Estimation of User's Attention based on Gaze and Environment Measurements for Robotic Wheelchair

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Abstract

In this paper, we describe a robotic wheelchair system as a guide robot. This system detects the head pose and gaze direction osf the user, and recognizes its position and the surrounding environment using a range sensor and a map. Since the system can detect where the user is looking from the measurements, it can estimate the attention of the user on the wheelchair by the duration of gaze. Experimental results indicate the validity of the speed control assistance using the estimation of user's attention.

I. Introduction

With the increase in the number of senior citizens, there has been a growing demand for human-friendly wheelchairs as mobility aids. However, driving conventional electric wheelchairs imposes burdens on their users both physically and mentally. They must do continuous steering with the joystick while paying close attention to the surroundings. Thus several intelligent/robotic wheelchairs have been proposed to alleviate these burdens.

Such researches addresses two major categories. The first one is the autonomous capability. Sensors such as encoders and ultrasonic range sensors are used to localize their own position and to detect obstacles[1][2]. The wheelchairs can navigate to a specified goal and/or avoid obstacles autonomously. The second one is the interface for easy operation. To build simple and intuitive interfaces, multi-modal information can be utilized. In some researches, voice information is utilized to give commands to wheelchairs[3][4]. Other researches utilized user's face direction to directly specify the direction to move. Since the goal of our research is to build practical robotic wheelchairs, both aspects of the research are inevitable. However in this paper, we are focusing on describing the interface aspects of our system. To build a smart interface for a robotic wheelchair, it is important for the system to know the user's attention. Since the visual information on human face, especially the motion of the head pose and gaze direction, is highly correlated to his/her attention, detection of such information can be utilized for a natural and intuitive interfaces. In the conventional researches about the interface of robotic wheelchair using visual information from the human face[5][6][7][8], the detected direction of the face is directly used as the direction to which the wheelchair moves. Therefore, the user needs to turn his/her face exactly to the desired direction. Moreover, there is no significant results regarding the intention recognition of the user.

In a previous work, we showed that both the direction of the face and that of the gaze almost coincided with each other when the user was concentrated in the operation[9]. In the current operation using the face, the wheelchair slows down when the user is looking around. In this paper, we describe a robotic wheelchair system which can detect the head pose and gaze direction and can recognize its position and the surrounding environment using a range sensor and a map. Since the system can detect where the user is looking from the measurements, we can estimate the attention of the user by the gazing duration. Experimental results indicate the validity of the speed control assistance using the estimation of user's attention.

II. System Configuration

In order to realize the intention recognition from the user's natural behavior, we developed our experimental robotic wheelchair system. **Fig.** 1 and **Fig.** 2 show the overview of our experiment system and the hardware architecture. We adapted a commercial electric wheelchair to be controlled by a notebook PC. The system has a pair of stereo CCD cameras to capture the facial image of the user and a laser range finder to recognize the surrounding environment.

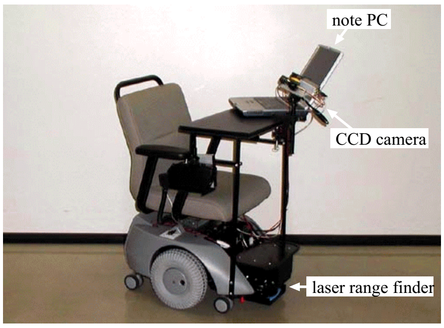


Fig. 1. *System overview*

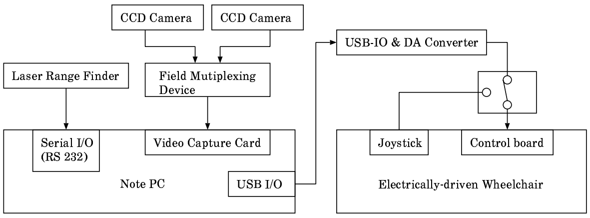


Fig. 2. *Hardware architecture of the control system*

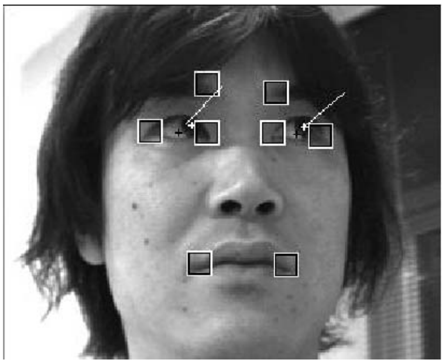


Fig. 3. *Result of face and gaze measurement*

A. Face and Gaze Measurement System

Our system can detect the head pose and gaze direction using a stereo vision system [10] which has the following advantages: non-contact, passive, real-time, robust, accurate, and compact. It can detect natural behavior with no contact with the user. **Fig.** 3 shows an example of the result of the measurement process. The squares indicate the positions of the features and the two lines indicate the gaze direction.

B. Wheelchair Localization

The wheelchair can recognize the position and the surrounding environment using a laser range finder and a map. The map consists of sets of line segments. **Fig.** 4 shows an example of the map. The initial position within the environment is given. The robotic wheelchair observes front scanning data of 180 degrees using a laser range finder. Then, the wheelchair extracts the scanning data about each angle from the map in the previous position and posture. Based on the matching of the two data, the wheelchair can estimate its position. The matching process utilizes a histogram-based method which is an extension to the matching method proposed by Weiss et al [11]. The outline of the process is described as follows:

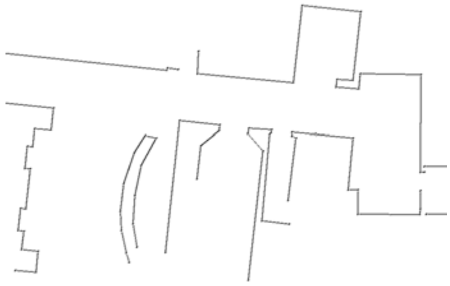


Fig. 4. *A map which consists of line segments*

1. Calculate angle-histograms of two scans and find the angular displacement $d\theta$ with the highest correlation.
2. Rotate the current scan by $d\theta$.
3. Calculate translation histograms of two scans along x and y directions.
4. Find the highest correlations dx, dy for x and y directions using histograms.

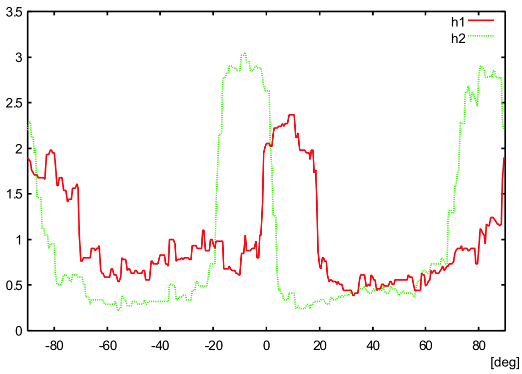
Fig. 5(a) shows an example of two angle-histograms, i.e. a current scan and an extracted data from the map. **Fig.** 5(b) illustrates the correlation between two angle-histograms shown in **Fig.** 5(a).

C. Estimation of User's Attention

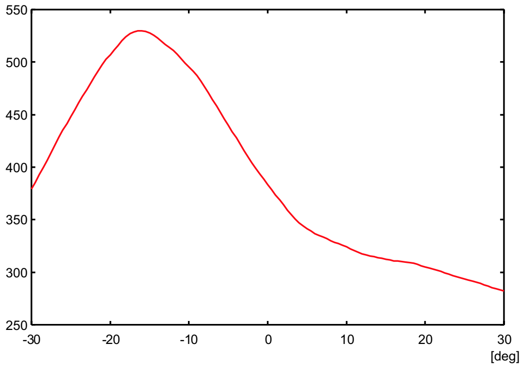
Based on the detection of both the gaze direction and the position within the map, the robotic wheelchair system can measure the user's fixation. From which, it estimates where the user is paying attention. Therefore, we adopt a histogram-based representation. The frequency of fixation is represented by what we call an attention histogram.

The following knowledge is used to define the attention histogram's parameters:

- It is known that human being's acuity of vision is about the central two degrees of visual angle, that is called Foveal Vision. Therefore the attention histogram has a distribution around the gaze direction. In order to simplify calculation, the frequency is made stepwise (see the formula below).
- The attention on each position decreases as the



(a) Two angle-histograms



(b) Correlations between two angle-histograms

Fig. 5. *The correlation between two scans*

distance from the user becomes large. Thus, the histogram decreases according to the distance.

- The frequency of the attention histogram in each position of the map is attenuated gradually over time.

The definition formula of the frequency is summarized as follows:

$$w_i(t) = \alpha \cdot w_i(t - \Delta t) + \begin{cases} 1/L & (\theta \leq 5[deg]) \\ 0.5/L & (5 < \theta \leq 10[deg]) \\ 0 & (\theta > 10[deg]) \end{cases}$$

$w_i(t)$: Frequency of the position i at time t

L : Distance between the position i and the wheelchair

α : Rate of the attenuation of frequency

θ : Angle from the gaze direction of the user

III. Experimental Results

A. Estimation of User's Attention

We made a preliminary experiment in which the attention of the user and the information on the environment are recorded. In the experiment, the user

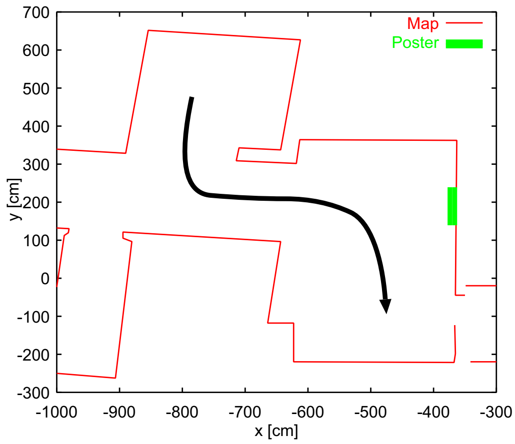


Fig. 6. *The route in the autonomous run*

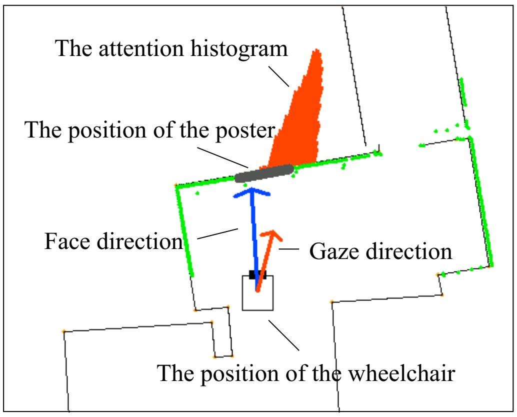
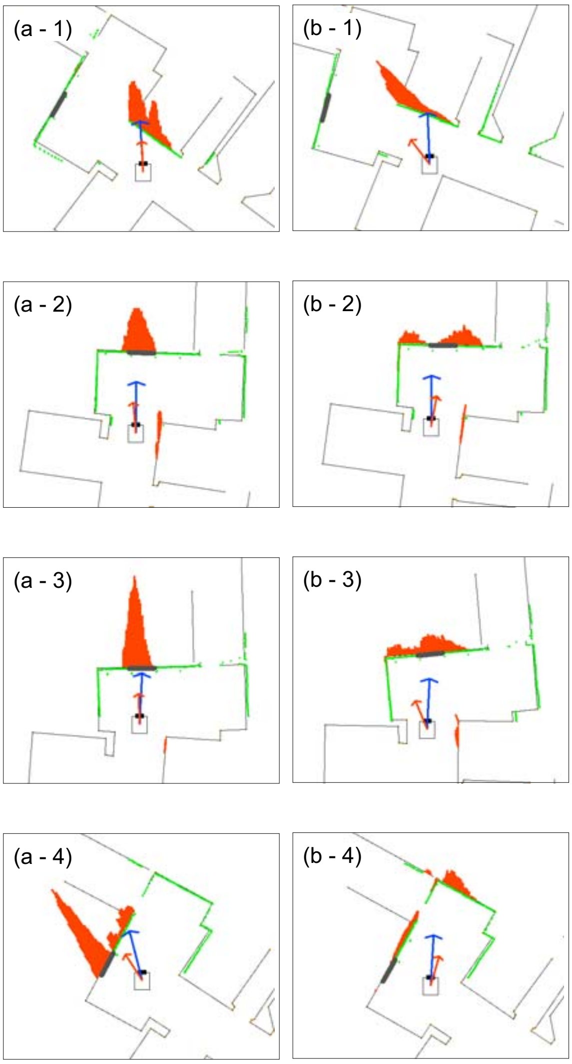


Fig. 7. *The state in the experiment*

rides on the wheelchair while this one is running autonomously. The user then pays attention to the poster in a first run and does not pay attention to the poster in a second run.

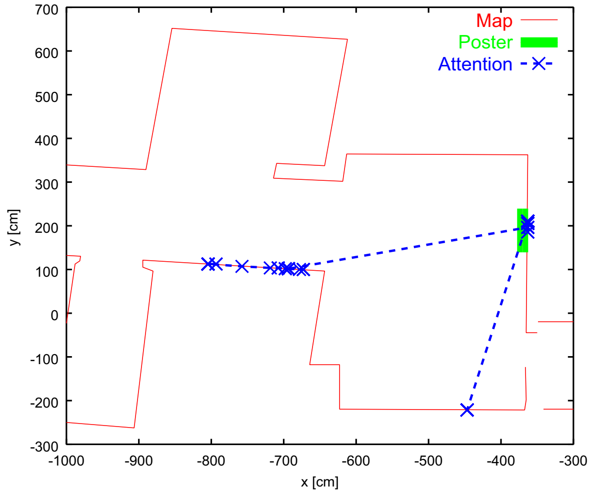
Fig. 6 shows the route of the autonomous run in the experimental environment. **Fig.** 7 shows measured face and gaze direction of the user and the estimated position of the wheelchair. In **Fig.** 7, a rectangle indicates the position of the wheelchair and the dots indicate the scans from the laser range finder. The long arrow indicates the detected direction of the face and the short arrow indicates the gaze direction respectively. The histogram on the map indicates the fixations at each position.

Fig. 8 shows the sequence of measured face and gaze direction and localization during the two autonomous runs. From the measurements of the facial and environmental information in **Fig.** 8(a) , it can be noticed that the user is paying attention to a poster

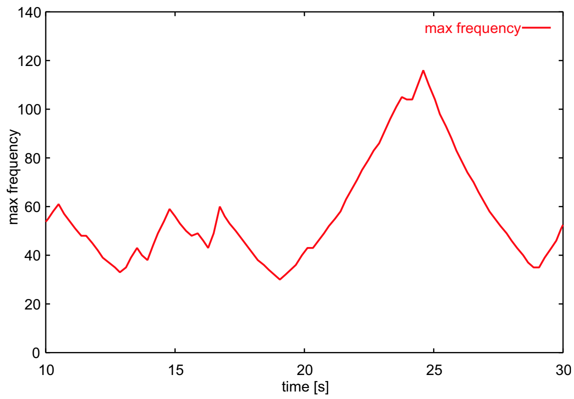


(a) Paying attention to the poster (b) Not paying attention to the poster

Fig. 8. *The sequence of measured face and gaze direction and localization during the autonomous run*



(a) The position of estimated attention



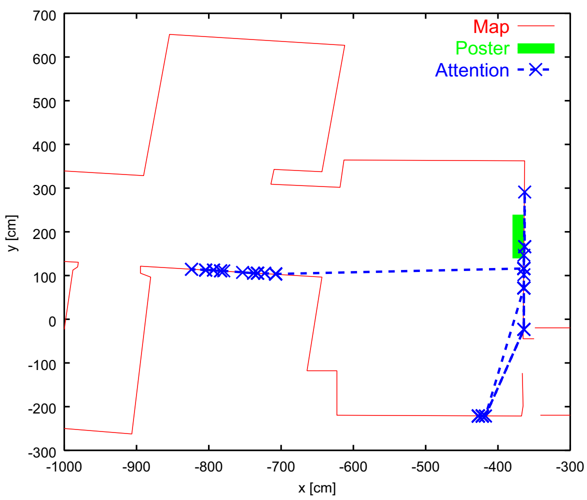
(b) The sequence of maximum frequency

Fig. 9. *The maximum frequency and the position of attention in the case that the user is paying attention to the poster*

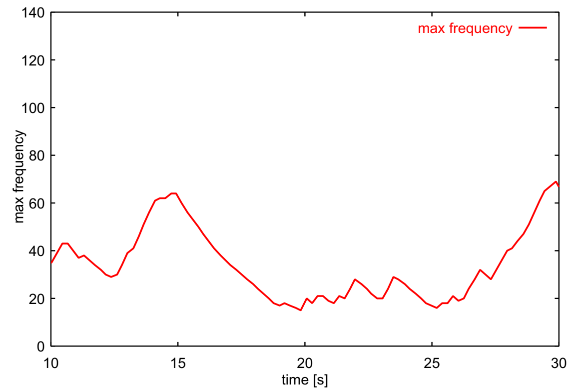
on the wall. In **Fig.** 8(a-2) and (a-3) the frequency of the histogram gets larger and is concentrated on the poster. From the measured results shown in **Fig.** 8(b), it can be easily recognized that the user is not paying attention to specified object in this sequence. The frequency of the histogram is relatively small at each position and is distributed.

Fig. 9 and **Fig.** 10 show the changes of maximum frequency of the histogram and the position of maximum frequency in the map. **Fig.** 9 corresponds to the measured results in the experiment of **Fig.** 8(a). From the measurements in **Fig.** 9(a), it can be noticed that the user is paying attention to the poster since the position of maximum frequency is concentrated on the poster. **Fig.** 9(b) shows that the frequency is large when the user is paying attention to the poster. **Fig.** 10 corresponds to the measured results in the experiment of **Fig.** 8(b). From the measured results shown in **Fig.** 10(a), it can be noticed that the position of maximum frequency is unsteady. **Fig.** 10(b) shows that the maximum frequency is relatively small throughout the experiment.

These experimental results indicate that the user's attention is related to the direction of both the gaze and the face, and can be distinguished by the mea-



(a) The position of estimated attention



(b) The sequence of maximum frequency

Fig. 10. *The maximum frequency and the position of attention in the case that the user is not paying attention to the poster*

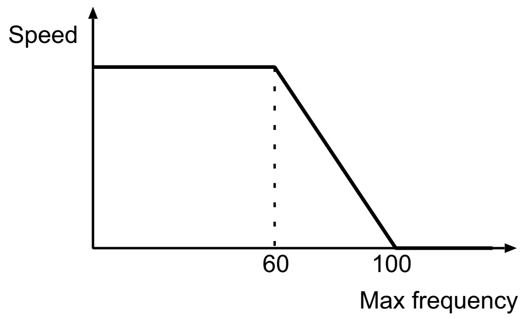


Fig. 11. *Adjustment of speed*

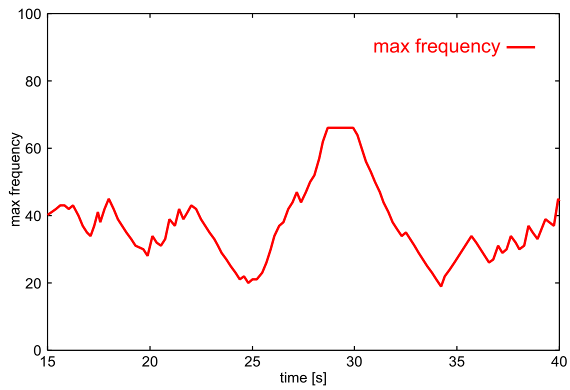


Fig. 12. *The maximum frequency in the speed control run*

sured information with our robotic wheelchair system.

B. Speed Control using Attention Estimation

The robotic wheelchair was equipped with a smart interface that controls the speed based on the estimation of user's attention. When the attention of the user is estimated, the wheelchair reduces its speed so that the user may have enough time to fully perceive the object. Then, the system controls the speed according to the size of the maximum frequency of the histogram. The experimental results were used to determine the control strategy of the wheelchair's speed. **Fig.** 11 shows the relation between the speed and the maximum frequency which is based on the results in **Fig.** 9 and **Fig.** 10.

Fig. 12 and **Fig.** 13 show the experiment in the autonomous run with the speed control. The route of the autonomous run is similar to **Fig.** 6. In **Fig.** 12, the change of maximum frequency of the histogram is shown. **Fig.** 13(a) shows the results of localization at 800ms interval. Since the wheelchair reduces the speed by estimating the user's attention, the intervals between positions are small at the point (A). **Fig.** 13(b) shows the snapshot of the user and the wheelchair system at the point (A). At this point, the user is looking at the poster and the system detects the user's attention. After the point (A), the wheelchair system runs at a constant speed since the user is not paying attention anymore. **Fig.** 13(c) shows the snapshot at the point (B). These results indicate the validity of the speed control assistance with the estimation of the user's attention.

IV. Summary

In this paper, we described a robotic wheelchair system which can detect the head pose and gaze direction using a real-time stereo vision system, and can recognize its position within the surrounding environment using a range sensor and a map. Since the system can detect where the user is looking from the measurements, we could estimate the user's attention by the duration of gaze. Experimental results indicate the validity of the speed control assistance with the estimation of user's attention.

As future works, we are planning to extend the application area of the wheelchair to various situations other than "a poster on the wall." For such an extension, we will start by measuring the fixation and the user's operation at various situations, and then analyze the relationship between them in order to estimate the user's attention.

Acknowledgments

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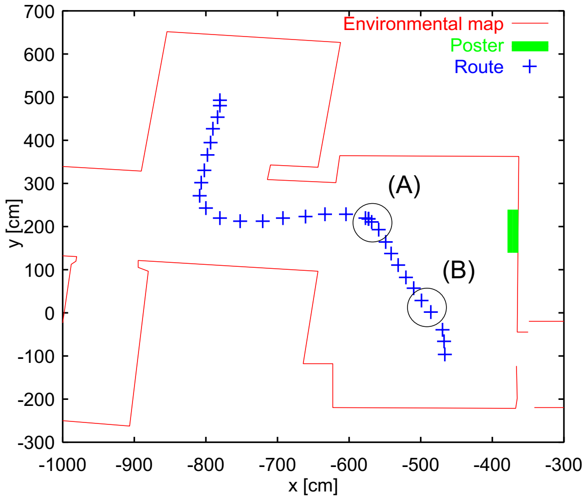

(a) The positions of the wheelchair at each 800ms

(b) Looking at the poster on the point A

(c) Running on the point B without paying attentions

Fig. 13. *The speed control run*