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Navigating High-Resolution Image Visualization on a Large Display using Multimodal Interaction

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Abstract

Recently, there has been a significant increase in research on interactive visualization on a large display. Large display enables multiple people to work together to view and analyze large amounts of data at an extremely high-resolution. It also has the potential to promote a collaborative workspace for simultaneous interactions between multiple users. In this research we introduces the multimodal user interaction for navigating the high-resolution image visualization on a large display utilizing a multi-touch screen (near), Kinect gestures (far) and mobile interfaces (indirect). This approach aims to help multiple users seamlessly interact with the high-resolution visualization regardless of the distance between the user and the display.

Keywords: High-Resolution Image Visualization, Multimodal Interaction, Multi-User Simultaneous Interaction, Large Display

INTRODUCTION

As technology development grows very fast and becomes more diversified, it eventually becomes easier to analyze and predict occurrences in various fields, and this is particularly true for the field of weather. The increase of unusual climate changes including unexpected snow or rainstorms has made weather analysis and prediction an important necessity. That is why organizations such as the National Meteorological Satellite Center (NMSC), the Korea Meteorological Administration (KMA), and the Korea Institute of Ocean Science and Technology (KIOST) use meteorological and marine observation satellites for early detection of dangerous weather conditions [1]. They also develop innovative technologies such as hurricane analyzers and ultra-fast live weather predictions.

These technologies produce greater amounts of data, and such data often need to be correlated and interpreted by experts to find out more insight and knowledge. Under the circumstances, visualization is still one of the most powerful means in helping researchers solve problems and gain insights from the enormous amounts of data [2]. In order to analyze weather changes, experts in this field need to come together as a team in an interactive collaborative environment. Hence, this research introduced the multimodal user interaction for a high-resolution satellite image visualization system on a large display to help improve weather analysis and prediction.

Over the last few decades, a large display has become prevalent in various application domains, such as large-scale scientific visualization, education, game and public collaboration [3-6]. It is found that people gain productivity benefits from large tiled display as it provides greater physical space for collaboration of multiple users, delivers higher densities of information, and improves visibility at a distance [7-9]. Earlier research has focused on building tiled display systems and distributed rendering software for high-resolution graphics that cannot be displayed on the single display system [10-12]. Recently, a wide variety of interaction techniques and input devices have also been developed and examined for large display. However, there is only little research that deals with multimodal interaction on a large display.

Recently, there has been a significant increase in research on a large display. The large display provides more screen space for collaboration, higher densities of information and better visibility at a distance. However, user interaction on a large display is still challenging due to its screen resolution and size. This triggered a great deal of discussion regarding the interaction techniques on a large display [13,14]. There have been many works proposed for user interaction on a large display. Such research has garnered a great deal of attention, especially those that have investigated ways in utilizing large screens more efficiently [2], adjusting the cursor position or size [14], and creating new widgets to alleviate the difficulties in accessing distant information [15,16].

Furthermore, a lot of research has been devoted to various forms of input devices for large display such as physical movement in front of the display [17,18], a 3D gyro mouse [6,17] or Nintendo’s Wii remote controller [19], laser pointer [20], and specialized glove [21]. Following the widespread use of smartphones, research on interaction methods for large display has expanded to include the use of multi-touch screen wall [2,5], computer vision-based motion tracking and gesture

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interfaces [4,22-24], and mobile devices [3,25,26]. This naturally led researchers to consider the simultaneous use of multiple input devices by multiple users [12,27,28].

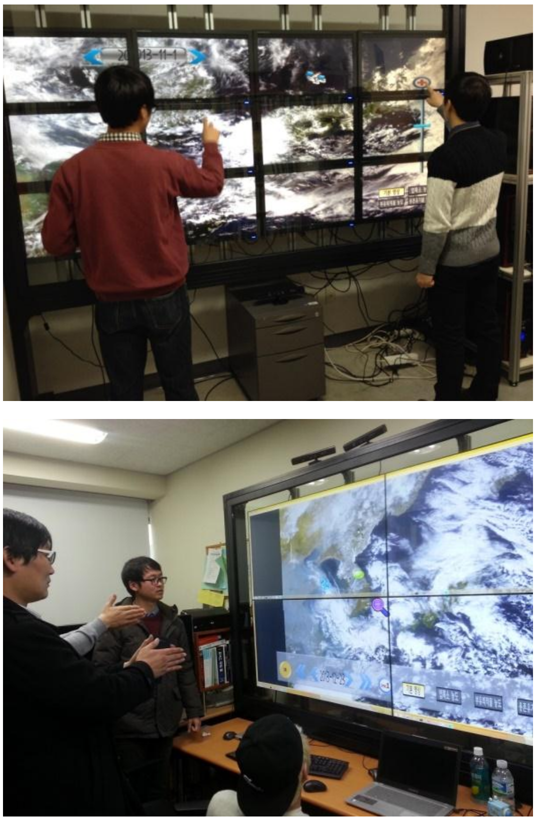

Figure. 1 User interaction using multi-touch, freehand gestures, and mobile interfaces with the Geostationary Ocean Color Imager (GOCI) high-resolution satellite image visualization on the 4x3 tiled display (top image) and the 2x2 large public display (bottom image)

Figure 1 shows researchers from KIOST interacting with the Geostationary Ocean Color Imager (GOCI) satellite image visualization system. They inspect high-resolution imagery data simultaneously and collaboratively using multi-touch screen, freehand gesture, and mobile interface both near the screen and from a distance. This multimodal interaction enable users to seamlessly perform the same actions with various input device. It makes easier for multiple users to come together and choose the desired input device rather than being restricted to use a single input modality, which makes interaction with a large display more effective and natural.

In this GOCI visualization system, the multimodal user interaction is implemented using direct multi-touch, freehand gestures, and a mobile interface. In order to operate the multi-touch screen, users must be right in front of the screen. Gesture interaction makes it possible for users to interact with the display at a distance as long as the users are within the camera's field of view. The mobile interface eliminates such spatial limitation and provides freedom of more indirect interaction with the additional information and data. Each input device has advantages and drawbacks, and this multimodal user interaction allows users to select input devices according to their needs and spatial requirements.

This paper first briefly describes the system overview of the GOCI (Geostationary Ocean Color Imager) satellite image visualization. It then discusses the design and the implementation of multimodal user interaction for the GOCI image visualization. Finally, it presents the conclusions and future directions.

GEOSTATIONARY OCEAN COLOR IMAGER (GOCI) SATELLITE IMAGE VISUALIZATION SYSTEM

Geostationary Ocean Color Imager (GOCI) is Korea's first static orbit meteorological satellite, operated by the Korea Institute of Ocean Science and Technology (KIOST) [1]. It provides high-quality images of ocean-color around the Korean Peninsula (covering 2,500km×2,500km) and allows for observation of short-term changes. For more than 7 years, it has captured the color of the ocean by taking 8 images per day at 500 meter spatial resolution. It also monitors and collects ocean data such as chlorophyll concentration, optical diffuse attenuation coefficients, concentration of dissolved organic material, and concentration of suspended particles.

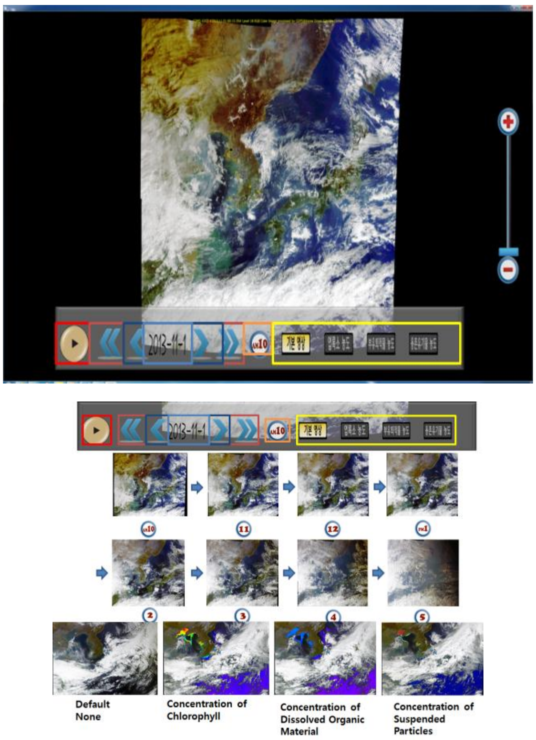

Figure. 2 The main screen of the Geostationary Ocean Color Imager (GOCI) visualization with animation play/pause, date (month/day) change, and ocean state buttons (default none, concentration of chlorophyll, concentration of dissolved organic material, and concentration of suspended particles)

Figure 2 shows an interactive high-resolution multi-level GOCI visualization system. This visualization shows the GOCI images observed in recent months and years. It displays a total of eight images from morning to night on a particular day in animated form so that the dynamic changes in ocean color for the day can be easily observed. In this system, users can move, magnify, or scale down the satellite image. They can also choose to play or pause animation or view a static image for a certain time of day. Furthermore, they can view the color of the ocean at four different states, i.e., default none, concentration of chlorophyll, concentration of dissolved organic material, and concentration of suspended particles.

Table. 1: The User Interaction for the GOCI Visualization System

User interactions	Category
Image Move (IM) Image Zoom (IZ)	Navigation
Date Change (DC)	Manipulation
Button Selection (BS)	Selection
Marker (MM)	Pointing
Snapshot (S)	Indirect command

As shown in Table 1, the user interaction for the GOCI visualization system is categorized as navigation, selection, manipulation, pointing, and indirect command. Image Move and Image Zoom are navigation tasks where users can freely move around or zoom in or out on the satellite image. Date Change and Button Selection are manipulation and selection tasks where users can specify the action or modify data properties or behaviors, e.g. animation play/pause, date change, and ocean states. Marker is needed for pointing (such as to select the button or move the slider bar). Snapshot and Weather information are provided on the mobile interface (as indirect command interaction).

The GOCI visualization system runs on a large high-resolution display and a cluster-based tiled display system. The large public display system is composed of four 40-inch thin-bezel Full HD LCD panels to create a seamless large 4K (3840 x 2160 screen resolution) public display screen. This system is driven by one computer and two high-quality graphics adapters, each with two graphics output ports connected to the LCD panel. The 4x3 tiled displays is constructed with twelve 24-inch LCD monitors (7680 x 3600 screen resolution). It is driven by a clustered system consisting of a master and six slave computers. Each slave computer is connected with two LCD displays and renders a portion of the entire screen. These individual parts are then brought together to create the full display.

The GOCI visualization system has been designed and developed with multimodal user interaction techniques using multi-touch, freehand gestures, and mobile interface. The multi-touch screen is used to support direct interaction of the near display users. The freehand gesture interaction is supported for users located at a distance from the display screen. The mobile interface is used for indirect and two-way user interaction. As mentioned, these devices can be used in any combination depending on the users' needs, while enabling seamless multi-scale user interaction.

DESIGN OF MULTIMODAL USER INTERACTION FOR GOCI VISUALIZATION SYSTEM

Table 2 shows the design of multimodal user interactions for the GOCI high-resolution multi-level satellite image visualization system. The multi-touch, freehand gestures and mobile interfaces are provided for near, far, and indirect-interaction modalities. The marker represents the cursor or pointer of each user interacting with the GOCI visualization system. The visual representation of the marker indicates "presence" of the user in the multi-user collaborative environment. Since the multi-touch screen can distinguish different users by their direct touches, the marker is not implemented for this input device.

Table. 2 Design on Multimodal User Interaction for the GOCI Visualization

	Multi-touch (Near)	Gesture (Far)	Mobile (Indirect)
IM	One finger pan	Left hand pan	One finger pan (Image Mode)
IZ	Two fingers stretch and pinch	Both arms stretch and pinch	Two fingers stretch and pinch (Image Mode)
DC	Three fingers slide	Left arm to the side and right hand pan	Date button press (Image Mode)
BS	One finger tap	Right hand hold	One finger double tap (Marker Mode)
MM	-	Right hand pan	One finger pan (Marker Mode)

1. Design of Multi-touch Interaction

The multi-touch panel is an input device that responds to finger contact on its sensors. Users must be near the screen and touch the screen with their fingers, which makes input error rare. Not only is the method itself easy, the generated events are distinguished depending on how many input points there are. The distance between the touch inputs is used to distinguish multiple user interactions when many users simultaneously use the touch screen. Figure 3 shows the multi-touch user interactions defined for the GOCI visualization system.

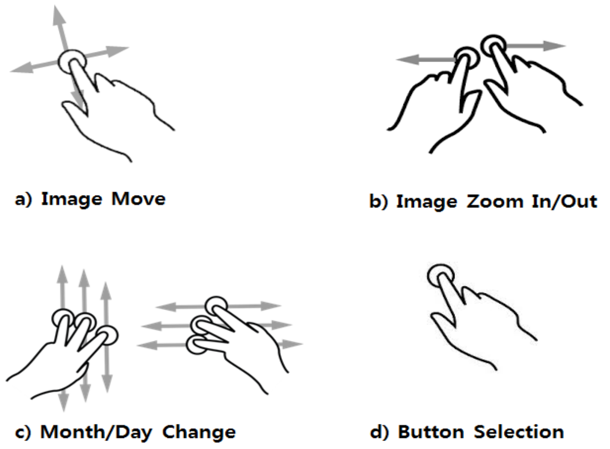

Figure. 3 Design of Multi-touch Interaction for GOCI Visualization System

Image Move (IM): One-point touching and dragging interaction moves the camera, allowing users to freely change the view of the satellite image. If multiple users move the camera at the same time, the user who has touched the screen first will have a first go at the camera. A visual feedback will appear over the other person's touch point telling them to wait. This will prevent undue conflict over who controls the camera.

Image Zoom (IZ): Two-point touch input interaction zooms the image in or out. Spreading two fingers outward causes the camera to zoom in and pinching the fingers close together causes the camera to zoom out.

Date Change (DC): With three-point touch input, swiping up moves the image to the next month and swiping down moves the image to the previous month. Swiping the left side (with respect to the user) of the screen moves the image to the next day and swiping the right side of the screen moves back to the previous day. If one user currently has control over the camera, the date cannot be changed.

Button Selection (BS): One-point finger tap on a button is processed as a button selection event. The buttons on the screen can be used to play or pause the animation of the satellite images, move to a different date, or display a different ocean state.

2. Design of Gesture Interaction

A motion-based freehand gesture interaction allows users, after stepping back from the screen, to use gestures to interact with the display. With gesture recognition techniques, each user is detected and given an identity and a number of different gestures can be specified. In the GOCI visualization system, users can freely interact with the satellite image datasets through a set of gestures. In order to create consistency in the multi-scale user interactions, the gesture interaction was designed as shown in Figure 4.

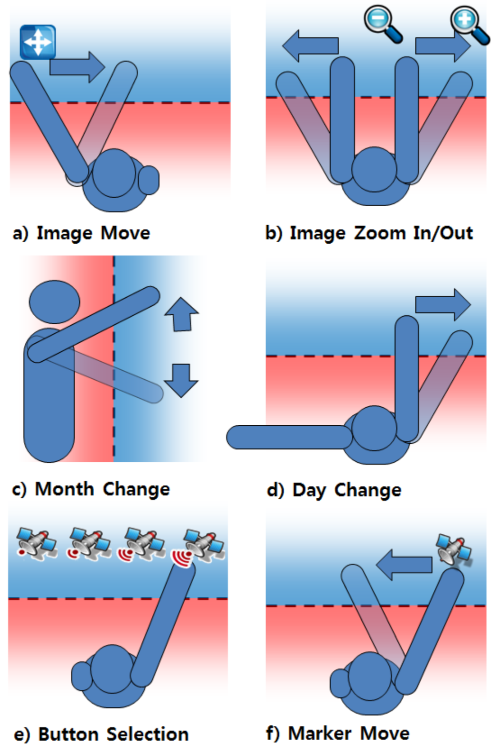

Figure. 4 Design of Gesture Interaction for the GOCI Visualization System

Image Move (IM): The user can move the view of the satellite image (i.e., change the camera view) by reaching his/her left arm out and moving freely in different directions.

Image Zoom (IZ): The user can zoom in while observing the satellite image by extending and spreading the arms outward. Conversely, zooming out will be achieved by extending the arms and moving them close together.

Date Change (DC): The user can change the month/day of the satellite images by moving his/her right arm from top to bottom (for change of month) and from left to right (for change of day) with his/her left arm set to the side.

Button Selection (BS): After moving the marker pointer to a button on the screen, the button can be selected by holding a marker on the button for three seconds. Figure 4 (e) shows the changes of the marker according to the time the button is selected.

Marker Move (MM): When the Kinect sensor recognizes a new user, the user's personal marker (different color) pointer will appear on the display. The user can move the pointer by moving his/her right hand with arm extended (with the left hand set to the side).

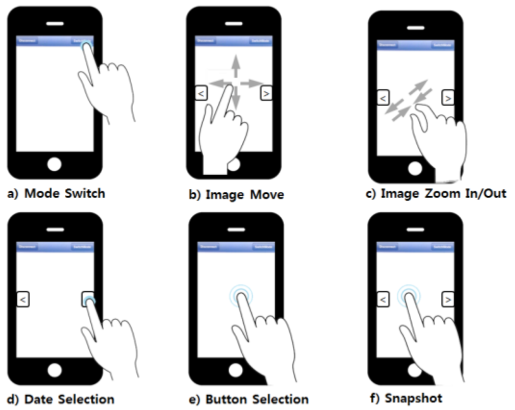

Figure. 5 Design of Mobile Interface for the GOCI Visualization System

3. Design of Mobile Interaction

When multiple users share the GOCI visualization system, personal mobile devices can be used to interact with the system. Additional information (e.g. detailed weather) can be viewed or data can be saved (e.g. screen snapshot) on the mobile device through communication with the visualization system. Even users not in the proximity of the display can interact with the visualization system using the mobile device. In other words, the mobile device eliminates spatial limitation. Figure 5 shows that there are two modes available for mobile device interaction.

Mode Switch: The user can toggle the Mode Switch button on the mobile interface to change the user interaction mode. In Marker Mode, only the marker can be moved. In Image Mode, only the satellite image can be manipulated.

Image Move (IM): The user can drag his/her finger on the mobile touch panel in Image Mode to move the satellite image on the large display.

Image Zoom (IZ): The user can stretch or pinch his/her fingers on the mobile touch panel in Image Mode to zoom in or out of the satellite image.

Date Change (DC): The user can press the '<' and '>' buttons on the mobile touch screen in Image Mode to change the date of the satellite images.

Button Selection (BS): The user can double-tap on the mobile touch panel in Marker Mode to select a button on the large display (after placing the marker on the button).

Marker Move (MM): In Marker Mode, the user can drag a finger on the mobile touch panel to move his/her personal marker on the large display.

Snapshot: The user can double-tap on the mobile touch screen in Image Mode to take a snapshot of currently visible satellite image and save it into the mobile device.

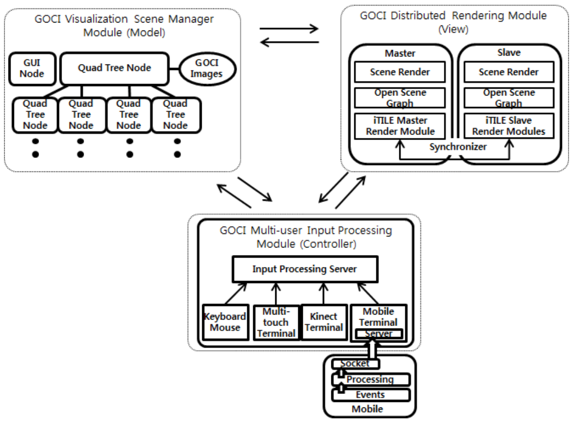

Figure. 6 The Geostationary Ocean Color Imager (GOCI) visualization system consisting of the visualization scene manager, distributed rendering, and multi-user input processing modules

IMPLEMENTATION

Figure 6 shows the overall structural diagram of the Geostationary Ocean Color Imager (GOCI) visualization system which is designed to support multiple users and multi-scale interaction over the high-resolution images. The system consists of a visualization scene manager module, a distributed rendering module, and a multi-user input processing module. The visualization scene manager module manages the data model such as the satellite images. The distributed rendering module works as the view and the multi-user input processing module works as the controller for manipulating data model and views. The input processing module supports multi-scale user interactions using multi-touch, freehand gestures and mobile interface.

1. GOCI Visualization Scene Manager Module

The GOCI visualization scene manager module manages enormous sets of multi-level satellite images collected over a period of several months to years. It also manages the graphical user interfaces (GUIs) on the screen such as the animation play/pause button, the navigation controls for accessing the images for a specific date/time frame, the ocean state buttons, and the image zoom in/out slider. In this research, a multi-level image loading technique has also been developed in which only the images in a certain area are loaded and rendered in real-time.

The Geostationary Ocean Color Imager (GOCI) takes 8 high-resolution images every day with additional four ocean data parameters. This results in the accumulation of up to 3,000 images per year. As can be expected, a great deal of memory and storage is required for the GOCI visualization system to render several months' worth of observed images. No matter how great the graphics power of a tiled display system is, it will not be able to handle this kind of memory overload easily. Also, managing such enormous sets of image data with the animation control for a specific date and time would require a lot of work.

In order to remedy this memory problem and provide quick access to specific regions of the images, the visualization scene manager module utilizes a quad tree node format to manage the images. That is, the images are clustered into groups of 1, 4 and 16, depending on the image level, to create a quad tree node. The quad image nodes divide two dimensional image space into four quadrants. Each quadrant is further divided into four regions until a certain threshold is met. This allows for smooth viewing and navigating of high-resolution satellite images on a display.

The GOCI visualization scene manager module receives control messages from the input processing module. When a new message is received, it changes the scene data accordingly and generates a new control message to notify to the controller to adjust the display rendering. For instance, when a user selects the specific date of satellite images (or zooms/moves the image), the scene manager module responds to such user interaction by loading the appropriate image data and notifying the controller to update the display.

2. GOCI Distributed Rendering Module

The distributed rendering module responds to render the GOCI visualization scene (i.e., high-resolution satellite images and GUIs) on the large tiled display system. This module is based on the iTILE framework [23]. The iTILE framework is designed for easy construction of 3D tiled display applications running on cluster-based computers (with master and slaves) or a single computer. The iTILE framework is written in C++, Microsoft winsock2 and QUANTA networking library, and Open Scene Graph (OSG) 3D graphics library for rendering. The distributed rendering module distributes the scene over slave nodes and synchronizes the rendering process among the master and slave computers.

The iTILE framework allows synchronization among the master and slave computers to share content information, rendering, and state changes of distributed objects. For instance, it sends out information about the master computer's view settings such as viewing location, direction, and domain to each slave computer whenever the data is changed. The master computer also synchronizes the initial content data when it starts, after which the master communicates with slave computers whenever content changes are made at run-time for synchronized rendering.

3. GOCI Multi-User Input Processing Module

Figure 7 shows the input processing flow diagram of GOCI's multi-scale user interaction. The input processing module consists of the input server and a number of input device terminals for different kinds of input devices such as multi-touch screen, Kinect sensor, and mobile device. This module is implemented using the Unified Input Processing Protocol to support multi-scale user interaction. It processes various inputs from multiple users synchronously or from a single user using a variety of input devices. It is designed to smoothly manage the inputs by identifying the users, overcoming the difference between the input values of various devices, and by accessing the simultaneous input values from multiple input devices.

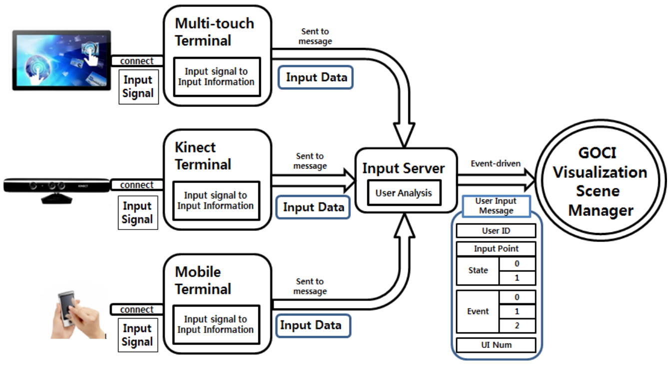

Figure. 7 Input processing flow diagram for the multimodal user interaction

The different raw inputs (such as, N-point and drag touches from the multi-touch panel, gestures and motions from the Kinect sensor, and gestures and UIs from the mobile device) are translated into the specific interaction events in the GOCI visualization system (as described in Table 2). Each input device terminal collects input signals from an input device and converts them into common input data, and the input data are then sent to the input server over a network. The input device terminal is handled by different computers suited for the specific input device. The input server combines the input data from input device terminals and uniformly processes input events.

The server constantly categorizes the input data of each user and transfers the interaction events to the visualization scene manager to render the scene accordingly. The server also handles multi-user conflict resolution. For instance, if two people try to interact with the same object on the system, the input device terminals send corresponding messages to the input server. In this case, the server adopts one user's interaction while ignoring the other users' interactions or the server will notify the other users about the conflict. This multi-scale user interaction approach enables the GOCI visualization running consistently regardless of input devices. Hence, users are able to choose appropriate input devices by their proximity to the screen, or multiple users with different devices can work together collaboratively.

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4. GOCI Multi-Level Image Technique

The Geostationary Ocean Color Imager (GOCI) visualization system is implemented with the image pyramid and the multi-level image loading technique. The image pyramid is a set of images that has been created by down sampling an original image to the desired level. Image pyramids are created in two ways. First, the Gaussian algorithm is used to create a down-sampling image from an image pyramid. Second, the Laplacian algorithm is used to create an up-sampling image from the image at the bottom of the image pyramid.

In this GOCI visualization, camera movement is used in a 3D environment to magnify or minimize the high-resolution satellite image. In other words, rather than actually magnifying or minimizing the image, the camera is moved around to create a similar effect. To do this, a fixed distance along the Z-axis is determined and the camera is moved along this distance to create the effect of making the image look larger or smaller. When the camera reaches the end of the fixed distance, the image is moved onto the next level.

However, when magnifying or minimizing the image, it is extremely inefficient to start with a high-resolution image. Therefore, an image pyramid is constructed, and after looking at the overall scaled down image, the image at the top of the pyramid (i.e., a low-resolution image) should be loaded first. As shown in Figure 8, after magnifying the image a few times, the image at the next higher level of resolution on the image pyramid should be loaded when the image has already been magnified to the point it begins to look blurry.

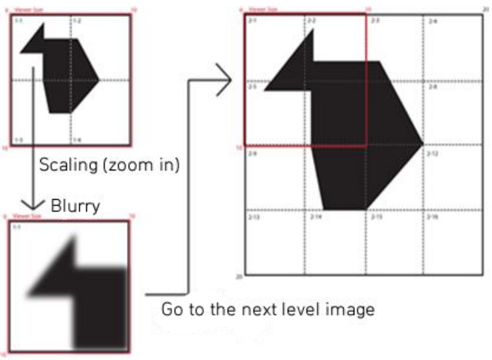

Figure. 8 Loading next level images for the View area when zooming

To discard the unnecessary parts of the image, it is necessary to figure out which part of the image will be shown when moving to the image to the next level to efficiently load only the desired section of the high-resolution image. Hence, the original high-resolution image is first tiled and divided into a quad tree node format. Then, only the node that is viewed by the camera in real-time is immediately loaded and rendered. Users can freely move the camera viewpoint, but the parameter coordinates in the view area must be updated in real-time, and each frame must be checked to see if there are any nodes within the parameters determined by the coordinates. Discovered nodes will render the images that are unique to these nodes. On the other hand, if the loaded image falls outside the view area, the respective node will immediately clear the memory of the image that has been loaded.

As the camera view moves, each node will continuously load and clear the respective images, and the users will not be aware of this. All they will experience is a smooth and fluid rendering of a single image. As the camera magnifies or minimizes the image, the quad tree node will change the image it loads. The camera continuously inspects the distance between the camera and the image in real-time. As the camera gets closer, the quad tree node will load an image of the next higher resolution level while clearing the memory of the previous image.

The GOCI visualization system can be viewed by date. The number of days starting from January 1 of the present year to the current date will determine the number of quad tree nodes to be created. Only the nodes for the date specified by the users will be activated. The image of the most recent date will be loaded when this application is first started, and when the user selects a certain date, the memory of the recent image will be deleted as the respective node is deactivated. The node respective to the selected date will be activated instead, and the node will then check to see if it has come into the camera view area to decide whether or not to load and render its image.

CONCLUSION AND FUTURE WORK

A large high-resolution display provides more screen space for collaboration, more information and better visibility from a distance. It allows multiple users to come together and create an environment where scientific visualization at an extremely high-resolution with more information can be laid out at the same time. However, user interaction on a large display is still challenging due to the large screen size and high resolution [13,14]. This triggered a great deal of discussion regarding interaction techniques and devices.

This research introduces the multimodal user interaction design and implementation for the high-resolution Geostationary Ocean Color Imager (GOCI) satellite image visualization system on a large display. This multimodal user interaction approach is designed to support efficient and natural simultaneous interaction with the GOCI visualization for users at any location. In this research, the multimodal user interaction was developed by using the multi-touch panel (near), gesture recognition (far) and mobile interfaces (far and indirect-interaction) to enable multiple users to choose more intuitive interfaces regardless of their proximity to the display.

The multi-touch panel supports near-range user interaction with direct touch and gestures. Gesture interface supports non-contact far user interaction with direct gestures. The mobile interface supports more distant user interaction with indirect gestures and pointing on mobile touch screen. To support multi-scale user interaction for any tiled display application, the input information from devices, such as multi-touch points, multi-user gestures, and mobile interface events, had to be abstracted and processed in the Input Terminal. The events were then combined and classified by users in the Input Server. Hence, multiple users were able to freely choose any of these interfaces for seamless interaction with the GOCI visualization system. For example, the satellite image can be moved, magnified, or scaled down, with the animation played, dates changed, different ocean states be viewed, etc.

Users on a large high-resolution display often interact at different distance to a display wall [28]. In conclusion, this research provided an approach enabling multiple users to come together to interact with the GOCI high-resolution satellite image visualization on a large display by more naturally receiving weather and geographical information in and around the Korean peninsula. This multimodal user interaction designed for the GOCI visualization aims at providing user interaction consistently regardless of user proximity to the screen.

In the future, different applications will be developed using this multimodal user interaction design to better facilitate multi-user collaborative interactions on a large display. In addition, user study will be conducted to evaluate the effectiveness of multimodal user interaction by multiple users and to discover social aspects of collaborative interactions such as access control and user participation. Comparative user evaluation study on multi-scale user interaction against multi-modal user interface is also possible.

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