Intuitive Navigation in an Enormous Virtual Environment

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Abstract

Without sophisticated assistance, a virtual reality user tends to easily lose his/her position and direction in an immersed enormous virtual environment. In order to enable a user to obtain accurate spatial perception in an environment, global information on the environment and the local information around the user must be presented. There is some literature devoted to the presentation of an overview (a global view) on the background view of a life-sized virtual environment (a local view) and on the viewpoint determination of the virtual environment. However, a method for controlling the bird's eye viewpoint intuitively has not yet been discussed. In this paper, a technique for the interlocked motion of coordinate pairs is proposed to intuitively control the "bird's eye" overview display of an entire large-scale virtual environment in a display system that present a user with both overviews (global views) and a life-sized virtual environment (a local view) simultaneously. This enables efficient navigation even in enormous and complicated environments using both global and local views. The motion of the bird's eye viewpoint interlocks with the relative motion of the user's viewpoint and his/her hand, therefore, the user can control the "bird's eye" viewpoint by intuitive manipulation. Experimental results show how efficiently the user recognizes his/her position and direction, and show the usefulness of the proposed method compared to the other viewpoint-control methods.

1 Introduction

Interactions in large complex virtual environments require various sophisticated techniques and algorithms to handle large-scale geometric databases. For instance, efficient algorithms for displaying complex geometric data are needed to achieve video frame rates. In spite of such efforts, a virtual reality user in an immersed virtual environment tends to lose his/her position and direction easily, unless there is sophisticated assistance. In order to enable a user to obtain accurate spatial perceptions in an environment, global information on surroundings and local information from a life-size view must be presented.

Humans construct cognitive maps of their environment to use in navigation [1], and such maps assist the user in maintaining knowledge of his/her current position and direction in a virtual environment [2]. The adequate presentation of environmental overviews from other viewpoints and in different scales assists the user in accurately recognizing the spatial environment. There is some literature devoted to presentation of an overview (also called a global view) on the background view of a life-sized virtual environment (also called a local view). Two typical ideas exist for presenting overviews of the environment. The first idea is to use miniature copies of the entire environment. This is called a world-in-miniature (WIM) [3]. WIM offers multiple viewpoints and scales, and is helpful in navigating and manipulating the virtual environment. The second idea is to use "bird's eye" overview images taken by virtual cameras from certain viewpoints. "Virtual GIS" (Geographic Information system) is an example that has an overview map inserted in the display [4]. Both overview examples present a global view in addition to a local view, however, a method for controlling the bird's eye viewpoint intuitively has not yet been discussed in the literature.

An approach that enables a user to efficiently construct cognitive maps of his/her environment provides the "authority" to intuitively control the viewpoint and scale of the overview. If the control of the scale, direction and/or viewpoints of the overview is transparent and easily understood by the user, he/she will easily recognize the entire environment. There is some literature devoted to viewpoint determination of the virtual environment. For example, eyeball-in-hand, scene-in-hand and flying-vehicle-control methods are good metaphors for viewpoint motion control techniques in a virtual environment [5]. However, an intuitive method for controlling the scale, direction and/or viewpoint of a "bird's eye" camera using the user's relative head and hand motions has not yet been discussed.

We propose a manipulation technique to intuitively control the "bird's eye" overview display of an entire large-scale virtual environment in a display system that presents a user with both overviews (global views) and a life-size virtual environment (a local view) simultaneously. This enables efficient navigation environments. The motion of the bird's eye viewpoint interlocks with the relative motion of the user's viewpoint and his/her hand. Therefore, the user can control the "bird's eye" viewpoint by intuitive manipulation.

2 Overview Use

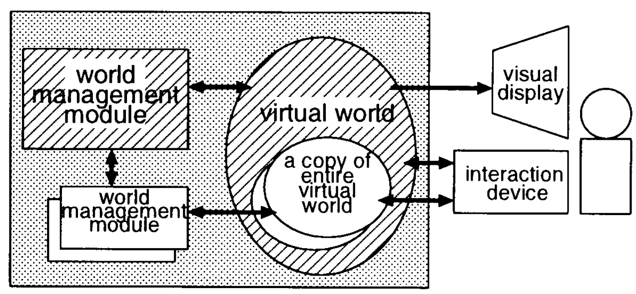
One of the most promising ideas for user navigation in large complex virtual environments is to provide the user both the global information of the environment and the local information around himself/herself. Though some approaches can be considered to provide a user with global information of the environment, an adequate presentation of both global views and life-sized local views can assist the user in obtaining accurate spatial perceptions of an enormous virtual environment. Two main ideas exist for presenting overviews of the environment. The first idea is to use miniature copies of the entire environment. This is called world-in-miniature (WIM) method [3]. WIM offers multiple viewpoints and scales, and is helpful in navigating and manipulating the virtual environment. The user can change the position and direction of the miniature by using a hand-held 6-D tracker. The second idea is to use "bird's eye" overview images taken by virtual cameras from certain viewpoints. "Virtual GIS" is an example that has an overview map inserted in the display [4]. Both overview examples present a global view in addition to a local view. However, a method for controlling the bird's eye viewpoint intuitively has not yet been discussed. This section compares the advantages and disadvantages of these two methods.

2.1 Miniature Copies

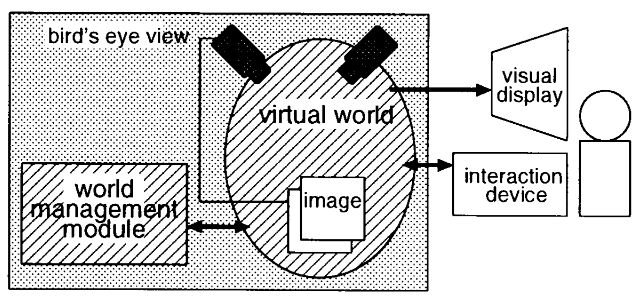
Multiple views of the environment from multiple viewpoints and scales helps the user to efficiently obtain accurate spatial perceptions of the environment. A typical example of this type of view is WIM [3]. Object manipulation in WIM reflects the corresponding manipulation in a life-size virtual world, and vice versa. Foe example, it is used to demonstrate the modeling of rooms. In order to present miniature copies of the entire world in addition to a life-sized view of the virtual world, it is necessary to make complete copies of the geometry of the entire virtual world first. Then, each miniature copy is located in a suitable position as a group of objects in the virtual environment. Finally, a life-size view is generated according to the user's viewpoint.

Figure 1(a) shows the concept of this actualization method of miniature copies. Multiple miniatures require corresponding multiple copies of geometry, therefore, the order of the data size of the geometry of the virtual world is proportional to the number of miniatures presented. This drawback implies that the miniature copy method is not suitable for an enormous and complicated environment such as a virtual nature environment.

Attributes of each object in the virtual world in a typical virtual reality system are managed by a world management software module. Examples of such attributes include the position/orientation of objects, collision/intersection among objects, status of grasping/manipulating/releasing, and so on. If the status of an object changes, the world management system also changes its attributes. For independent and transparent object manipulation using miniature copies, each copy must be organized by its individual world management module. When a user manipulates an object in a miniature copy, the attributes in the corresponding management module of the copied miniature world are updated. Then this change is transferred to the management module that organizes the entire virtual environment. Finally, this change is transferred again to another management module, which organizes the other miniature copies. Having multiple management modules for the entire world and multiple copies complicates software configuration of the virtual reality system as the number of miniature copies increases.



(a) miniature copies.



(b) bird's eye overview images.

Figure 1: Two different actualization methods of displaying overviews of a virtual environment.

2.2 "Bird's Eye" Overview Images

Another solution of efficient navigation in an enormous and complicated virtual environment is to use "bird's eye" overview images taken by virtual cameras from certain viewpoints. "Virtual GIS" is an example that has an overview map inserted in the display [4].

Figure 1(b) shows an actualization method of "bird's eye" overview images. Overview images taken by virtual cameras at certain viewpoints and scales efficiently assist the user in obtaining accurate spatial perceptions of the environment. Images are put in a virtual environment. Therefore, the original data size of the geometry of the virtual world does not increase even if the number of "bird's eye" overview images increases. Moreover, single management modules are sufficient to organize objects' attributes in the entire virtual environment. An overview image presents a global view in addition to a local view. Eyeball-in-hand and scene-in-hand metaphors are known to manipulate the viewpoint of a virtual environment by determining the position of either the camera or the environment [5]. However, an intuitive method for controlling the bird's eye viewpoint using the user's relative head and hand motions has not yet been discussed. A method for intuitively controlling the viewpoint of the bird's eye to provide overview images is described in the next section.

3 Intuitive Control of the Viewpoint for the "Bird's Eye" Camera

This section proposes a method that intuitively controls the position and orientation of the "bird's eye" camera. For this purpose, we introduce new coordinates for a palmtop virtual environment that correspond to the user's hand motions.

3.1 Coordinates for a Palmtop Virtual Environment

Six parameters for translation (X, Y, Z) and rotation (ψ, ϕ, θ) of the bird's eye viewpoint must be determined to generate an overview image. In order to control these parameters intuitively, an "interlock" of the bird's eye viewpoint and the user's viewpoint is introduced. Figure 2 shows the coordinate systems used in the proposed method. The world coordinates represent the position and orientation of all objects in the entire virtual environment, and they correspond to globally-aligned directional representations (north, south, east and west). The user's coordinates determine his/her view direction and view volume and correspond to user-aligned directional representations (front, rear, left, and right). The third coordinates are for the "bird's eye" overview. A bird's eye camera that perceives the environment is located at the origin of these coordinates.

In addition to the above three coordinate systems, coordinates for a palmtop virtual environment that correspond to the user's hand motion is introduced. This fourth coordinate system is used only to determine the bird's eye viewpoint, and the bird's eye overview image is generated according to its position and orientation. The user observes the generated bird's eye overview image through the window on the projection plane.

3.2 Interlocked Motion between the Bird's Eye Viewpoint and a User's Viewpoint

In order to achieve intuitive control of the viewpoint and orientation of the "bird's eye" camera, an "interlocked motion" between the bird's eye viewpoint

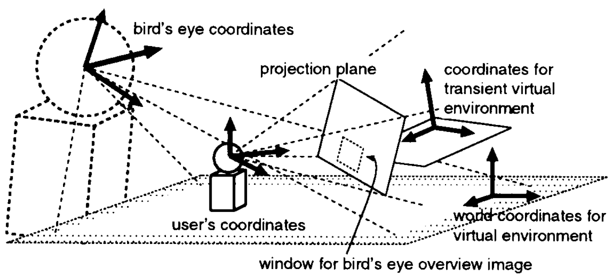


Figure 2: Coordinate system of a proposed method for bird's eye overview images.

and the user's viewpoint is proposed. Figure 3 shows the simplified explanation in 2-D. The relative motion (position and orientation) between the bird's eye coordinates and the world coordinate system for an entire virtual environment is interlocked with the relative motion (position and orientation) between the user's coordinate system and the coordinates of the palmtop virtual environment. In other words, a pair of coordinate systems (i.e., the user's coordinates and the coordinates for the palmtop virtual environment) interlocks with another pair of coordinate systems (i.e., the bird's eye coordinates and the world coordinate system of entire virtual environment). Figure 4 shows the pairs of interlocking coordinate systems. X, Y, Z correspond to the world coordinate system axes, and x, y, z correspond to the coordinates for the palmtop virtual environment axes. The correspondence between the origin of the palmtop virtual environment and the origin of the world coordinate is assumed to be established.

Point P_u is the intersection of a perpendicular line through the horizontal plane of the palmtop virtual environment and the viewpoint of the user, O_u. Point S_u is the intersection of the horizontal plane of the palmtop virtual environment and a straight line passing through O_u and the center of the window of the bird's eye overview image, C. The angles $(\psi_u, \phi_u, \theta_u)$ are rotations of the straight line O_uS_u in the coordinates for the palmtop virtual environment around the x, y, z axes, respectively. Similarly, point P_b is the intersection of a perpendicular line through the horizontal plane of the entire virtual environment and the bird's eye viewpoint, O_b. Point S_b is the intersection of the horizontal plane of the entire virtual environment and the axis line passing through O_b. The angles $(\psi_b, \phi_b, \theta_b)$ are rotations of the straight line O_bS_b in the world coordinate X, Y, Z axes, respectively.

The interlocked pairs of coordinate systems are used to determine the parameters of the bird's eye camera. (X_b, Y_b, Z_b), the XYZ coordinates of the bird's eye camera is obtained by magnifying the xyz coordinates of the user's viewpoint (x_u, y_u, z_u) A times. Here, A is the magnifying power given in advance. The angles $(\psi_b, \phi_b, \theta_b)$, orientation coordinates, are determined by using the orientation components of the straight line $O_u S_u$ and the coordinates for the palmtop virtual environment.

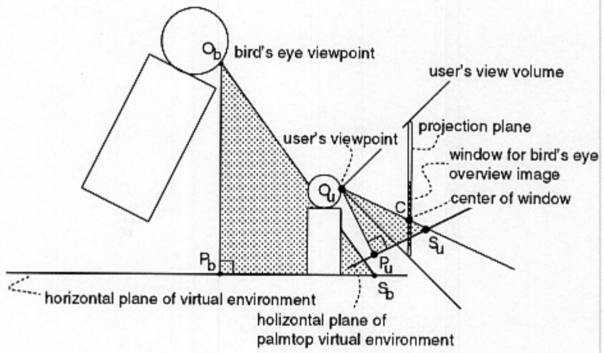


Figure 3: Interlocked pairs of coordinate systems (simplified to 2-D).

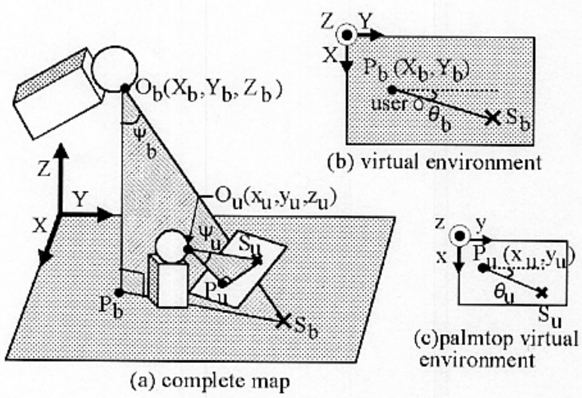


Figure 4: Interlocked pairs of coordinate systems.

3.3 Presentation of "Bird's eye" overview images

Figure 5 shows an example presenting a "bird's eye" overview from an adequate viewpoint (a global view) on the background view of a life-sized virtual environment (a local view). The original data size of the geometry of the virtual world does not increase even as the number of "bird's eye" overview images increases, and a single management software module is sufficient to organize the objects' attributes for the entire virtual environment. By introducing the "interlocked motion" between the bird's eye viewpoint and the user's viewpoint, intuitive control of the viewpoint and orientation of the "bird's eye" camera can be achieved.

Six parameters of position and orientation for a bird's eye camera can be determined by the interlocked pairs of coordinate systems, as described in the previous section. Based on this idea, sophisticated display methods using both the bird's eye overview image and the life-sized local image are obtained by using constraints on parameters to determine the attitude of the bird's eye camera [6].

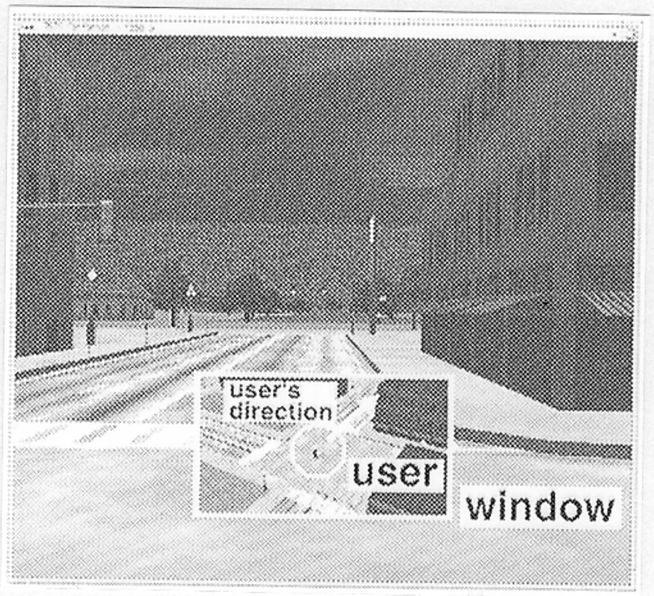


Figure 5: An example image presented to the user (a life-size local view and a "bird's eye overview image)

4 Navigation Systems using Overviews

Navigation systems in a virtual environment can be established by presenting an overview (a global view) on the background view of a life-sized virtual environment (a local view). This section describes the methods needed to establish such systems, using four different methods to control the direction and viewpoints of the overview, respectively.

4.1 Interlocked Motion of Coordinate Pairs

Figure 6 shows the concept of a navigation system using the interlocked motion of coordinate pairs. The user controls the position and orientation of the palmtop virtual environment by using a hand-held 6-D tracker. The user's viewpoint and orientation are also measured by a 6-D tracker attached to the user's head. The coordinates of the bird's eye camera are obtained by magnifying the coordinates of the user's viewpoint A times. Here, A is the scale parameter given in advance.

As described in 3.2, the motion of a bird's eye camera against the world coordinate system (i.e., the entire virtual environment) is determined by the relative motion of a user's hand (i.e., the palmtop virtual environment) against the user's head. In other words, a user controls the viewpoint of the bird's eye camera using the cooperative motions of his/her head and hand.

4.2 Eyeball-in-Hand

Figure 7 shows the concept of a navigation system using the eyeball-in-hand metaphor. The virtual environment is stationary, while the user's viewpoint and orientation are measured by a 6-D tracker attached to the user's head. Thus, the user observes a non-distorted image according to his/her head motion. In this case, the motion of the bird's eye camera directly corresponds to the motion of the user's hand measured by a hand-held 6-D tracker. The motion of the bird's eye camera is obtained by magnifying the motion of the user's hand motion A times. Here, A is the scale parameter given in advance, similar to 4.1. Therefore, a user controls the viewpoint of the bird's eye camera using only his/her hand motion.

4.3 Scene-in-Hand

Figure 8 shows the concept of a navigation system using the scene-in-hand metaphor. The viewpoint of the bird's eye camera is fixed at an certain point in the world coordinate system, while the motion of the virtual environment directly corresponds to the motion of the user's hand measured by a hand-held 6-D tracker. Therefore, a user indirectly controls the viewpoint of the bird's eye camera using only his/her hand motion. The motion of the virtual environment is obtained by magnifying the motion of the user's hand motion A times. Here, A is the scale parameter given in advance, similar to 4.1. The user's viewpoint and orientation are also measured by a 6-D tracker attached to the user's head. Thus, the user observes a non-distorted image according to his/her head motion.

4.4 World-in-Miniature

Figure 9 shows the concept of a navigation system using the world-in-miniature metaphor. The user controls the position and orientation of the miniature of the virtual environment by using a hand-held 6-D tracker. The user's viewpoint and orientation are also measured by a 6-D tracker attached to his/her head, therefore, the user observes the $1/A$ scaled miniature in the scene of the life-sized virtual environment. Though both motions of the user's head and hand are independent, this configuration can be said to be a special case of the system using a scene-in-hand metaphor in which the viewpoint of the bird's eye camera is fixed to the user's viewpoint.

5 Experiments

An experiment was conducted to compare the four different techniques used to control the direction and viewpoints of the overview.

5.1 Experimental Method

Five virtual environments of 2.8 km^2 were designed. Each of them contained four mountains of approximately 450 m in height and two ponds. Though they have simple configurations, without sophisticated assistance, a user can easily easily lose his/her position and direction in an immersed virtual

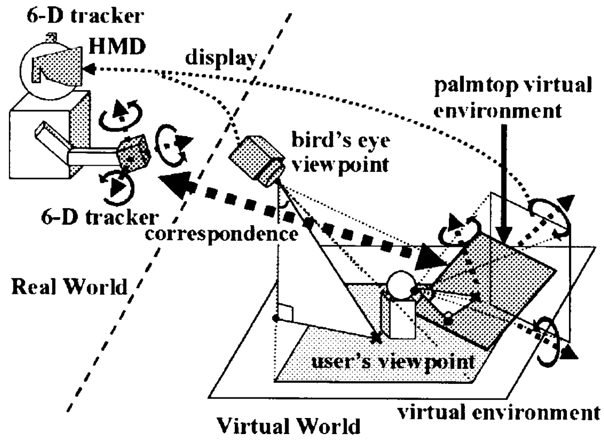


Figure 6: Concept of a navigation system using the interlocked motion of coordinate pairs.

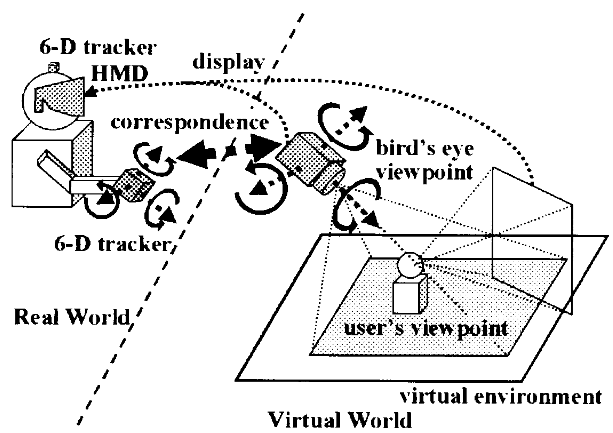


Figure 7: Concept of a navigation system using the eyeball-in-hand.

environment. A user can not go into the mountain and pond by detecting an interference. One of the five virtual environment was used for practice, and the remaining four environments were used for trials in unknown setups on the subjects.

Subjects were asked to follow six landmarks in order as quickly as possible, however, landmarks were occluded by mountains in the user's life-sized local view during the traversal. Therefore, they needed to check the position of the next landmark by using the global overviews. Figure 10 shows an experimental virtual environment and landmarks. Four different methods of controlling the direction and viewpoints of the overview were used in random order. A user was assumed to move at a uniform velocity in the virtual

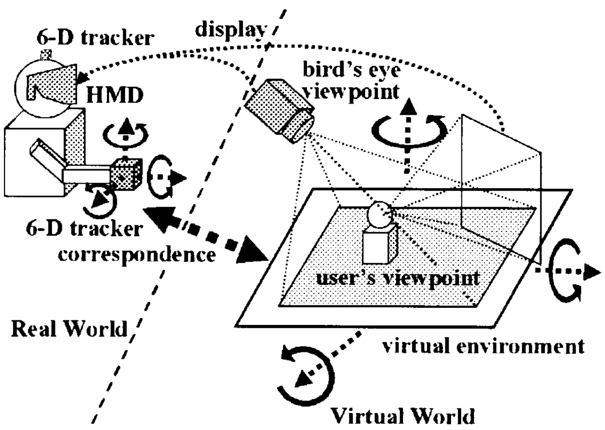


Figure 8: Concept of a navigation system using the scene-in-hand.

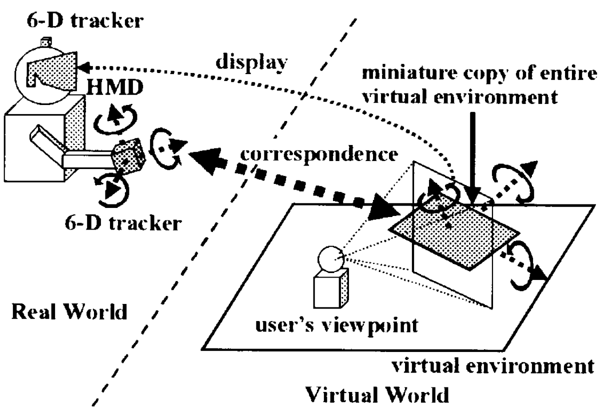


Figure 9: Concept of a navigation system using the world-in-miniature.

environment for all methods.

5.2 Experimental Result

The average ratio of the total traversed length in the experimental virtual environment to the shortest course by one typical subject is shown in Figure 11. Results show that the viewpoint controlling method of the interlocked motion of coordinate pairs (IMCP) was most efficient. Moreover, the subject completed the task more efficiently with the bird's eye overview image methods (i.e., interlocked motion of coordinate pairs, eyeball-in-hand, and scene-in-hand) than with the world-in-miniature method. These results correspond to the comments made by subjects that it was difficult to see the miniature and life-sized local views simultaneously during the traversal.

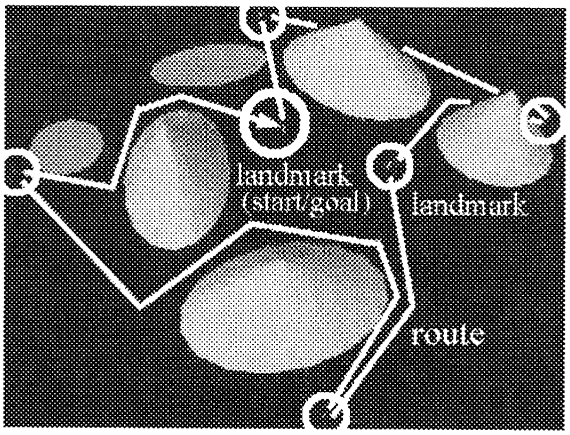


Figure 10: An experimental virtual environment and landmarks.

A user felt an intuitive sensation that he was manipulating the bird's eye camera by using the eyeball-in-hand metaphor, but it was sometimes difficult to place the bird's eye camera at the user's desired position. For example, a user was at a loss when the direction of the bird's eye camera faced in the user's direction because the bird's eye camera moved in the opposite direction of the hand-held 6-D tracker's motion. It was difficult to intuitively control the global view viewpoint with the scene-in-hand metaphor, because it used the bird's eye camera in a fixed position in the world coordinates, and also, the motion of the user's head did not reflect the motion of the viewpoint of the bird's eye camera. Finally, the method of the interlocked motion of coordinate pairs provided the user intuitive control of the viewpoint of the "bird's eye" camera. The user observed the virtual environment through the window by manipulating the palmtop virtual environment with natural movements.

6 Summary and Conclusion

A technique for the interlocked motion of coordinate pairs was proposed to intuitively control the "bird's eye" overview display of an entire large-scale virtual environment in a display system that presents a user with both overviews (global views) and a life-sized virtual environment (a local view) simultaneously. In the experiments, the proposed method was compared with three different methods to control the direction and viewpoints of the overview, i.e., the eyeball-in-hand, scene-in-hand, and world-in-miniature metaphors. The proposed method enabled efficient navigation even in enormous and complicated environments using both global and local views. The motion of the bird's eye viewpoint interlocked with the relative motion of the user's viewpoint and his/her hand, therefore, the user could control the "bird's eye" viewpoint by intuitive manipulation.

Future work will include the adequate control of scale parameters, object manipulation using the

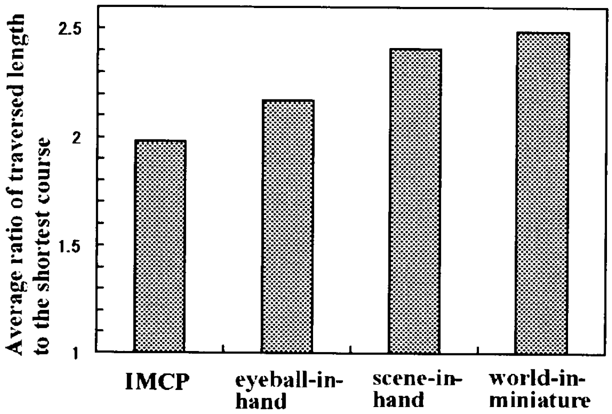


Figure 11: Average ratio of traversed length to the shortest course.

"bird's eye" overview images, cooperative work of several users supported by the "bird's eye" overview images, and so on.

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