Proceedings of the 17th World Congress
The International Federation of Automatic Control
Seoul, Korea, July 6-11, 2008

UBIQUITOUS DISPLAY FOR HUMAN CENTERED INTERFACE -Fixed Shape Projection and Parameter Optimization-

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Abstract - Projection based information display system was proposed and its problems were considered in previous papers. In usual cases, a man should approach information sources which are located around our living environment. E.g. bulletin boards, artificial signs, local maps, etc. However, the proposed system is able to afford human with relevant information by projecting it on where the human is facing so that the man does not need to move for seeking information. The proposed system is based on Intelligent Space and a projector mounted mobile robot which is called ubiquitous display. In this paper, a fixed shape projection method and an optimal parameter selection method are proposed and their results are shown.

Keywords: Intelligent Space, Mobile Robot, Information Display, Human Interface, Intelligent Machines

1. INTRODUCTION

In our living environment, the most famous and representative ways of transferring information are road signs, guide maps, notice boards, etc. In these kinds of information display methods, constant information is written on fixed media in advance and those media are located at some specified place. It is the most common way of transferring information from past to now since the birth of human being. However, there are lots of problems in such methods. First problem; in order for a user to obtain information, the user should search for the place where the information media is located. Second problem; since the information which can be presented to the user is limited, there is no guarantee that the user is able to obtain necessary information. Third problem; when information should be modified, time and efforts are required for renewal. These problems cause the waste of time and effort in usual time. Moreover, they will bring about serious crisis in emergency. As for these problems, it is thought that the problems are caused by “passive information display”; a user approaches information. However, to the contrary, if information approaches a user, the above-mentioned problematical point can be solved. In this paper, “active information display” will be proposed to achieve a human centered information transfer method.

1.1 Intelligent Space

Before proposing the active information display system, Intelligent Space, which is deeply related system with the proposing system in this paper, is introduced.

In recent years, computer and computer networks have proliferated and become an important part of most people’s daily lives. Not only diverse research on computers and computer networks, but also computer aided research has been greatly advanced over the last several years. Intelligent environments are one example. Intelligent environments are able to monitor what is occurring in themselves, to build models of environment, to communicate with their inhabitants and to act on the basis of decisions they make. Especially the capability of the environment to act as a context-sensitive user interface (e.g. to respond to gestures) and react in certain situations (e.g. accidents, intruders) promises a range of application scenarios such as intelligent hospital rooms, offices, factories, asylums for the aged, etc. We concluded that such systems are the natural product of technological progress and since 1996 have been promoting the concept of ‘Intelligent Space’ (Lee, *et al*., 2002).

The main purpose of Intelligent Space is to realize human-centered systems (Fig.1). Many intelligent systems have already been developed. However, when a human wants to use such a system, he must first learn how to operate the system. Moreover, since most systems have no mobility, humans should move to operate them. In our concept of Intelligent Space, humans can express their will in intuitive actions or unconscious usual actions so that the human does not need to learn how to use Intelligent Space. Since humans are in an

Intelligent Space, humans do not have to move around to interact with it. Even other intelligent systems (e.g. computers, VCRs, air conditioners, etc.) can be operated in an Intelligent Space, as long as they are agents of that Intelligent Space.

2. PROPOSED METHOD

2.1 Related Works

So far, research on developing active information display was performed in a mobile device based information presentation (Nakamoto, et al., 2006) and pan tilt mechanism projector based information presentation (Narumi, et al., 2006; Mitsugami, et al., 2005). In addition to above methods, CRT or LCD Monitors are located at some specified place to present information for users. However due to the first problem, which was described in Introduction, such CRT or LCD Monitors based systems cannot be said as active information display system.

Mobile device based information display methods have several problems such as; a user should carry mobile device always; in case of cellular phone or PDA, its small screen cannot display enough information at once; in case of using HMD, users may get stress on using it because of its weight, dizziness, blocking user's sight and so on.

A pan-tilt mechanism and a projector based information display methods are able to display information on various locations by its pan and tilt movement, and the projector is able to display various information, this method does not request people to carry something always. Renewing information is not a time consuming job in this method any more. Since this method is able to display at various places of real environment, it is useful to utilize this system in displaying information for undefined multi-user.

In addition to above methods, there is an active information display method based on voice. However, in comparison with information based on vision, the voice method has remarkably little information and it is almost impossible to present information to a specified user.

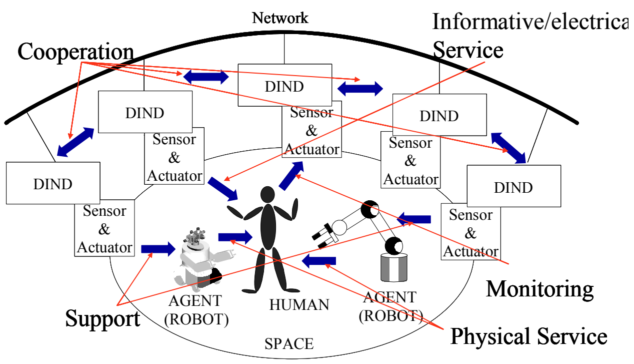

Fig.1 Intelligent Space

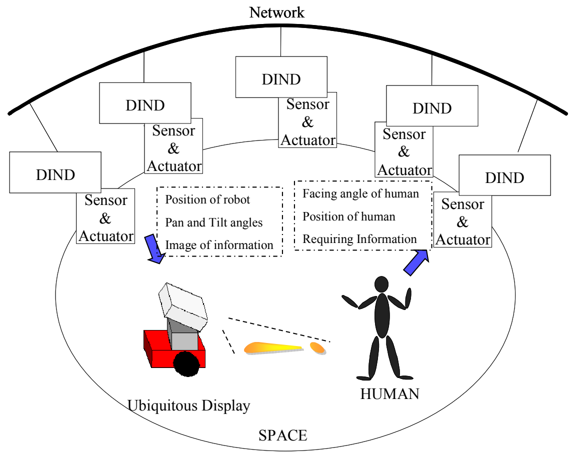

Fig. 2 Intelligent Space, Human and Ubiquitous Display

2.2 Features of the proposed system

In this paper, to achieve active information display system, it is proposed that Intelligent Space is used for gathering active information and a pan and tilt mechanism based projector mounted mobile robot is used for active information display system. We named this projector mounted mobile robot as Ubiquitous Display 1(UD-1). As it is shown in Fig.2, Intelligent Space recognizes location and facing angle of human with its sensors. The information which the human wants is also recognized by Intelligent Space. Based on gathered data, the information to be presented is decided by Intelligent Space and based on where to display the information, location of the projector mounted robot and angles of the mounted projector are decided. With this combined system, an active information display system is achieved and all the problems are overcome. Since a user does not have to carry any special devices to be served with information, it can be said that the proposed system is indeed a human centered system.

The proposed system has following features in comparison with fixed place pan and tilt mechanism projector.

<u>*Ubiquitous Display Feature*</u> As for the information presentation such as the conventional sign or instruction, the information can be got only at the fixed place where the source of the information is located. The range that the projector with a pan and tilt mechanism fixed in a specified place can cover is wider than the conventional information presentation technique. However the range where the projector can cover is

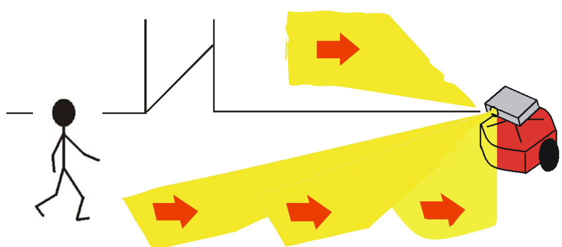

Fig. 3 Ubiquitous Display Feature

decided by the pan and tilt movable range and ability of the projector.

In the case of a ubiquitous display system, due to the pan and tilt mechanism and mobility based on the mobile robot base, the limitation of information displaying area disappears and information can be displayed on various places. In Fig.3, this feature is described.

In this research, the feature that information can be displayed at anywhere is named "ubiquitous display feature"

Seamless Display Feature Above mentioned ubiquitous display feature can be achieved if lots of fixed location projectors with pan and tilt mechanisms are located in a space. However, very precise calibration is required in order for two projectors to display a picture seamlessly at boundaries of surfaces, and actually it is almost impossible to achieve such performance with normal projectors. At some special theaters, well calibrated multi-projectors are used and a seamless display is achieved in it. However, such projectors have special lens which are designed based on the geometry of the screen of the special theater and each projector costs more than dozens of normal projector.

On the other hand, seamless display is always possible because there is no limitation in the displaying area when the proposed system is used. In Fig.4, such a feature is described. Perhaps there are no boundaries between displayed pictures.

In this research, the feature that information can be displayed without seam is named "seamless display feature"

Adaptable Display Feature In the case of a projector which is installed in a space, if an obstacle, which is often the user himself, is located between the projector and display area, the light from the projector is shut out and it is impossible to present information at intended position.

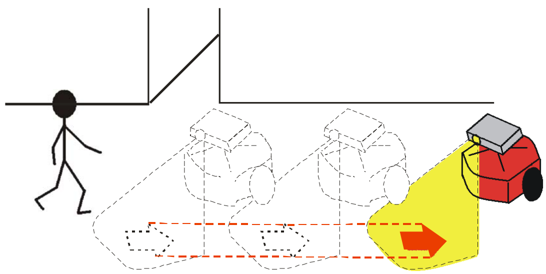

Fig. 4 Seamless Display Feature

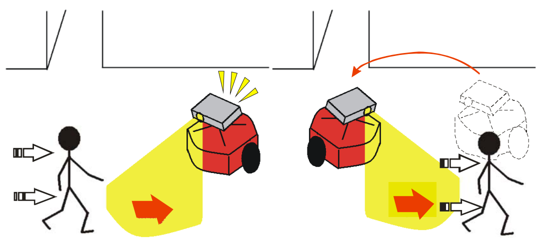

Fig. 5 Adaptive Display Feature

However, the proposed system is able to move to the place where the light from the projector is not influenced. Since Intelligent Space monitors human, ubiquitous display system and other obstacles, possible position to project information is determined and let ubiquitous display system to move. In Fig.5, such a feature is described.

In this research, the feature that the proposed system adapts to various situations flexibly is named "adaptable display feature".

Interactive Display Feature Since Intelligent Space work as a smart interface, ubiquitous display does not need any kinds of interface for users. Intelligent Space decides what a user is wanting and what is required for a user. The total system, including Intelligent Space, ubiquitous display and a user, works interactively. Intelligent Space provides information via ubiquitous display system then the user reacts to what is displayed. Intelligent Space provides new information based on the users reaction and this loop continues. In this research, this feature is named "interactive display feature".

3. UBIQUITOUS DISPLAY

The UD-1 is composed of a mobile robot, a pan-tilt mechanism, a projector and some hardware.

3.1 Features of Ubiquitous Display

Since the basement of the projector is able to move, center of gravity of the UD-1 is very important and it should be lessened enough for stable movements. However, if the projector is placed higher, the area of information projected is getting wider. Since the projector is a massive element in the UD-1, there is trade-off relation between the height of the projector and stable movements of UD-1. In this paper, the height of the projector is determined as 1m by consideration of the trade-off relation. Batteries, an inverter and other massive parts are placed low in order to increase stability of the UD-1's movement.

The movable range of pan and tilt angles of the projector are -150 ~ 150 degree and -50 ~ 90 degree respectively so that the UD-1 is able to project an image everywhere except on floor within about 1m distance from the UD-1.

3.2 Demonstration

The UD-1 is composed of five parts; a projector, a pan-tilt mechanism, a power supply, a mobile robot and a computer (Fig.6).

To verify usefulness of the UD-1, a simple guidance demonstration was performed. Usually when a people does not know way to get an aimed goal, he should look around to find

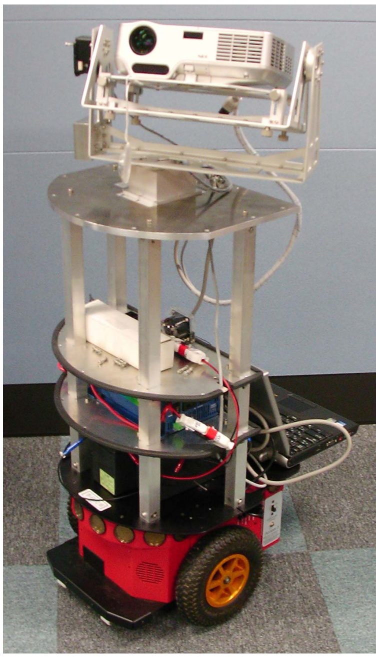

Fig. 6 A Photo of Ubiquitous Display System

local map guide panel and even though he succeed in finding the map, he should figure out the geometrical relation among current position, the goal position and the map. This is a typical example of passive information display. In this demonstration, the goal was told to Intelligent Space by a user and Intelligent Space generates a path which leads to the goal and a CG arrow is drawn on where the user is looking at by the ubiquitous display.

In Fig.7, the appearance of the demonstration is shown. The prepared scenario was that a user, who wants to get to elevator hall, is guided by the UD-1 with simple symbol CG and a few texts. When it starts guidance, the goal is presented with text data. While the system is guiding in straight aisle, a simple arrow instructs the user where to go. Several meters before changing the direction, the system projects simple animation to inform changing of direction. When the system reaches the goal, the fact that the user reached the goal is informed.

3.2 Fixed Shape Display

When information whether its form is text or graphics is projected on walls or floors, the projected image changes its shape from the original image based on geometrical relation between surface of wall or floor and projector.

Let P is input image of the projector of UD-1 and let R is a projected image on a surface then their relation is as follows.

$$R \cong \mathbf{H}_{PR} P \qquad (1)$$

By utilizing $(\mathbf{H}_{PR})^{-1}$, it is transformable between an input image and a projected image. To cope with rotation of a projector, a virtual surface is adopted (Mitsugami, *et al.*, 2005). In this paper, the virtual surface method is extended to cope

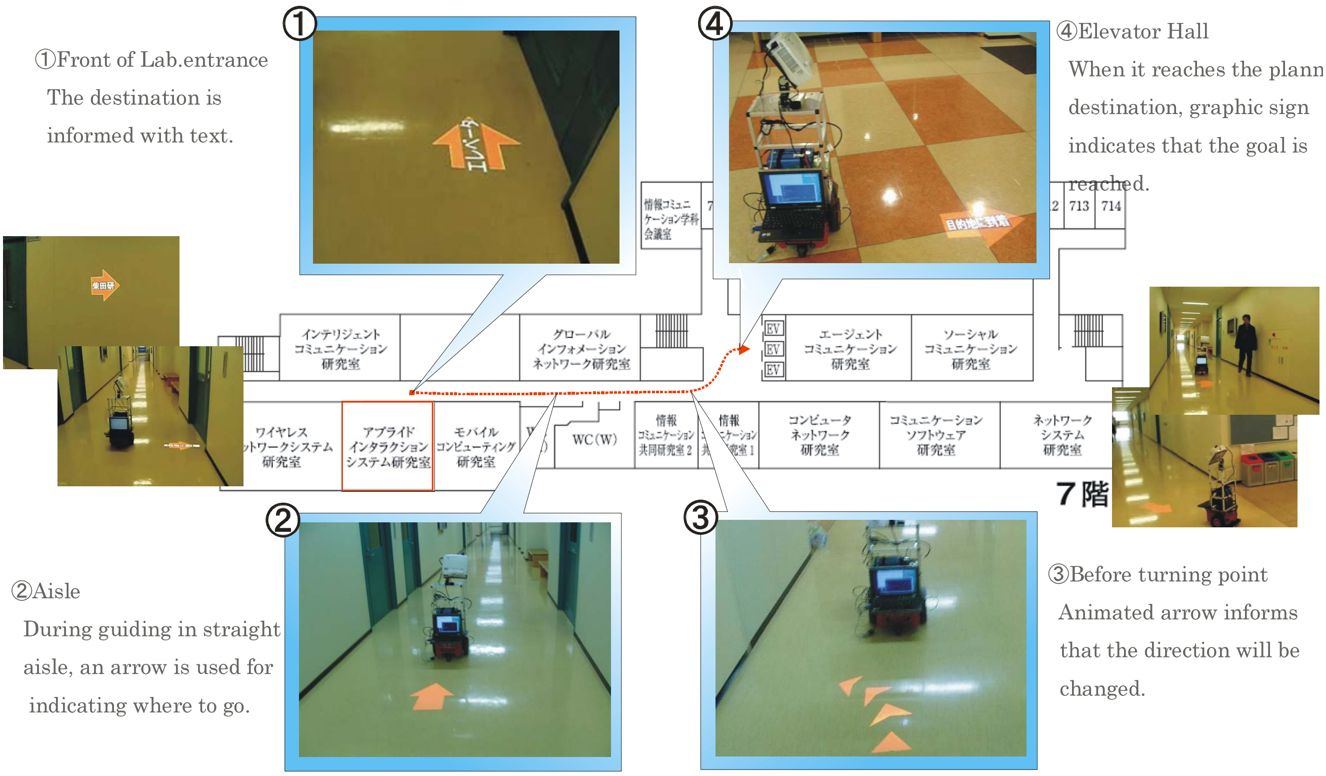

Fig. 7 Guidance experiment and examples of CG image projection on floors and walls

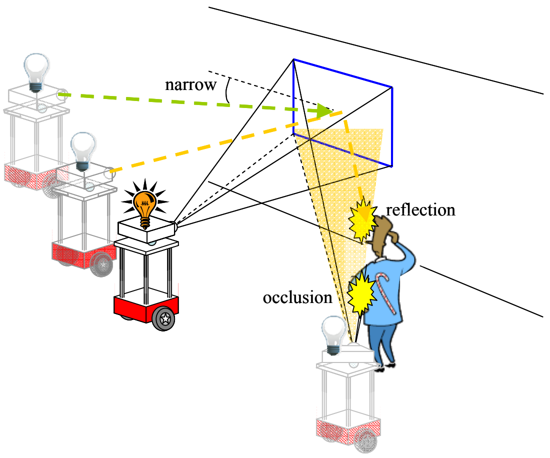

Fig. 8 Conditions to be considered to display information on environment with UD-1

with movement of UD-1 as well as rotation of the projector.

3.2 Parameter Optimization

Usually 6 DOF is considered enough to express a posture of an object in environment. However in case of UD-1, to project an image on a surface, there are 11DOF. Followings are the 11DOF.

- Posture of UD-1 : $(x_{robot}, y_{robot}, \phi_{robot})$
- Pan-Tilt Mechanism : $(\theta_{dxl}^{pan}, \theta_{dxl}^{tilt})$
  Pan : $-150 \le \theta_{dxl}^{pan} \le 150$[deg]
  Tilt : $-55 \le \theta_{dxl}^{pan} \le 80$[deg]
- Image : $(x_{img}, y_{img}, z_{img}, \varphi_{img}^{roll}, \varphi_{img}^{pitch}, \varphi_{img}^{yaw})$
  Roll Angle : $(-\pi < \varphi_{img}^{roll} < \pi)$
  Pitch Angle : $(-\pi < \varphi_{img}^{pitch} < \pi)$
  Yaw Angle : $(-\pi < \varphi_{img}^{yaw} < \pi)$

Since there is redundancy in UD-1 to display an information image on a surface, a method to find optimal values of UD-1 is required. As it is shown in Fig.8, lots of conditions should be considered in determining of parameters. If the angle between UD-1 and a surface is too narrow, the resolution of the projected image becomes unbalanced. If reflected light based on specular reflection makes user's eyes sting, user is not able to get information from the UD-1 properly. If the light from the UD-1 is blocked by user or other obstacles, the information image cannot be displayed.

In consideration of such conditions, we proposed an evaluation function to determine optimal parameters.

Horizontal angle between normal to the projection plane and UD-1 : θ_{pan}

$$\theta_{pan} = \tan^{-1}\left(\frac{y_o - y_c}{x_o - x_c}\right) - \frac{\pi}{2} \qquad (2)$$

Vertical angle between normal to the projection plane and the projector of UD-1 : θ_{tilt}

$$\theta_{tilt} = \tan^{-1}\frac{h_o - h_c}{\sqrt{(y_o - y)^2 + (x_o - x)^2}} - \phi_{tiltGap} \qquad (3)$$

, where $\phi_{tiltGap}$ is projection angle of the projector which is described in its manual.

Distance from image projected position : D

$$D = 1 - \left| \frac{\sqrt{(y_o - y_c)^2 + (x_o - x_c)^2} - Th'}{Th' - Th} \right| \qquad (4)$$

$$Th' = \frac{Th_2 - Th_1}{2} \qquad (5)$$

$$Th_1 = \frac{29}{16} x_{obj} \qquad (6)$$

$$Th_2 = \frac{1024}{108} Th_1 \qquad (7)$$

, where Th_1 is a minimum distance between the projector and a projected image while size of the projected image is fixed, Th_2 is a maximum distance between the projector and a projected image while resolution of the projected image is higher than the resolution limit and x_{obj} is width of the projected image. A coefficient of $29/16$ in (6) is determined from relation of projection length and projection size from specifications of the projector. A coefficient of $1024/108$ in (7) is determined from the minimum resolution, decided by us empirically, and the maximum resolution of the projector.

Position of occlusion free : Occ

$$Occ = \frac{2\left| \tan^{-1}\left(\frac{y_o - y}{x_o - x}\right) - \tan^{-1}\left(\frac{y_o - y_u}{x_o - x_u}\right) \right|}{projectionRange} \qquad (8)$$

, where $projectionRange$ is a horizontal angle of projected light.

Let $(\hat{\theta}_{\mathrm{pan}}, \hat{\theta}_{\mathrm{tilt}}, \hat{D}, \hat{Occ})$ be normalized parameters of above. Then we propose (9) as an evaluation function for the parameters.

$$\mathrm{J}(x, y) = \hat{\theta}_{pan} \times \sqrt{\hat{\theta}_{tilt}} \times \hat{D} \times \hat{Occ} \qquad (9)$$

UD-1 is able to decide its parameters with (9), when (9) becomes maximum value.

4. EXPERIMENT AND SIMULATION

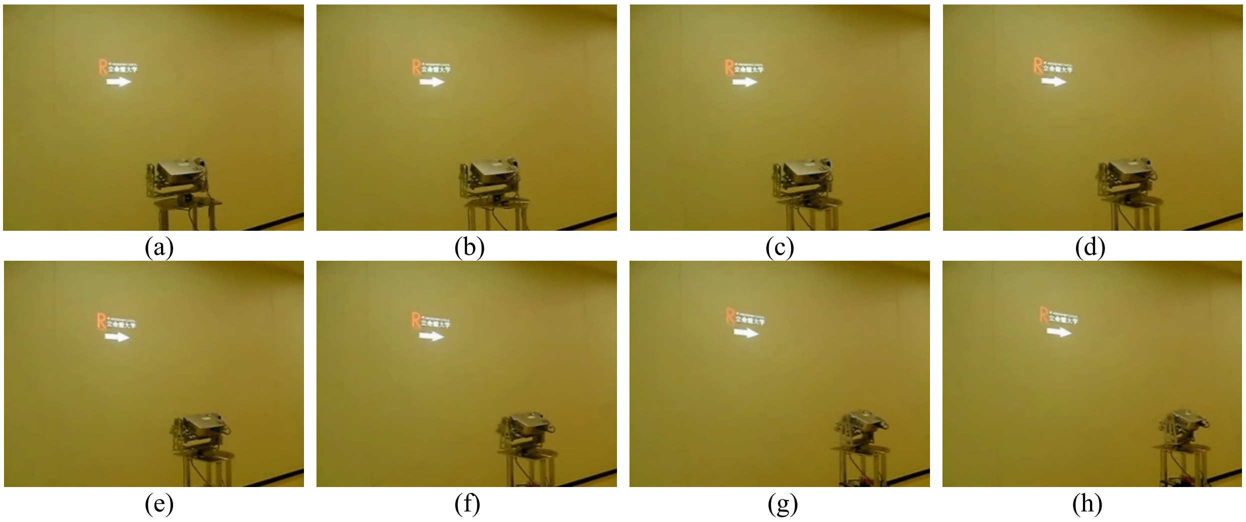

Fig. 9 Fixed shape projection is performed while the UD-1 is moving: (a)~(c) show that the UD-1 is changing its direction and (c)~(h) show that the UD-1 is advancing.

An experiment was performed to verify the proposed method of fixed shape display. In Fig.9, a CG that informs a message was projected on a fixed position. During the UD-1's moving, the message was projected in same size and shape. However, in fact, there was some position error and distortion of the projected image due to localization error of the UD-1.

Based on (9), a simulation was performed. The result is shown in Fig.10. In the simulation a man is watching a wall and the best position for UD-1 to display an information image is calculated based on proposed evaluation function. Dark red area is the best position where the evaluation function holds the biggest value.

5. CONCLUSION

In this paper, a fixed shape projection method and an optimal parameter selection method for UD-1 were proposed. Experiment and simulation results showed that the proposed methods are working correctly. However, there are many problems to be solved and further studies are required to utilize the proposed methods.

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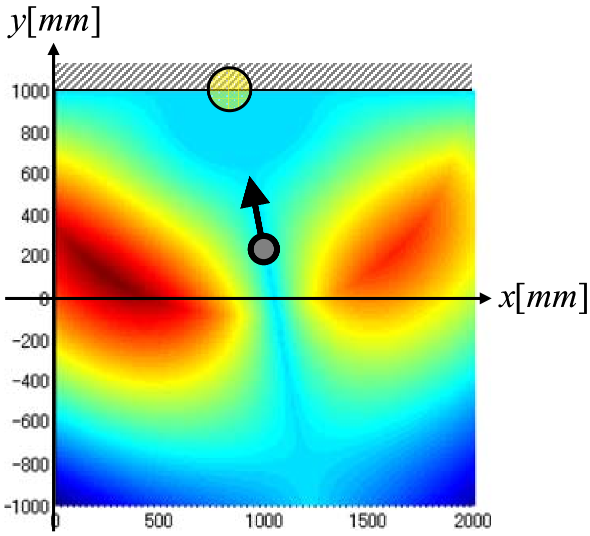

Fig. 10 Simulation result : Big circle is indicating a position where a user is watching on a wall and small circle with arrow is indicating a user and his facing direction. Color shows value of evaluation function J. In this case the best position of UD-1 is (250, 100).