HAPTIC WALKTHROUGH SIMULATOR:
Its Design and Application to Studies on Cognitive Map

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ABSTRACT

Walkthrough simulation is effective for design and presentation of buildings or urban space. This paper presents method of implementing walkthrough simulator which provides haptic feedback for walking motion. The walker wears omni-directional sliding devices on the feet, which generate feel of walking while position of the walker is fixed in the physical world. Scene of virtual space is displayed in a head-mounted display corresponding with the motion of the feet and head. The system is applied to studies on human spatial recognition process, which is called "cognitive map". Distance estimation is selected as a fundamental problem in cognitive map. From the results, the exponent of the power function for estimated distance decreases as the memory load increases. Comparing two conditions, walking and flying by hand gesture, it is observed that haptic feedback for the walking motion improves the performance of distance estimation.

Key Words : Walkthrough, Haptic feedback, Virtual reality, Cognitive map

1. INTRODUCTION

The recent evolution of computer graphics enables landscape simulation. The major application area of virtual reality technology is design of buildings or urban space. Simulating virtual buildings, before they are physically constructed, is useful for designers and clients[1]. A head-mounted display(HMD) provides 360-degree image of virtual space. However, walkable area of the virtual space is strictly limited according to the sensing range of the motion tracking sensor or wire harness of the tactile input device. A possible method for exploring virtual space is hand gesture. Current system for virtual reality uses index finger to point a direction. In terms of natural interaction, haptic feedback for walking motion is essential to exploration of virtual space. The primary object of our research is presenting sense of walking while position of the walker is fixed in the physical world[2]. The basic idea of a prototype system is illustrated in Figure 1. The trunk of the walker is fixed to the framework of the system by safety harness. The harness does not restrict the motion of the legs and arms. The walker wears omni-directional sliding devices on the feet, which enable the walker to turn left or right. The motion of the feet is measured by ultrasonic sensors. From the result of measurement, image of the virtual space is displayed in the head-mounted display corresponding with the motion of the walker. Friction force from the floor is generated by the sliding device. Overall view of the system is shown in Figure 2.

The system is applied to study on human spatial recognition process, which is called "cognitive map." Since quantitative experiments on cognitive map under controlled conditions are very difficult in the physical world, CG-space is currently used for this research field[3]. Distance estimation is selected as a fundamental problem in cognitive map. Through the experiments for distance estimation in test space, such as straight and square courses, characteristic of estimated distance is studied. Effect of haptic feedback is also examined under two conditions:
(1) Moving by walking
(2) Moving by flying by hand gesture.

2. Method of Virtual Walking

2-1. Sliding device

A simple device for virtual walking is a treadmill, ordinary used for physical fitness. Application of this device to virtual building simulator was developed at UNC. However, it only allows the walker to straight forward motion. Two dimensional sliding devices are required for the walker to change the direction. We developed specialized roller skate equipped with four casters, which enables two dimensional motion. The device has a break pad at the top. While the walker steps forward, the break pad generals friction force at the

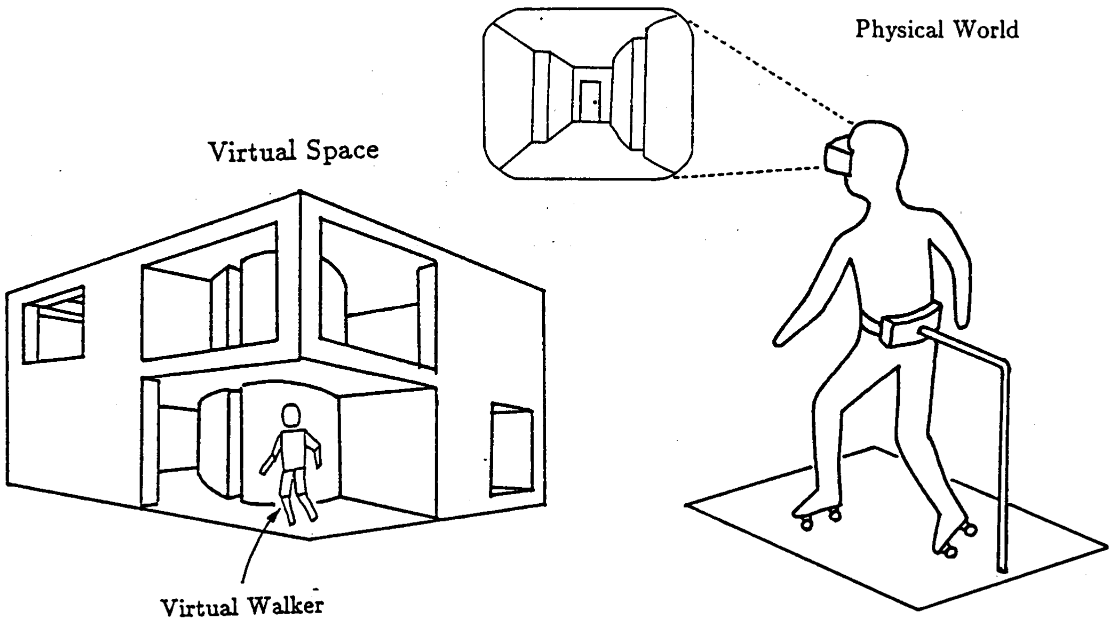

Figure 1. Basic idea of virtual walking

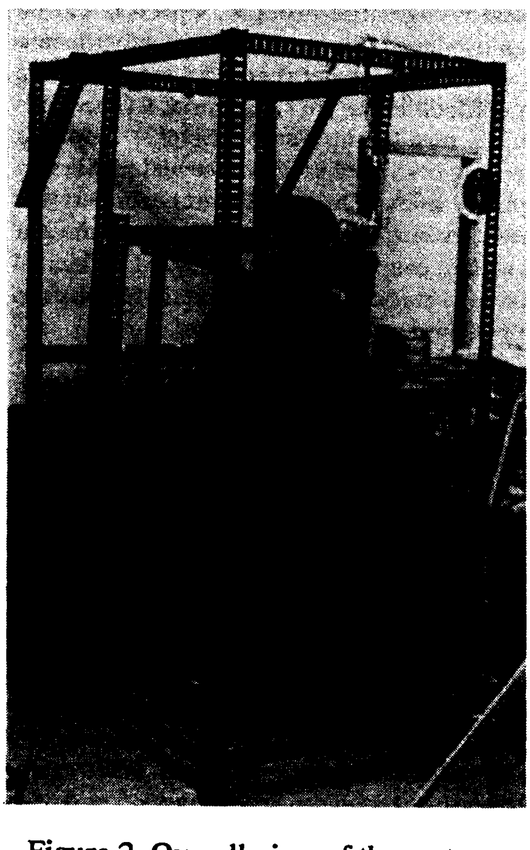

Figure 2. Overall view of the system

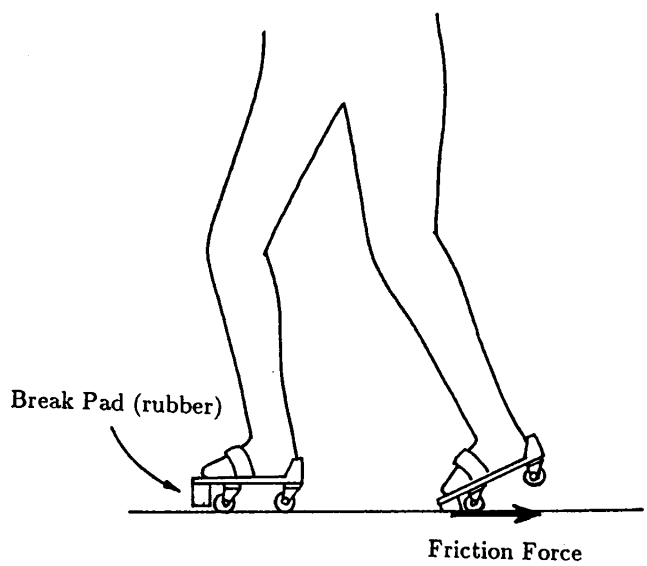

Figure 3. The sliding device

backward foot (Figure 3). The friction force enhances haptic feedback.

2-2. Framework and harness

The walker is fixed to the framework of the system by a belt at the waist position. The belt restricts forward and backward motion, and does not suspend the weight of the walker. Safety harness at the shoulder is only for emergency such as falling down.

The framework has an ability to combine following haptic displays:

(1) master manipulator

We have developed a master manipulator to present weight and rigidity of objects in virtual space[4].

(2) virtual staircase display

Connecting a string to the sliding device, reaction force from virtual staircase is applied to the walker's leg[5].

2-3. Motion tracking

Scene of the virtual space is generated corresponding with the results of motion tracking of the feet and head. The motion of the feet are measured by ultrasonic sensors. These sensors are composed of ultrasonic transmitters and receivers. The distances between those components are determined by the required time for propagation of an ultrasonic wave. Two transmitters and three receivers are used to triangulate the position of the feet(Figure 4). Sampling rate of each sensor is 20 Hz. The personal computer calculates the triangulation in 5 msec. Precision of the measurement is 1 cm. Figure 5 indicates examples of motion tracking data of the left foot:

(a)forward and backward motion

(b)left and right motion

The data includes noise from the sensors. The noise is filtered by software, so as not to disturb the image on the HMD. The length of a step is measured by the forward and backward motion of the foot. The turning angle of the body is measured by the left and right motion of the foot. The angle is determined by a following equation:

$$a = \tan^{-1}(X_d / Y_d)$$

where X_d : left/right displacement of the foot

Y_d : forward displacement of the foot

The position and orientation of the body in the virtual space are determined by the length of steps and turning angles.

The motion of the head is tracked by mechanical linkage called goniometer. The device measures 6 degree-of-freedom motion of the HMD. Angle of each joint is measured by potentiometer. Sampling rate of the goniometer is 100Hz.

3. Hardware Configuration

The hardware configuration of the system is indicated in Figure 6. The system employs two computers: a graphics computer for real-time image of a virtual space and an I/O computer which supervises sensors for motion tracking. These computers are connected by serial (RS-232C) communication line.

3-1. Graphic computer and display

Image of the virtual space is generated by a personal computer and a graphics accelerator. The inexpensive accelerator named "Personal HOOPS" (KOBELCO Corp.) provides real-time image. This apparatus employs two Transputers: a T800(10Mips) for coordinate transformation and a T414(10Mips) for rendering. Development of our graphics application is supported by its HOOPS library. The graphics performance is 125K 3-D vectors/sec. The update rate of the image is about 4 Hz . The personal computer manages a solid model of the virtual space. The image on the CRT of the Personal HOOPS is converted to NTSC standard video signal, and sent to the HMD. Two 2.7-inches liquid crystal displays are mounted on the HMD, which presents stereoscopic image. The effective field of view is 30 degrees.

3-2. I/O computer and sensors

The I/O computer supervises ultrasonic sensors and goniometer. The CPU of the computer is i386SX(16MHz) with i387SX. Ultrasonic sensors are interfaced to the personal computer by parallel input and output unit(PIO). Joint angles of the goniometer is obtained by analog-to-degital(A/D) convertors. The computer calculates the position and orientation of the walker's head, which are described in a coordinate system fixed to the virtual space.

4. Experiments on Cognitive Map

4-1. Method

Two psychological experiments were conducted to investigate human spatial recognition performance. Computer-generated virtual space is indispensable to create a controlled experimental environment. Subjects of the experiments are 3 university students(male).

(1) Experiment 1.

The test course of the experiment is a straight path as shown in Figure 7. Subjects are asked to walk along the path from the starting point to the goal watching the CG image by HMD. Figure 8 shows an image of the test

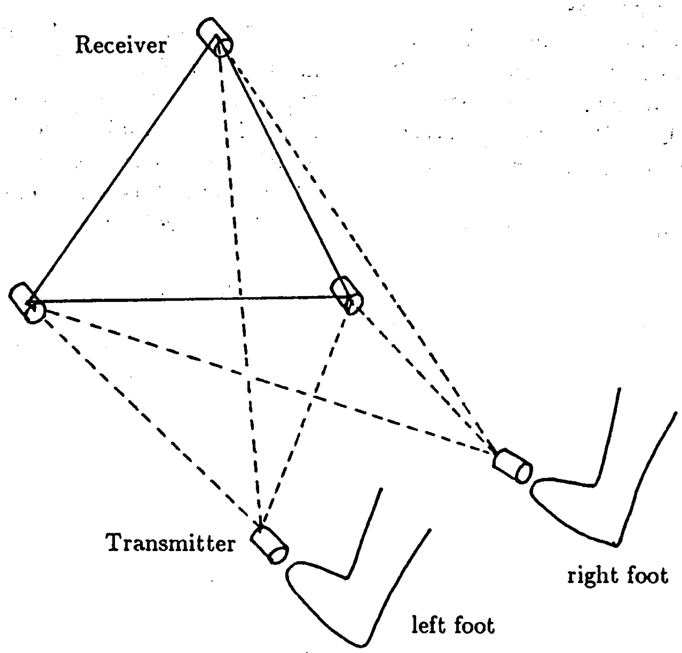

Figure 4. Triangulation of the feet

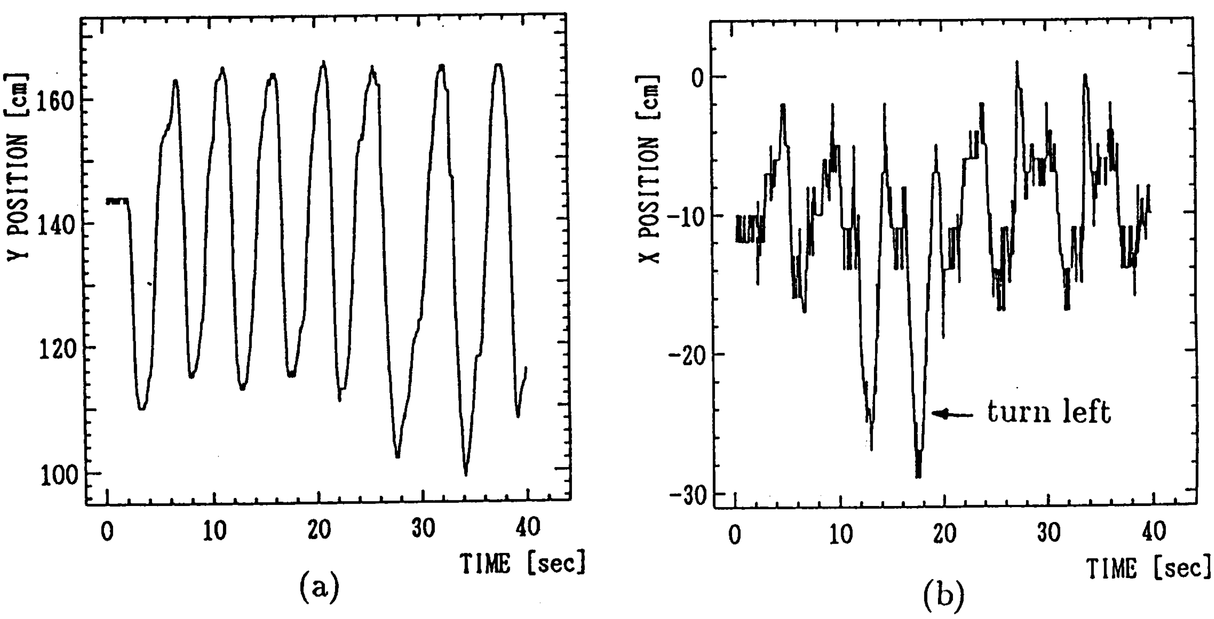

Figure 5. Results of motion tracking

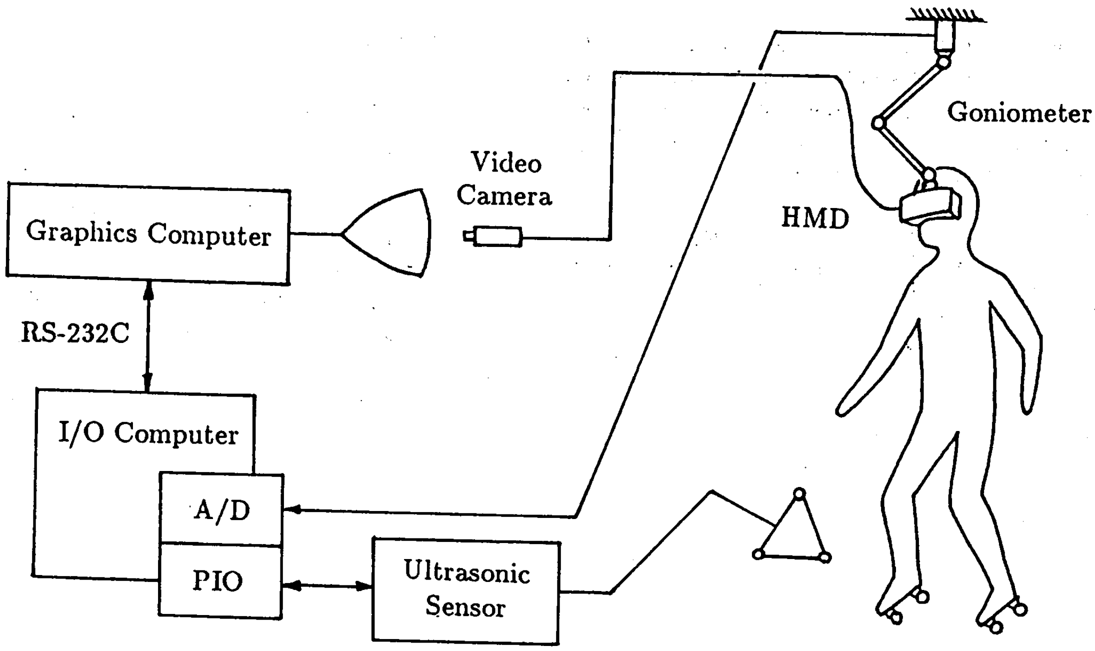

Figure 6. Hardware configuration

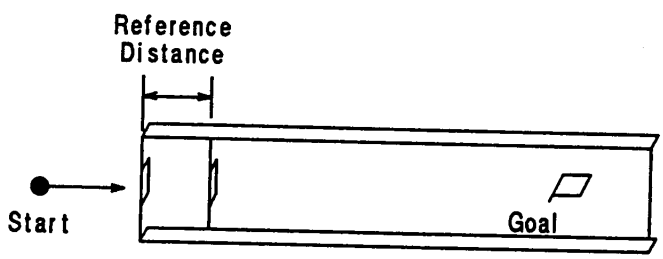

Figure 7. Test space (Straight path)

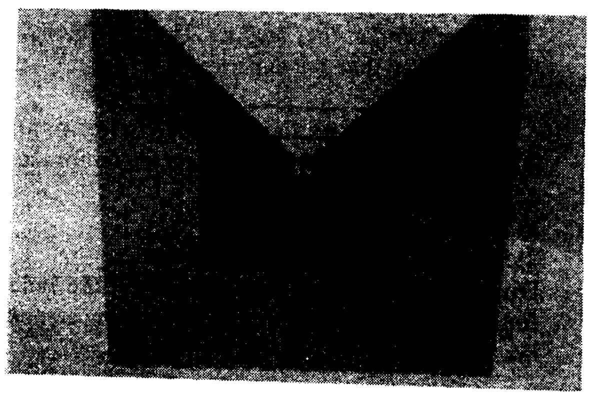

Figure 8. Scene of the straight path

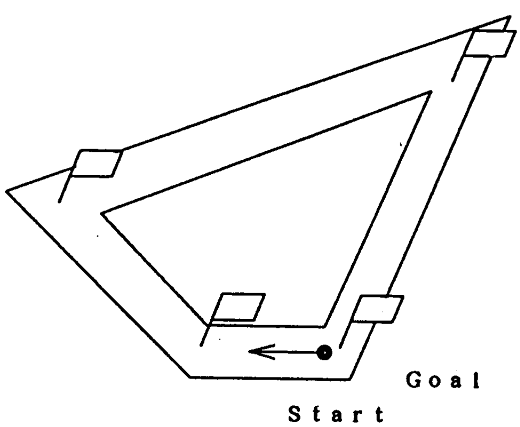

Figure 9. Test space (Square course)

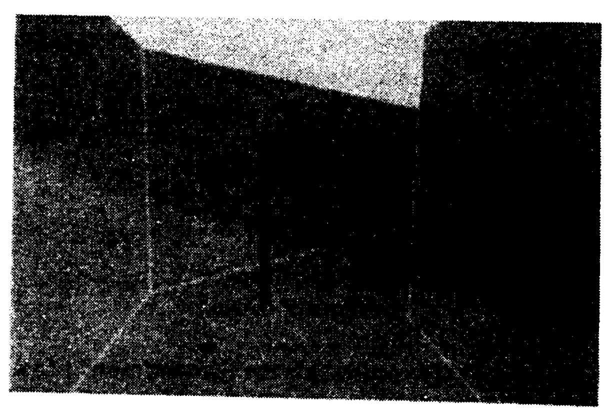

Figure 10. Scene of the square course

course. The width of the path and the height of the walls are 3m. As subjects moved along the course, they memorize distance between the second gate and the goal. After they finished walking, they are asked to plot the position of the goal on a data sheet on which the walls and reference distance are marked. We prepared seven estimated distances: 4,6,8,10,12,14, and 16m. The reference distance is 2m.

(1) Experiment 2.

The test course of the experiment is a closed square path as shown in Figure 9. Path lengths are 5,10,15, and 20m. Subjects are asked to walk around the path watching the CG image by HMD. Figure 10 shows an image of the test course. The width of the path and the height of the walls are 3m. As subjects moved along the course, they memorize each distance between the corners. After they finished walking, they are asked to make a sketch of it on a data sheet on which the first section of the path is marked. The remembered distance is evaluated from the sketches. We prepared six test courses, combining four path distances. The first section is 5m in each test course. In this case, the subjects had to remember 3 distances and corner angles. Thus, the memory load is heavier than the experiment 1.

In order to examine the effect of haptic feedback, following two conditions are set for these experiments:

1) Moving by walking
2) Moving by flying by hand gesture

Direction of flight is determined by the index finger, and speed is determined by bending angle of the thumb.

4-2. Results

(1) Experiment 1.

The relationship between physical distance and estimated distance is shown in Figure 11. In this case, "physical distance" is a distance between the second gate and the goal in the virtual test course. Estimated distance is evaluated from the data sheet. From the result, the subjects underestimate long distances. The curve indicated in Figure 11 is a power function:

$$Y = 4.99\,X^{0.75} \qquad (1)$$

where X: physical distance
Y: estimated distance

Equation (1) represents the Stevens' power low, which is generally used in the research fields of human sensation[6].

Figure 12 shows the result of estimated distance by flying. The curve indicated in Figure 12 is a power function:

$$Y = 0.98\,X^{0.84} \qquad (2)$$

Comparing Figure 11 and 12, estimated distances by flying are lower than those by walking.

(2) Experiment 2.

The relationship between physical distance and estimated distance is shown in Figure 13. Large black circles indicate average values of estimated distances. The result also shows that the subjects underestimate long distances. The curve indicated in Figure 13 is a power function:

$$Y = 1.75\,X^{0.66} \qquad (3)$$

Figure 14 shows the result of estimated distance by flying. The curve indicated in Figure 14 is a power function:

$$Y = 2.40\,X^{0.44} \qquad (4)$$

Comparing Figure 13 and 14, estimated distances by flying are lower than those by walking. The amount of underestimation is larger than that in the experiment 1.

The results of the two experiments show that haptic feedback for walking motion improves human spatial recognition performance.

5. Other Application Areas

Application areas of the walkthrough simulator can be focused on following fields:

(1)Design of buildings and equipments
- designer-client dialogues in constructing homes or shops
- collision detection of equipments in large scale plants such as a nuclear reactor

(2)User interface for multi-media database
- displaying stored data in a virtual museum

(3)Entertainment and health
- taking a walk in a virtual tourist resort

(4)Welfare
-aid for rehabilitation

5. CONCLUSION

This paper has shown our current works on walkthrough simulator. Through the experiments of distance estimation, effect of haptic feedback is clarified. Recently, research on virtual reality technology is rapidly developing. Although various techniques have been proposed, theory for designing virtual environments has not been established. Study on human factors or cognitive

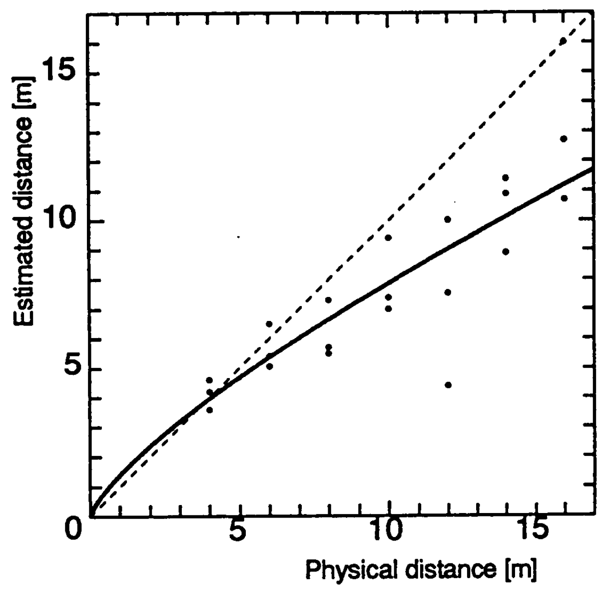

Figure 11. Characteristics of estimated distance by walking (Experiment 1)

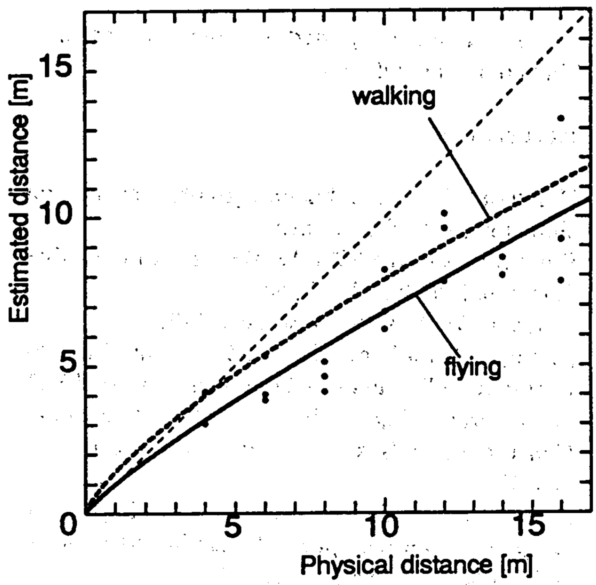

Figure 12. Characteristics of estimated distance by flying (Experiment 1)

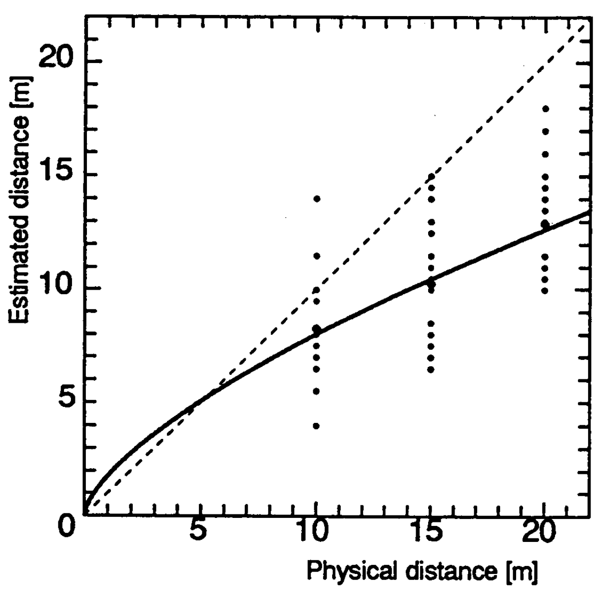

Figure 13. Characteristics of estimated distance by walking (Experiment 2)

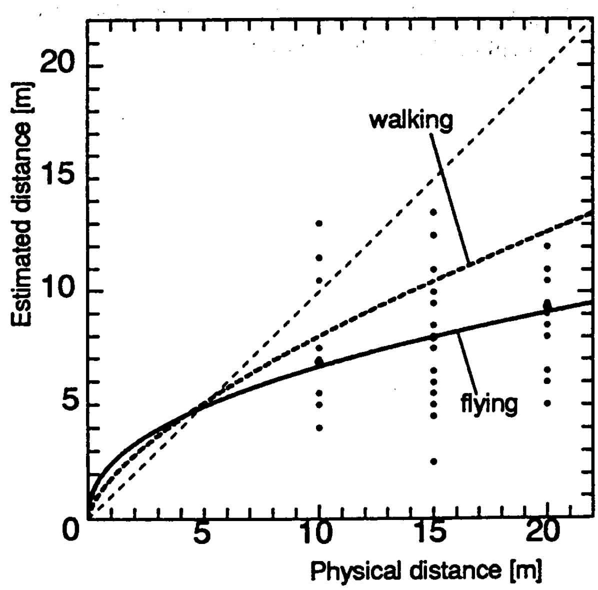

Figure 14. Characteristics of estimated distance by flying (Experiment 2)

characteristics of virtual worlds will be essential to this research field.

Acknowledgment

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