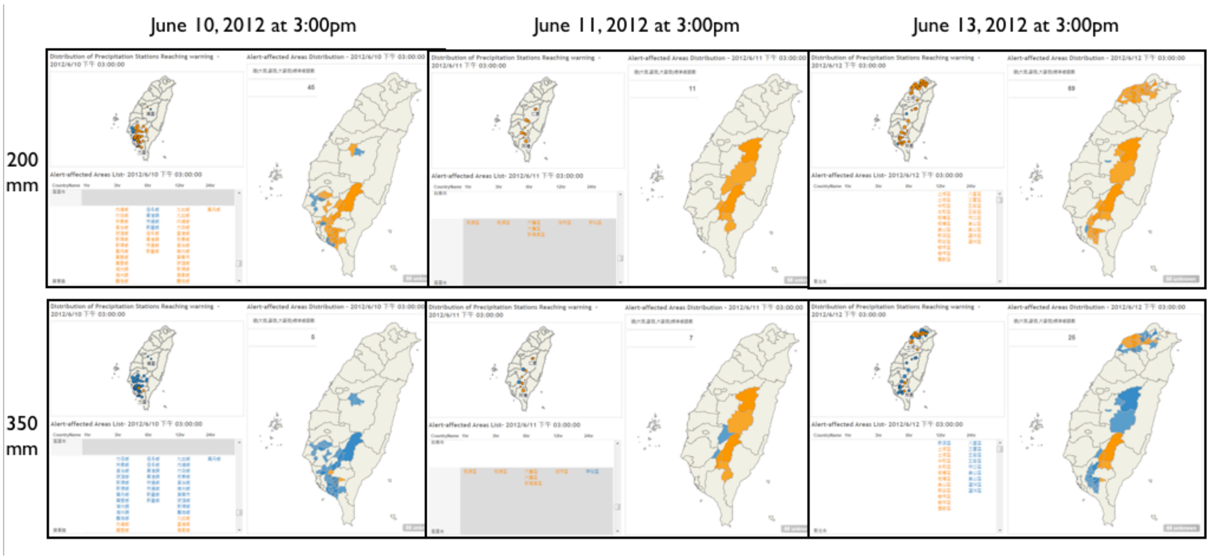

Fig. 8: The Dynamic queries function (Figure changes horizontally by changing the date, and changes vertically by changing the alert threshold.)

7. CONCLUSION AND FUTURE WORK

In this research, we develop an Interactive Data Visualization System (IDVS) for flood warnings that can help decision makers rapidly determine the potential flood areas and react with disaster mitigation plans accordingly . In the IDVS, the multi-dimensional flood-related data is collected, and each row contains property-wise information such as the 1-, 3-, 6-, 12-, 24-hour precipitation accumulations and its own alert threshold for two different levels of flood warning. Four interactive functions, Datatips, Dashboard, Data brushing, and Dynamic queries, were developed for this system, which allowed users to manipulate the critical information directly and to obtain visual feedback. Datatips display different levels of detailed information hidden behind a specific element, from different event dates, locations, to precipitations and alert thresholds, when the mouse hovers over it without losing the overall sense of clarity. By collecting both the rainfall-related and geographical information together in a single dashboard, users are able to gain deeper insight into their relationship by comparing different views and making communication more convenient than paper-based presentation. Data brushing allows users to explore the exact locations of the towns and their triggered precipitations in other displays. Dynamic queries provide two scroll bars that are able to filter the data by date and time or by the 24-hour accumulated precipitation. This research used disaster information from a flood occurring in Taiwan on 10th June 2012 to implement the system.

Thus, the proposed method can improve the efficiency of dealing with multi-dimensional information and facilitates decision making for users. As a result, by taking advantage of the IDVS, users can save time usually wasted on mapping information coming from different sources and inefficient communication with team members. In future research, we will conduct an interview with five experts by offering five practical problem–related questionnaires to see the experts' exploration of the IDVS program and their assessment. The results will show whether this system can allow users to easily comprehend and interpret disaster information.

8. ACKNOWLEDGEMENT

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