

A Study on Virtual Reality System Control using Multi-Display and Zigbee Sensor

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Summary

The display type and interactive interface are important elements of virtual reality for increasing the levels of user interest and immersion. With the advancements in hardware performance, virtual reality systems are being widely used in games, broadcasting, education and cultural contents. Accordingly, there is an increasing need for research regarding wireless interfaces that can provide users with the freedom of movement and the control of virtual reality.

This paper explains the process of developing a ZA sensor that consists of Zigbee and an accelerometer for virtual reality interactions and proposes the means of controlling virtual reality systems using the ZA sensor. The paper also proposes a multi-display method for implementing large displays and an active interaction technique using the ZA sensor to allow users to experience liberal movements.

Key words :

Simulation, Zigbee, Multi-display, Water

1. Introduction

The integration of computer and communication that started in the 1970s has opened the door for the infinite competition of wired and wireless integrated services in the 21st century, and the capability to quickly transmit tremendous amounts of data has allowed people to surpass the concept of time and space and transform the cyber world into a reality. Almost every country in today's world is focused on the infrastructure for making the virtual world into reality. Expanding the concept of telecommunication network, a broadband communication network referred to as BcN is capable of transmitting various types of broadband and multimedia information including voice, video and data. Virtual reality is an intriguing field which allows users to carry out in the virtual environment things that have not been feasible due to time and space restrictions of the real world to fulfill human needs through indirect experience. With technological advances, an increasing number of applications have adopted virtual reality, and there are numerous studies being conducted to provide more realistic virtual experiences. In addition to virtual reality contents, the interaction between the virtual environment and the user is an important element for implementing realistic and experiential virtual reality.

The user must be able to exercise liberal actions and movements to increase the levels of immersion and the experience. However, most virtual reality systems provide limited display areas and user movements for interaction. In the case of a highly immersive first-person virtual reality, there is the interface restriction that the user must wear an HMD. Although dome-type virtual reality experience theaters offer virtual reality experience to many people simultaneously, significant costs are required for construction. As for interaction, first-person systems increase the level of immersion by allowing users to wear data gloves and data suits, which increase the level of immersion but involves high costs and restricted user movements. In the case of large-scale virtual reality theaters, most offer touch-screen or button-type displays that are limited to display areas.

This paper explains the process of developing a ZA sensor that consists of Zigbee and an accelerometer for virtual reality interactions and proposes the means of controlling virtual reality systems using the ZA sensor. The paper also proposes a multi-display method for implementing large displays and an active interaction technique using the ZA sensor to allow users to experience liberal movements. The objective of this paper is to minimize input and output interface restrictions such as interactive interfaces and displays and enhance the levels of user interest and immersion based on the proposed approach.

2. Related Work

Virtual reality is a computer technology that provides users with a 3D virtual environment that is very similar to the actual world and allows users to freely manipulate various input and output devices and react to a wide range of situations in the virtual environment.

The goal of the system-user interaction in virtual reality is not to be limited to conventional interfaces such as keyboard or mouse and react to a variety of intuitive and realistic user inputs. One of the means frequently used to enhance the level of user immersion is the wireless interface that minimizes the restrictions on user movement.

There are several technologies that can be used to implement wireless interfaces including Bluetooth, RFID and Zigbee as well as direct interaction with laser pointer projection screen[1].

Among the technologies, Zigbee is used in various applications due to its wide communication range, location tracking and easy implementation. The peephole display proposed by Yee uses motion tracking to overcome limited work spaces that have been restricted by screen sizes of mobile devices for pen interaction[2].

Rekimoto et al. conducted various studies on motion tracking using slope sensors[3]. Hwang introduced a motion recognition algorithm using 3-axis accelerometer and vision algorithm. Using location tracking of the motion recognition algorithm, movements with four degrees of freedom - pitch, roll, yaw and 1D translation - were achieved [4].

In IceTel, a multi-HD display software solution developed in Sweden for multi video display called WATCHOUT[5]. WATCHOUT is a digital multi-screen display solution capable of displaying various outputs including digital images and videos. It displays a wide range of integrated images on diverse screen layouts without any joints. In 2004, Peter Stephenson proposed an interactive virtual aquarium, which was reflected from a mirror on to a touch screen for interaction, as shown in Fig. 1. It was also designed to be remotely controlled from mobile devices[6].



Fig. 1 Interaction using Touch Screen and Mobile Devices

3. Multi-Display System and ZA Sensor

Fig. 2 displays the overall configuration of the system proposed in this paper. When a user manipulates the interface with a ZA sensor attached, the sensor transmits the acceleration data to the virtual reality system server over a wireless network, and the server uses the received data to send the interaction data that match the virtual environment to the multi display system.

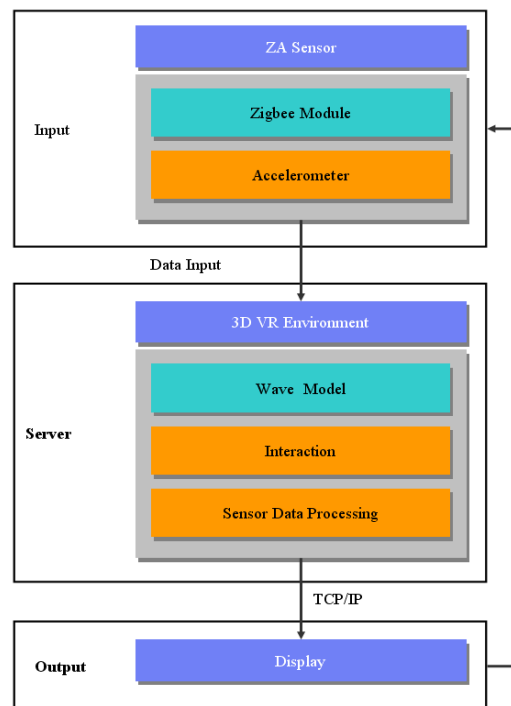


Fig. 2 Overall Configuration of the System

3.1 Real-Time Wave Simulation

In order to apply the proposed method, a real-time simulation of ocean waves was implemented. There are a number of methods for creating waves including height map, Perlin noise[7] and the Gerstner wave model[8].

This study generated waves with a sampling method using the Gerstner wave model and a regional filter. Most deep sea waves propagate in the form of a Trochoid wave, which can be represented by trajectory of a random point on a circle rolling along a straight line. It is similar to the sine wave as shown in Fig. 3.

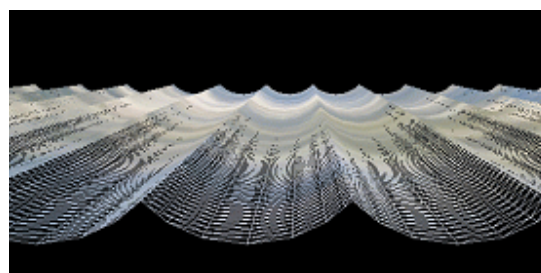


Fig. 3 The Trochoid Wave

Although waves can be easily created using the Trochoid waveform, generated waves are too simplistic. Thus more realistic waves were rendered using the Gerstner wave

algorithm, which expresses waves by calculating positions of individual vertices on the mesh surface that represents the ocean. The basic parameters of the Gerstner wave are indicated in Fig. 4.

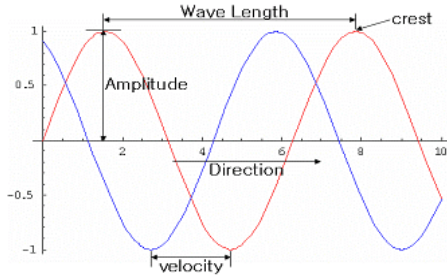


Fig. 4 Basic Parameters of the Gerstner Wave

Wavelength(λ : the distance between two crests) affects the frequency.

$$\omega = 2\pi / \lambda \quad (1)$$

- Amplitude(A): Wave height
- Speed(S): Traveling velocity of the wave
- Direction(D): Directional vector of the wave propagation

If a mesh point on the wave surface is denoted as $x_0 = (x_0, y_0)$ and the height at the point as y_0 , the location of the mesh point at time t with an amplitude A , can be written as Eq.(2).

$$\begin{aligned} x &= x_0 - (D/k)A \sin(D \cdot x_0 - \omega t) \\ y &= A \cos(D \cdot x_0 - \omega t) \end{aligned} \quad (2)$$

Fig. 5 illustrates the waves generated using Eq.(2).

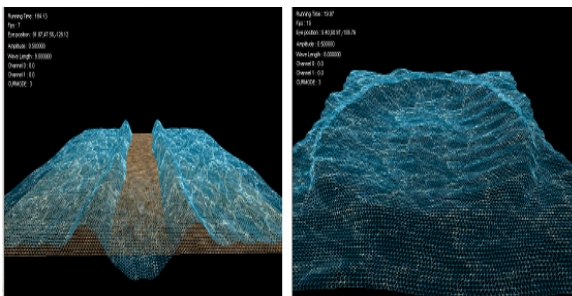


Fig. 5 Wave generated by combining 4 Gerstner waves

3.2 ZA Sensor

ZA sensor is a wireless user interface that converts user movements into input data and transmits it to the virtual reality system. Communication between ZA sensor and computer uses the Zigbee protocol. A ZA sensor consists of a Zigbee module for wireless communication and a 3-axis accelerometer for recognizing user movements. The IEEE 802.15.4 protocol is used for communication with the system. Zigbee is one of PAN communication standards that feature low-capacity and low-power data transmission. Global vendors have formed to Zigbee Alliance to provide international standards. Zigbee is widely used in intelligent home networking systems designed for the era of ubiquitous computing. 2.4GHz, 868MHz and 915MHz frequency bands are used for Zigbee, and Korea uses the ISM band of 2.4GHz. IEEE 802.15.4a, standardization of which is currently under way, provides a location tracking range of about 1m. ZA sensor's accelerometer has a 14-bit ADC output with a Vref(Reference Voltage) of 2.5V. The AD output value during accelerometer movement can be converted into actual acceleration using Eq.(3).

ADXL203 measures acceleration in $\pm 1g$ increments with a rate of $\pm 560mV/g$ and a 0g output of 1.5V.

$$\begin{aligned} V &= AD/2^{14} * 2.5, \quad A_x(g) = (V_x - 1.5)/0.56 \\ A_y(g) &= (V_y - 1.5)/0.56 \end{aligned} \quad (3)$$

A_x and A_y denote accelerations in "x" and "y" axes, respectively and "g" is the permissible unit gravitational acceleration of the sensor. The acceleration of each axis of the AD value output from the accelerometer has to be converted into the rotation value of the corresponding axis so that it can be used as the input data of the virtual reality system. The accelerometer outputs acceleration data of each axis for gravitational accelerations between -1g and +1g based on the perpendicular state of gravity. The acquired acceleration data can be converted into rotation values of pitch and roll using arcsin as in Eq.(4).

$$\begin{aligned} \text{PITCH} &= \text{asin}(A_x/g) \\ \text{ROLL} &= \text{asin}(A_y/g) \end{aligned} \quad (4)$$

In the case of a large-scale virtual reality system, the scope of user movement depends on the physical space, and the ability to track user's location is essential for effective interaction. Accordingly, this paper uses Zigbee's RSSI to track user's location.

3.3 Multi-Display System

A large-scale virtual reality system requires a large display system. However, using a single large display requires a substantial cost, and multi-display systems are preferred for cost considerations.

For the sake of expandability, the basic configuration of multi-display is the flat-type multiple display system.

However, conventional multi-display systems divide 2D images and videos, or divide the viewing angle on a single rendering system for 3D contents. Such approaches cause distortion for large viewing angles, making it difficult to connect multiple displays.

In order to resolve these problems, this paper proposes the pseudo-perspective projection approach that minimizes the distortion caused by viewing angles by allocating viewpoints on each display and connecting display devices to implement a multi-display system in the 3D environment.

The virtual environment must be implemented in 3D for the user to experience more realistic virtual reality. The constructed 3D objects undergo orthogonal or perspective projection before being displayed on a 2D screen.

3.3.1 A fundamental Projection Technique

Perspective projection is a fundamental projection technique in 3D computer graphics that enhances the sense of reality by converting the environment and objects with a perspective projection matrix for rendering.

However, single viewpoint perspective projection restricts the viewing angle, making it impossible to link multiple displays. Thus projection must be performed using multiple viewpoints to link multiple displays. Positioning the camera angle of a display on a straight line creates a share area, and a object located in the share area are displayed with redundancy.

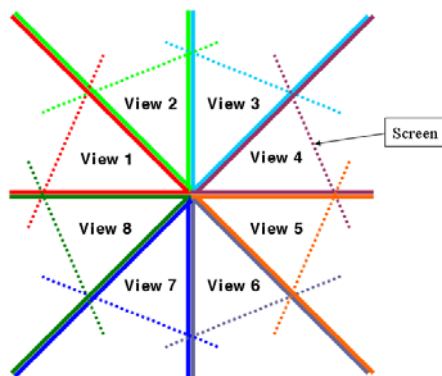


Fig. 6 Configuration of Cylindrical Multi-Display System

Furthermore, if an object near a viewpoint can be positioned in a dead angle, resulting in parts of other objects to be displayed or not being displayed at all. For these reasons, displays cannot be arranged in parallel and must be constructed in a cylindrical shape to minimize the share area as well as the dead angle. The number of displays for a cylindrical display system is determined by the size of the viewing angle.

In Fig. 6, the viewing angle(Fovy) = $\pi/4$, or 45° , so the multi-display system can consist up to eight displays.

3.3.2 Pseudo-Perspective Projection Technique

It is difficult to implement a flat-type multiple display system using the perspective projection because of share area and dead angle. In order to resolve the problem, this study proposes the pseudo-perspective projection technique that does not create share area or dead angle and provides perspective to an interactive object.

The transformation of the object for approximating perspective projection is based on scale conversion. Scale adjustment according to the viewing angle involves the scale factor approaching 1 as the angle(θ) between apex "P" and viewpoint "E" becomes smaller, and scale factor decreasing as the angle increases, as expressed in Eq.(5).

$$\text{Scale Factor} = |V \cdot W| \quad (5)$$

Here, $V = (P-E)/|P-E|$ and W is the unit vector in the viewing direction. The scale factor for adjustment according to distance is set based on object's apex "P" and threshold "T" at viewpoint "E".

Eq.(6) can be set so that scale factor < 1 if the distance to object is greater than the threshold value, scale factor scale factor ≈ 1 if the distance is equal to threshold, and scale factor > 1 if the distance is less than threshold.

$$\text{Scale Factor} = \frac{1}{\frac{\sqrt{|P-E|}}{T}} \quad (6)$$

3.3.3 Recognizing User Location and Motion using ZA Sensor

Accurate location recognition using the RSSI included in the IEEE 802.15.4 protocol is difficult because of the distortion caused by the surrounding environment including wave reflection, diffraction and diffusion.

Furthermore, noise and jumps are created in genuine AD values output from the sensor when the data output from the accelerometer is processed and used for user motion

recognition. The normalization process of raw data must be completed in advance to alleviate various errors associated with location and motion recognition including distortion, noise and jump.

Three normalization methods Q-buffer leveling, Q-buffer min-max leveling and Kalman filter were comparatively analyzed for the purpose of this study and adopted Kalman filter based on its highest normalization performance.

Kalman filter is used to isolate signal from noise and adequately predict changes according to time in a single system, providing an optimal estimation of the current as well as future states. The adopted normalization algorithm can be categorized into normalization using Q-buffer and Kalman filter. As illustrated in Fig. 7, the Q-buffer normalization algorithm stores the continuous incoming data stream in Q-buffer and then levels the buffer.

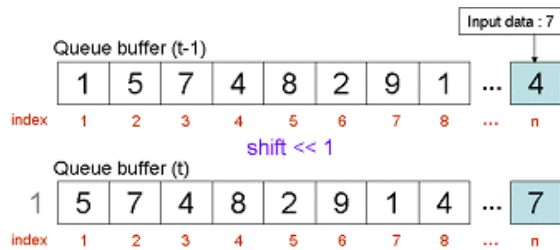


Fig. 7 Data Processing of Q-buffer

Zigbee-based location recognition is a RTLS technology that uses the RSSI included in the IEEE 802.15.4 protocol for a limited area. RSSI is included in most wireless communication protocols, and it is used to determine whether to join a network created by a wireless AP or a coordinator. The RSSI value is also used to establish the transmission and reception frequency band.

RSSI outputs a high dBm value if the transmission node is located near the reception node, and vice versa. An RP is established for every specific distance(50cm) within the pre-defined range of user movement, and the RSSI from each RP is stored in the server database to create a table. RPT applies triangulation to the distance converted by RRT and establishes the location nearest to the adjacent RP as the user location. The process of estimating the position nearest to the current location consists of the following four steps.

- Step 1 : Normalize RSSI received from each fixed node with Kalman filter
- Step 2 : Store in the rpt structure the number of the fixed nodes and their coordinate data that coincide with RSSI in RTP.
- Step 3 : Return coordinate values if the number of fixed node matches stored in rpt is 3 or greater
- Step 4 : Return an approximate coordinate by comparing the rpt coordinate with the RRT distance data if

the number of fixed node matches stored in rpt is less than 3 .

4. Experimental Results

The techniques proposed in this paper were simulated using a system with a 2.6GHz CPU, 1GB memory, and 600Mhz GPU implemented with DirectX SDK 9.0. Simulations of interactions between terrain and water, and between moving objects and water waves were performed on a screen resolution of 800 * 600.

This study constructed a multi-display system by adopting pseudo-perspective projection and implemented interactions of location and motion recognition based on ZA sensors.

Experiments were conducted to present a virtual environment with a deep sea background on a multi-display system that uses pseudo-perspective projection as well as an interaction where the ZA sensor detects user's motion and changes fish's movement accordingly.

The experiments were conducted with a system consisting of three multi-display clients using a projector and three fixed nodes(Zigbee) to receive the RSSI and acceleration data from ZA sensors, as depicted in Fig. 8.

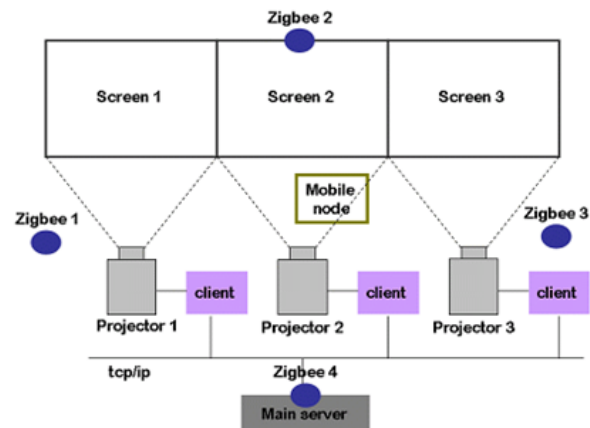


Fig. 8 Overall Configuration of the Multi-Screen

When a user equipped with a ZA sensor moves, the user's location is analyzed using the RSSI of ZA sensor Zigbee and the user's motion is recognized based on the movement of the ZA sensor.

Fig. 9 displays the ZA sensor and fixed node Zigbee, interactive interfaces used for the experiments.



Fig. 9 ZA Sensor and Fixed Node

A multi-display system was constructed with a multi-rendering system using pseudo-perspective projection, and each display system exchanges interaction data with the server through TCP/IP communication.

The environmental information of virtual reality was implemented with Height-map. As shown in Fig. 10, each x, y and z data of the overall Height-map is managed as a database by the server, and each display creates a virtual environment by searching the database(mysql) for the Height-map data of the corresponding index area.

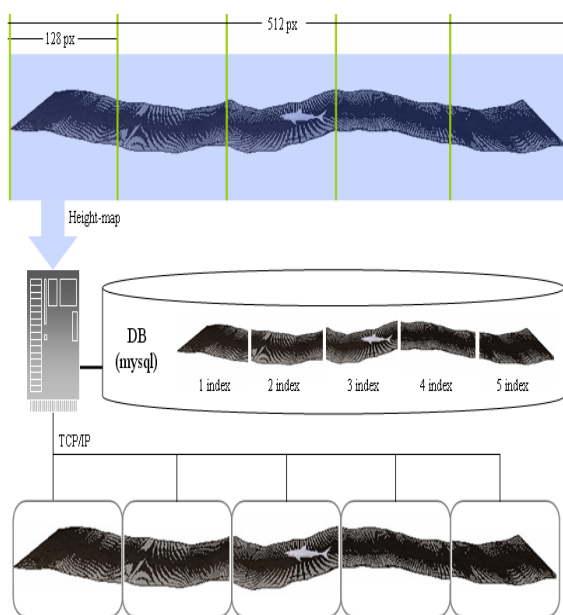


Fig. 10 Height-map Database Structure

Fig. 11 illustrates the results of placing 10 fish of an identical size at different locations and applying perpendicular projection and pseudo-perspective projection.

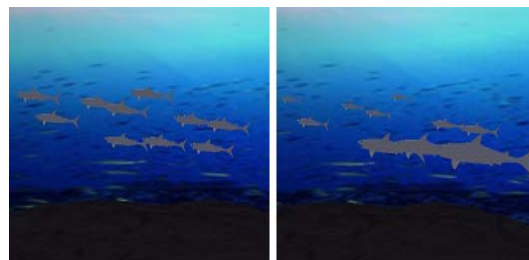


Fig. 11 perpendicular projection and pseudo-perspective projection

Fig.12 displays the interaction between ZA sensor and a multi-display system implemented with pseudo-perspective projection.

The problems of perspective projection - share area and dead angle - were resolved and there was no distortion at the boundaries with adjoining displays when a fish moved according to the location and movement of a ZA sensor.



Fig. 12 Interaction between ZA Sensor and a Multi-Display System

The performances of the Q-buffer leveling algorithm and the Kalman filter were compared by compiling 100 sets of data from two groups of experiments with tilting and translation of the accelerometer. The tilting experiment

was conducted by varying the angle vertically by 45° in both directions from the horizontal position(0°). As shown in Fig. 13, Kalman filter's graph approximated the trajectory of the original data graph to remove noise from the original data.

On the other hand, Q-buffer min-max leveling and Q-buffer leveling graphs indicate a delay according to the Q-buffer size, and there were discrepancies between the locations of maximum/ minimum peaks and the original data.

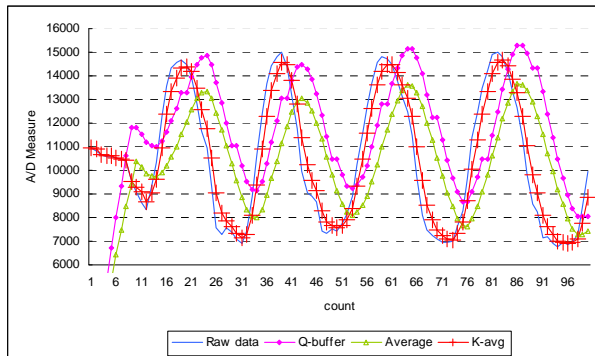


Fig. 13 Results of Accelerometer Tilting Experiment (100 sets, 4 cycles)

The maximum range of user movement was set at $6 \times 3m^2$ and fixed nodes were positioned at (300, 0), (0, 150), (600, 150) and (300, 300) for recognizing user location. The mobile node transmitted at a rate of 10 transmissions per second (10msec), and the fixed node normalized the received RSSI with the Kalman filter before transmitting it to the server.

The server estimates an optimal location using RTP and RRT and sends the location information to the client. In order to generate RRT, one of the pre-processes of location recognition, 100 sets of data were collected for each 50cm for up to 600cm. The compiled data were processed with the Kalman filter to produce the RRT data shown in Table 1.

Table 1 : RSSI Reference Table

Distance (cm)	RSSI (dbm)	Distance (cm)	RSSI (dbm)	Distance (cm)	RSS I(dbm)
0	36	250	48	500	60
50	37	300	53	550	60
100	40	350	55	600	61
150	43	400	57		
200	45	450	59		

5. Conclusion

This paper proposed an active user interaction method using the ZA sensor wireless interface as well as an approach for implementing a multi-display 3D environment. The proposed approaches are expected to enhance user convenience and immersion by using ZA sensors that allow active interactions by recognizing user's location and movement rather than static interactive interfaces such as touch screen and buttons.

Using generic perspective projection to implement a realistic 3D environment of multiple viewpoints created problems of share area and dead angle. This paper proposed pseudo-perspective projection to resolve such problems. The effectiveness of the proposed technique was verified by designing and constructing a multi-display system based on the proposed method.

Future research efforts will involve studying various sensors for more precise location tracking as well as implementation of motion algorithms and databases for recognizing various user gestures. In addition, virtual reality researches will be conducted to improve the qualities of 3D objects and environments to enhance the in-situ and realistic experience of the virtual world.

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