Goal-Posture-Determination of a Steerable Mobile Robot for Active Information Display

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Abstract

A projection-based active information display system was proposed. The proposed system is based on Intelligent Space and a steerable projector mounted mobile robot which is called Ubiquitous Display (UD). In order to transfer visual information for a human in the Intelligent Space, the UD projects a certain shape of an image with a fixed size. Due to redundancy of degree of freedom (DOF), there are lots of situations to project a same shape and size of the image on a surface. In this paper, we describe a method to determine a goal posture of the UD. Here, the goal posture is the most efficient position and orientation of the UD so as to project visual information and it is determined by the Intelligent Space. To verify the proposed method, simulation and demonstration are carried out.

***Keywords**: Steerable Projector, Mobile Robot, Goal Posture, Active Information Display, Intelligent Space,*

Ⅰ. Introduction

As robots are increasingly integrated into human society, interaction methods between human and robots are getting one of a main research theme[1]. For human-robot interaction, a vision modality is the most commonly employed. Especially displaying text and graphics for output helps intuitive understanding. Thus, a lot of researches using visual information are being made.

In this case, one is able to use a physical output device such as monitor and mobile devices. Monitor or computer screen is located at some specific place to present information for people. Therefore in order for a user to obtain information, the user should search for the place where the information media is located. Carrying a mobile device can solve this problem, but its small screen cannot display enough information at one. To clear up these problems, we introduced projection-based active information display system [2-5]. The system is based on Intelligent Space [6-7] and a steerable projector mounted mobile robot which is called Ubiquitous Display (UD). The Intelligent Space includes several Distributed Intelligent Network Devices (DINDs). A DIND consists of a camera and a network device, which is connected to the agent server. In this environment, as a human subject seeks new information, the system first estimates the location and gaze of the user using several cameras. Secondly, it determines a projected area on which visual information is displayed, and then calculates a place where the UD has to be located. Consequently, the UD moves to the goal location and visual information is projected to the area using a projector mounted on the UD. The projected image is intentionally warped to compensate visual distortion occurred by the geometrical relation between the user and the projected image. Our projection-based active information display system is shown in Fig. 1. More details about this system were described in the reference [5]. In order to project a certain shape of visual information with a fixed size, the way of projecting an image is not singular. Due to redundancy of degree of freedom (DOF), there are lots of situations to project a same shape and size of the image on a surface. In our active information display system, it is important to select optimal parameters for the UD such as position and orientation of the UD, pan-tilt angles, and parameters of a homography. In this paper, we describe a method to determine a goal posture of the UD. Here, the goal posture is the most

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efficient position and orientation of the UD so as to project visual information and it is determined by the Intelligent Space.

II. Determining Parameters

Usually 6 DOFs are considered enough to express a posture of an object in environment. However, in case of the UD, to project an image on a surface, there are 11 DOFs. Followings are the 11 DOFs [3].

• Posture of UD : $(x_{robot}, y_{robot}, \phi_{robot})$

• Pan-tilt mechanism : $(\theta^{pan}, \theta^{tilt})$

• Image : $(x, y, z, \varphi^{roll}, \varphi^{pitch}, \varphi^{yaw})$

Since there is redundancy in the UD to project visual information, a method to find optimal values of the UD is required. The procedure for determining the parameters is shown in Fig. 2. Given the position of human, the direction of human's gaze, and the position of the UD, the Intelligent Space decides a center position of screen on the surface to project an image firstly. The Intelligent Space determines a goal posture based on the position of human, the position of the UD, and the center position of screen. At this time, lots of conditions are considered.

For example, we consider the image quality of projected image and the mobility of the UD. We calculate values of the evaluation function considering these conditions. The goal position $(x^g_{robot}, y^g_{robot})$ is the position having the maximum value. Since the orientation angle is taken counter-clockwise from the X-axis, the orientation ϕ^g_{robot} of the UD at the goal position can be obtained from the direction vector between the goal position and the center position of screen on the surface. The Intelligent Space controls the UD along the smooth path generated by the path planning process. After the UD reaches the goal position, the Intelligent Space measures the current posture $(x^c_{robot}, y^c_{robot}, \phi^c_{robot})$ of the UD again. In order to compensate the error between $(x^g_{robot}, y^g_{robot}, \phi^g_{robot})$ and $(x^c_{robot}, y^c_{robot}, \phi^c_{robot})$, the Intelligent Space determines angles of pan and tilt of mirror. Then, the Intelligent Space calculates a homography and makes an image to be projected.

III. Determining goal posture

In order to project visual information on a surface by the UD, we first determine the goal posture $(x^g_{robot}, y^g_{robot}, \phi^g_{robot})$ of the UD. For this, we consider lots of conditions as follows:

1) The UD should transfer visual information without distortion. If the angle between the UD and a surface is narrow, the resolution of the projected image becomes unbalanced. If the distance between the UD and a surface is not suitable, the projected image is not clear.

2) The UD should transfer visual information without occlusion. If the light from projector mounted on the mobile robot is blocked by a user or other obstacles, shadows are cast on the display surface.

3) The UD should not interfere with the view of a user.

4) The UD should move along the shortest path from the current position to the goal position.

5) The UD should be prepared to respond to the dynamic situation.

To determine the goal position of the UD, firstly we select the candidates for position of the UD. After that, we calculate values of the evaluation function about selected positions and determine the goal position as the position having the maximum value.

3.1. Selection of candidates

In order to select candidates for position of the UD, we define the membership function. We assume that following parameters are given.

• Center position of screen on the surface to project : $(x_{screen}, y_{screen}, z_{screen})$

• Focal length of the projector : $FocalLength$

• Projection angle of the projector : θ_p

• Width of visual information of the projector : $Width$

The membership function is like this.

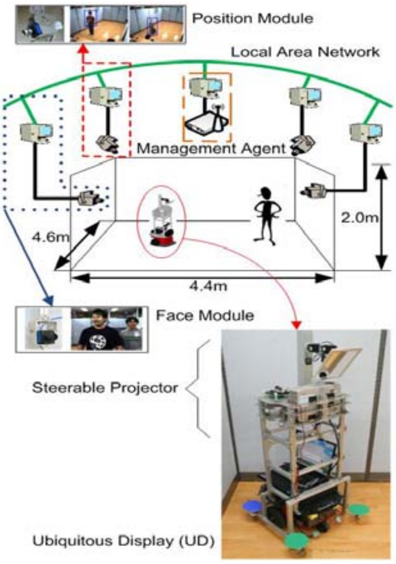

Figure 1. Projection-based active information display system

$$IsCandidate(x,y)=\prod_{i=1}^{N_C} F_i^C(x,y) \tag{1}$$

$$\begin{pmatrix} N_C : number\ of\ factors\ for\ selection\ of\ candidates \\ F_i^C : i^{th}\ factor \end{pmatrix}$$

$$1)\, F_1^C(x,y)=\begin{cases} 1 & Th_{\min} \le dist_{focus}(x,y) \le Th_{\max} \\ 0 & otherwise \end{cases}$$

$$dist_{focus}(x,y)=\sqrt{(x-x_{screen})^2+(y-y_{screen})^2}$$

$$Th_{\max}=FocalLength+margin1$$

$$Th_{\min}=FocalLength-margin2$$

$$2)\, F_2^C(x,y)=\begin{cases} 1 & dist_{angle}(x,y)\ge r \\ 0 & otherwise \end{cases}$$

$$dist_{angle}(x,y)=\sqrt{(x-x_{screen})^2+(y-y_{screen}-R\cos\theta_p)^2}$$

$$R=\frac{Width}{2\sin\theta_p}$$

$$3)\, F_3^C(x,y)=\begin{cases} 1 & otherwise \\ 0 & if\ the\ UD\ interferes\ with\ the\ view\ of\ a\ user \end{cases}$$

$$4)\, F_4^C(x,y)=\begin{cases} 1 & otherwise \\ 0 & if\ the\ light\ is\ blocked\ by\ a\ user \end{cases}$$

$$5)\ F_5^C(x,y)=\begin{cases}1 & \cos^{-1}\left(\dfrac{\mathbf{v}}{\|\mathbf{v}\|}\cdot\mathbf{n}\right)-\dfrac{\pi}{2}\geq\theta_{\min}\\ 0 & otherwise\end{cases}$$

- $\mathbf{v}$: *the direction vector of the UD at* (x,y)

  $\left(\mathbf{v}:=\left(x_{screen}-x,\, y_{screen}-y\right)\right)$
- $\mathbf{n}$: *the normal vector of the surface(wall)* $\left(\|\mathbf{n}\|=1\right)$
- $\theta_{\min}$: *minimum angle between the UD and the surface*

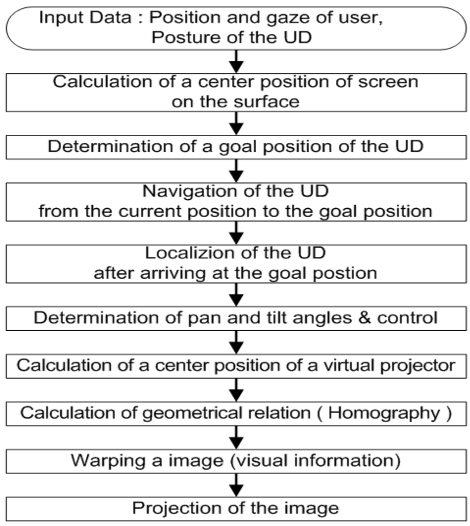

Figure 2. Projection-based active information display system

3.2. Determination of the goal position by an evaluation function

In order to determine a goal position of the UD, we define an evaluation function. Here, we consider the resolution of the projected image, length of a path for the UD, responsiveness of the UD, and etc. The evaluation function is like following.

$$J(x,y)=\prod_{i=1}^{N_E}F_i^G(x,y) \tag{2}$$

$$\begin{pmatrix}N_E : number\ of\ factors\ for\ evaluation\\ F_i^G : i^{th}\ factor\end{pmatrix}$$

$$1)\ F_1^G(x,y)=\frac{1}{2}\left(1+\cos(\theta-b)\right)$$

- b : *bias term*
- $\theta=\cos^{-1}\left(\dfrac{\mathbf{v}_1}{\|\mathbf{v}_1\|}\cdot\dfrac{\mathbf{v}_2}{\|\mathbf{v}_2\|}\right)$

$$\begin{bmatrix}\circ\mathbf{v}_1=\left(x-x_{screen},\, y-y_{screen}\right)\\ \circ\mathbf{v}_2=\left(x_{human}-x_{screen},\, y_{human}-y_{screen}\right)\end{bmatrix}$$

$$2)\ F_2^G(x,y) = 1 - \frac{\left|dist_{focus}(x,y) - FocalLength\right|}{margin}$$

$$\square\ dist_{focus}(x,y) = \sqrt{(x - x_{screen})^2 + (y - y_{screen})^2}$$

$$\square\ margin = \begin{cases} margin1 & if\ dist_{focus}(x,y) \geq FocalLength \\ -margin2 & otherwise \end{cases}$$

$$3)\ F_3^G(x,y) = 1 - \frac{pathLength(x,y) - path_{\min}}{path_{\max} - path_{\min}}$$

$\square\ pathLength(x,y) : number\ of\ grid\ cells\ from\ (x_{robot}, y_{robot})\ to\ (x,y)$

$\circ\ (x_{robot}, y_{robot}) : current\ position\ of\ the\ UD$

$\square\ path_{\max} = maximum\ of\ pathLength(x,y)$

$(The\ path\ is\ found\ by\ A^*.)$

$$4)\ F_4^G(x,y) = \frac{Count(x,y)}{8}$$

$\square\ Count(x,y) : number\ of\ candidate\ cells\ out\ of\ eight\ neighboring\ cells$

$$5)\ F_5^G(x,y) = \begin{cases} 1 - \dfrac{dist_{human}(x,y)}{max\_dist + Th} & if\ dist_{human}(x,y) \geq Th \\ \varepsilon & otherwise \end{cases}$$

$$\square\ dist_{human}(x,y) = \sqrt{(x - x_{human})^2 + (y - y_{human})^2}$$

$\square\ Th : Personal\ distance\ for\ interactions$

The goal position $(x_{robot}^g, y_{robot}^g)$ is a position having the maximum value of the evaluation function $J(x,y)$.

$$(x_{robot}^g, y_{robot}^g) = \arg\max_{(x,y)\in S} J(x,y) \tag{3}$$

$$where, S = \{(x,y) \mid (x,y)\ is\ a\ center\ position\ of\ the\ candidate\ cell\}$$

3.3. Determination of the goal orientation

When the UD arrives at the goal position, the UD should stand towards the center point of screen on the surface to project. Since the goal orientation of the UD is the angle that is taken counter-clockwise from the X-axis, it can be calculated by eq. (4).

$$\phi_{robot}^g = \begin{cases} \cos^{-1}\left(\dfrac{\mathbf{v}}{\|\mathbf{v}\|} \cdot \mathbf{e}_1\right) & if\ \mathbf{v}\ is\ in\ the\ quadrant\ 1\ or\ 2 \\ 2\pi - \cos^{-1}\left(\dfrac{\mathbf{v}}{\|\mathbf{v}\|} \cdot \mathbf{e}_1\right) & if\ \mathbf{v}\ is\ in\ the\ quadrant\ 3\ or\ 4 \end{cases} \tag{4}$$

$$\square\ \mathbf{v} = (x_{screen} - x_{robot}^g, y_{screen} - y_{robot}^g)$$

$$\square\ \mathbf{e}_1 : the\ direction\ vector\ of\ X-axis\ \ (\|\mathbf{e}_1\| = 1)$$

IV. Experimental results

Given current position of the user, center position of the screen, and current posture of the UD, we simulate to find a goal position. Table 1 shows initial conditions used in this simulation and Table 2 shows some parameters.

Table 1. Initial conditions for a simulation

Condition	Value
Current position of the user	(310cm, 150cm)
Center position of the screen	(25cm, 0cm)
Current posture of the UD	(340cm, 250cm, 180°)

Table 2. Parameter values

Parameter	Value
$b: bias\ term$	15°
$FocalLength$	130cm
$margin1$	30cm
$margin2$	10cm
Th	76cm
ε	$\begin{cases} 0.2 & if\ 46 \le dist_{human}(x,y) \le 75 \\ 0.01 & if\ dist_{human}(x,y) \le 45 \end{cases}$

For simulation, we use only x and y coordinates. In Fig. 3, we visualized these settings. First of all, we should select candidates for position of the UD. Fig. 4 shows the grid map to represent the environment after process of selecting the candidates by using the membership function. We define a candidate cell as a cell that the candidates account for more than 50% of a cell. Each number indicates the candidate cell ID. We calculate a value of the evaluation function for each center positions of the cells. The parameter Th is derived from the proxemics[8]. In this study, we use a value of personal distance. As shown in Table 3, we can decide that a goal position is a center position of 7th cell (i.e. $\left(x^g_{robot}, y^g_{robot}\right) = (230,130)$). The goal orientation ϕ^g_{robot} is 278.7462° as shown Fig. 5. After determination of a goal position, the Intelligent Space generates a smooth path from the current position to the goal position considering the orientation of the UD by using the Kanayama-Hartman's algorithm[9-10]. The Result is shown in Fig. 6.

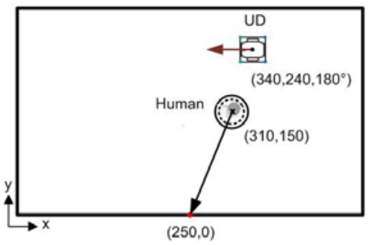

Figure 3. Initial condition for a simulation

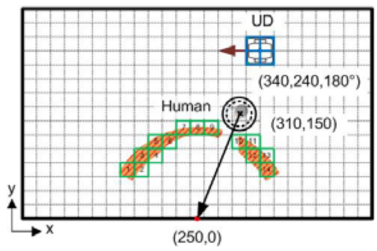

Figure 4. Grid map and the candidate cell ID

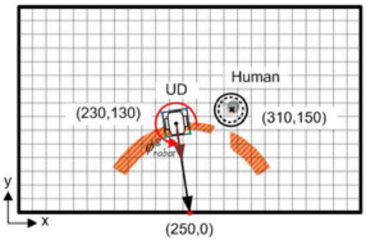

Figure 5. The goal posture of the UD

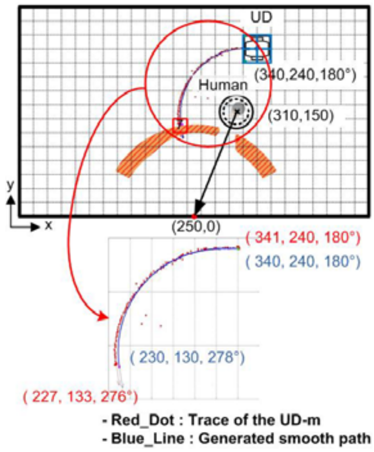

Figure 6. Experimental result

Table 3. Calculation results of the evaluation function

Cell ID	F_1^G	F_2^G	F_3^G	F_4^G	F_5^G	$J(x,y)$
1	0.7362	0.2066	0	0.2500	0.2982	0
2	0.7824	0	0.1000	0.3750	0.3674	0
3	0.8317	0.0416	0.2000	0.5000	0.4024	0.0014
4	0.8803	0	0.3000	0.5000	0.4736	0
5	0.9075	0.5300	0.4000	0.3750	0.5037	0.0363
6	0.9464	0	0.5000	0.3750	0.5774	0
7	0.9817	0.9490	0.7000	0.2500	0.6765	0.1103
8	0.9965	1.0000	0.6000	0.2500	0.2000	0.0299
9	0.9997	0.9490	0.5000	0.1250	0.1000	0.0059
10	0.9949	0.5300	0.9000	0.2500	0.1000	0.0119
11	1.0000	0.7995	1.0000	0.3750	0.1000	0.0300
12	0.9982	0.0416	0.9000	0.3750	0.2000	0.0028
13	0.9905	0.8488	1.0000	0.3750	0.2000	0.0631
14	0.9750	0.2066	0.9000	0.2500	0.6491	0.0294

V. Conclusion

In this paper, we described a method to determine a goal posture of the UD. The Intelligent Space determines a goal posture based on the position of the user, the position of the UD, and the center position of screen. Considering lots of conditions, we proposed the membership function and the evaluation function. We could find the goal posture reasonably. The Intelligent Space can control the UD along the smooth path and the UD can project visual image on surface where the user is facing by utilizing the inverse matrix of the projective transformation (homography) between the user and the projector. Since we focused on implementation of the active information display system, simple methods are chosen. In order to satisfy a real-time functionality, we have to improve these methods into fast and efficient methods.

VI. Acknowledgments

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