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Preliminary Analysis of Gait Changes that Correspond to Gaze Directions

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***Abstract*—Human gait (way of walking) can be changed to correspond to human gaze direction. We aim to realize a gait-based gaze estimation scheme by modeling the relations between gait and gaze. In this paper, as a first step to our goal, we show the preliminary analysis results of the relations between gait and gaze. From the results, we confirmed that arm swing is affected by the gaze direction. We confirmed a tendency for the opposite arm's amplitude in the gazing direction to decrease. For these analysis, we constructed an immersive walking environment in which we measured subject gaits in various gazing situations by a motion capturing system and an eye tracker. The environment consisted of a treadmill and 180 multi-screens for presenting the gazing target. Our analysis results suggest the possibility of gaze estimation based on gait.**

I. Introduction

Human gaze information includes interests, emotions, and intentions [1], [2]. Gazes are useful in marketing and advertisements fields [3], [4]. For example in marketing, if we can estimate the interests of customer targets from gaze information, we can recommend items related to those customers are interested in. Thus, gaze tracking in such public spaces as shopping malls is important.

Although many gaze tracking methods have been proposed so far [5], [6], gaze tracking in public spaces remains problematic. Existing gaze tracking methods are divided into two types: wearable and fixed. Obviously, wearable types cannot be used because the observation targets need to wear the devices. On the other hand, the fixed types require high-resolution eye images. Due to this limitation, fixed types can only be used near the device. However, we cannot set up a fixed type eye tracker in such arrangements in marketing scenes. Thus, neither conventional system cannot be applied to public spaces.

To solve such problems and realize gaze tracking in public spaces, we consider an indirect scheme for gaze direction estimation, i.e., gaze estimation, using body motion changes caused by gazing direction without directly observing the eye region. We focus on gait. As a first step to our goal, we analyze the gait changes that correspond to the gaze direction. For such analysis, since we need gait data in various gaze directions, we construct an immersive walking environment that consists of multiple projectors/screens and a treadmill and perform experiments in it. In this paper, we show the results of analyzing gait changes that correspond to gaze directions and discuss the possibility of gaze direction estimation from gaits.

II. Related Research

Many researchers have been investigating the relations among gaze, head, and body poses [7]-[10]. Nakashima et al. examined the relations of gaze and head directions in visual tasks [7] and concluded that the distributions of gaze directions depend on the head directions. Gaze distributions are shifted to the head directions. Researches exists on the relation of eye and head movements while walking. McDonald et al. proposed an adaptive control model for human head and eye movements and confirmed compensatory eye movements for head movements due to walking to visually fixate on an object [8]. Imai et al. examined the relations among body, head, and eye movement during straight walking and turning corners [9].

For obtaining the relations between human gait and gazing direction, [11] reported that arm swings are affected by the gazing direction. Based on their results, we want to realize gaze direction estimation from gaits. In this paper, we analyze the gait changes that correspond to the gaze direction using a motion capturing system and an eye tracking system in immersive walking environments that consisted of a treadmill and multiple screens.

III. Immersive Walking Environment

A. System Configuration

Figure 1 shows our experiment's constructed immersive walking environment that consisted of multiple screens/projectors and a treadmill. The gazing target is displayed on the screens, and the subject is walking on the treadmill and looking at the gazing target. Since the gazing targets are shown in various positions/directions, we can obtain the gaits of subjects while they are looking in various directions.

We used a wearable eye tracker (NAC EMR-9) to measure the subject gaze directions and a motion capturing system (Vicon) to measure their gaits. Here, the motion capturing system can accurately measure the 3D postures of subjects. The wearable eye tracking device consisted of eye cameras and a view camera (Fig. 2) and can measure subject gaze directions as 2D positions in the view camera. To analyze the relation between gait and gaze, we need to obtain both pieces of data in a fixed common coordinate system. Thus we need to calibrate the relation between the eye tracker and motion capture systems in advance to convert the 2D gaze information to 3D gazing directions. In the next section, we explain the system calibration.

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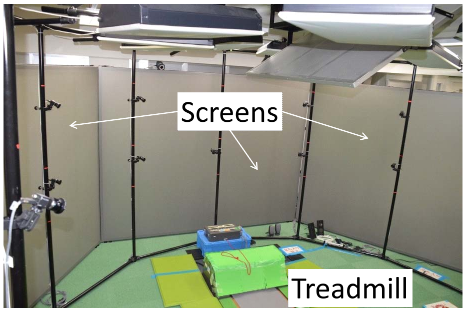

Fig. 1. Immersive walking environment

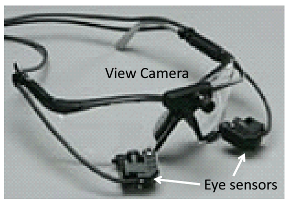

Fig. 2. Eye tracker (NAC EMR-9)

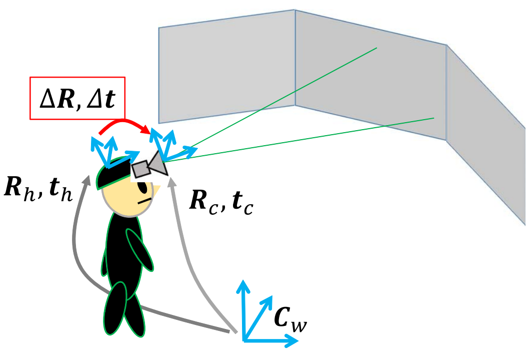

Fig. 3. Relations among devices

B. System Calibration

Figure 3 shows the relation between the motion capture and eye tracker systems. To properly integrate the gaze and gait data, we need the poses and positions of view camera $R_c^{(t)}, t_c^{(t)}$ in world coordinates C_w at time t during the experiments. However, it is difficult to accurately estimate $R_c^{(t)}, t_c^{(t)}$ by only the view camera observations. Here, since the view camera is mounted on the subject's head, $R_c^{(t)}, t_c^{(t)}$ of the view cameras are changed in conjunction with the pose and position of the subjects' head $R_h^{(t)}, t_h^{(t)}$ that can be measured by the motion capture system. If relative relations ΔR and Δt between $R_c^{(t)}, t_c^{(t)}$ and $R_h^{(t)}, t_h^{(t)}$ are known, we can obtain $R_c^{(t)}, t_c^{(t)}$:

$$\mathbf{R}_c = \Delta\mathbf{R}_c\mathbf{R}_h \tag{1}$$

$$\mathbf{t}_c = \mathbf{R}_c\mathbf{R}_h^{-1}\mathbf{t}_h + \Delta\mathbf{t} \tag{2}$$

To estimate ΔR and Δt, first, a chessboard is displayed on the screens and more than three images are captured by the view camera. The poses, positions, and intrinsic parameters of the view camera, $R_c^{(t)}, t_c^{(t)}$, and A, can be estimated from these observations. At the same time, the poses and positions of the subject's head at the view camera capturing timings are acquired by the motion capture system. Then we calculate ΔR and Δt. These calibration steps must be performed once in advance.

By using the parameters calculated in the calibration step, we can convert the 2D gaze information measured by the eye tracker to the 3D gaze direction in the world coordinates. Let $p = [u, v]'$ be the 2D gaze positions in the view camera, and V, the 3D gaze directions in C_w, can be calculated as

$$\mathbf{V} = s\mathbf{R}_c^{-1}\mathbf{A}^{-1}\tilde{\mathbf{p}} \tag{3}$$

where $\tilde{p} = [u, v, 1]'$ and s is constant.

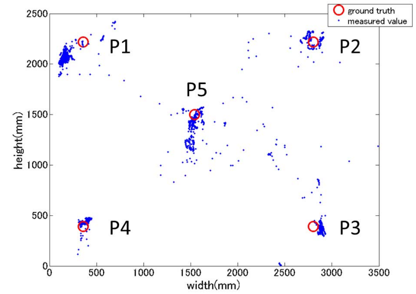

Fig. 4. Estimated 3D gaze directions (fixed target)

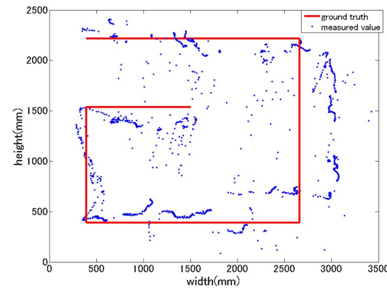

Fig. 5. Estimated 3D gaze directions (moving target)

C. Accuracy Evaluation of 3D Gaze Directions

To evaluate the conversion accuracy of our 3D gaze directions, we performed the following experiment. We displayed the gazing targets in front of the subjects who looked at them. We performed two experiments: when subjects looked at fixed targets and when they tracked moving targets. Figs. 4 and 5 show the converted 3D gaze directions. Here, "○" and the lines denote the displayed gazing targets and their trajectories (true values). Table I shows the measured errors of the 3D gaze directions. The errors of the converted 3D gaze directions are less than five degrees. Considering that humans cannot accurately look at the targets, such accuracy is sufficient to analyze the relations between gaze and gait.

TABLE I. ESTIMATED 3D GAZE DIRECTION ERRORS [DEG]

	P1	P2	P3	P4	P5	Ave.
Horizontal	5.77	3.70	6.53	3.45	3.33	4.71
Vertical	5.92	5.50	1.29	3.52	5.24	4.59

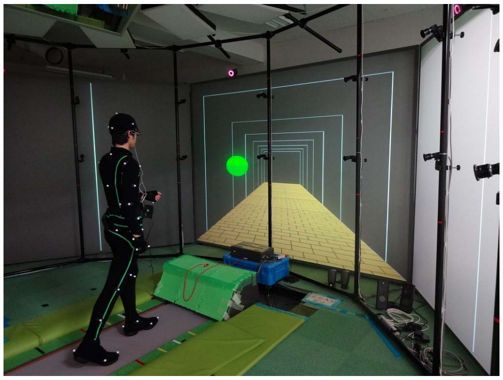

Fig. 6. Experimental environment

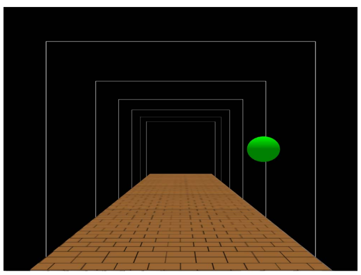

Fig. 7. Example virtual space view

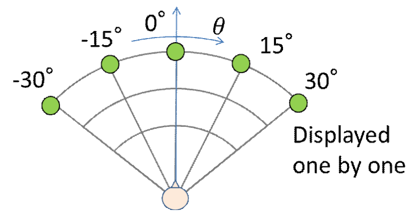

Fig. 8. Experimental conditions

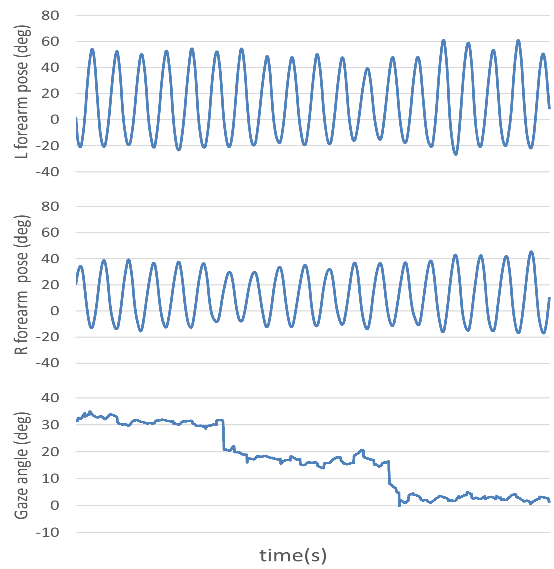

Fig. 9. Forearm motion of Subject F

IV. Analysis of Gait Changes Corresponding to Gazing Directions

In this section, we explain our immersive walking environment experiments and show the preliminary analysis results of the gait changes that correspond to the subject gaze directions.

Figure 6 shows the experimental environment. In our experiment, not only the gazing target but also a corridor-like virtual space are shown on multiple screens to create a sense of immersion in the environment for the subjects. Fig. 7 shows an example of the virtual space and the gazing targets. The virtual space views are changed based on the subject's walking speed on the treadmill. We used a 50-cm diameter, green sphere as a gazing target, which is only shown on the front screen for safety concerns.

To analyze the gait effects due to the gazing directions and such factors as distance to the gazing target and the motion of the gazing targets, we need to capture gait data in such gazing situations. In this paper's preliminary analysis, we focused on the subjects when they were looking at fixed gazing targets.

A. Procedures

The following are our experimental procedures. Before the experiments, the subjects walked on the treadmill for ten minutes to get used to it. We controlled its speed and set it to a rate chosen by the subjects.

Next we performed our experiments. We prepared five conditions (Fig. 8). In each condition, the gazing target was shown at its designated position for seven seconds. The subjects were instructed to look at the gazing target while walking. The orders of the conditions were counter-balanced, and the subjects took three-minute breaks after walking for five minutes to reduce fatigue.

B. Results

We performed experiments with nine male subjects (A-I) whose ages ranged from 21 to 24. We focused on the motion of their forearms. Fig. 9 shows an example of the obtained forearm motions and gaze directions. The forearm pose is zero when it is vertically downward, and the pose becomes positive when the forearm is moved forward.

From these observation data, we calculated the forearm amplitudes during all gait cycles and the averaged gaze direction during them (Fig. 10). In addition, we calculated the ratios of the amplitude of the right forearm swing to the left forearmfs amplitude. With these values, we analyzed the relations between gaze and gait.

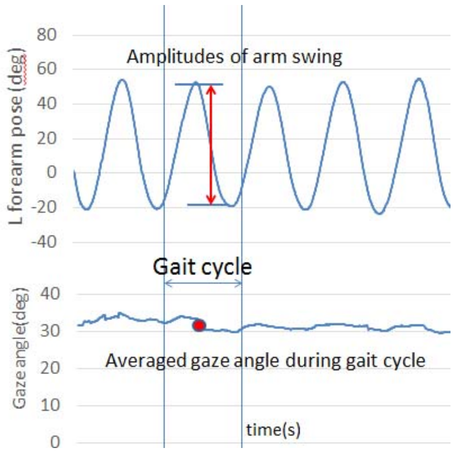

Fig. 10. Feature extraction of arm swing and gaze

TABLE II. CHANGE OF FOREARM AMPLITUDE RATES

	left	right
Subject A	0.0094	**0.0809**
Subject B	**-0.0497**	**0.1437**
Subject C	**-0.0513**	-0.0041
Subject D	**-0.0516**	**0.0236**
Subject E	0.0006	**0.0206**
Subject F	**-0.0564**	**0.0180**
Subject G	**-0.0207**	-0.1208
Subject H	**-0.0561**	**0.0345**
Subject I	**-0.0319**	0.0095

Figures 11-14 show the relations between the gaze and the forearm amplitudes of Subjects B and F. Figs. 15 and 16 show the ratios of both forearm amplitudes (R/L). The horizontal axes denote the averaged gazing directions during a gait cycle, and the vertical axes denote the amplitudes or their ratios during the gait cycle. The lines denotes the line fitting results by robust estimation. Table II is the gradients of the lines fitted to the amplitudes results, which are the average change rates of the arm swing amplitudes with respect to the gazing directions. Table III is the gradients of the fitted lines of the ratios. They are the average change rates of the ratio to the gazing directions.

We confirmed the tendency of the forearm swing amplitudes to be affected by the gazing directions. The amplitudes of the opposite forearm to the gazing directions decreased. When a subject is looking to the right side, the amplitudes of the left forearm swing are increased, and the right forearmfs amplitudes are decreased. The results that show this tendency are shown in bold in Table II; most subjects show such a tendency. From Table III, we confirmed that the ratios of the right arm swing amplitudes to the left amplitudes are increased when the subjects look at the right side. Such tendencies are shown in bold in Table III.

We confirmed that gait is affected by the gazing directions and that gait and gaze have a consistent relation. Although further analysis is required, these results suggest the possibility of gaze direction estimation based on gait.

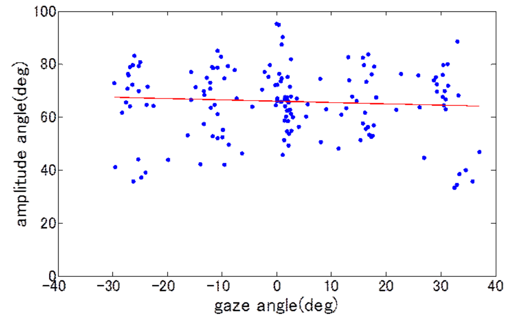

Fig. 11. Results of amplitudes of left forearm and gaze: Subject B

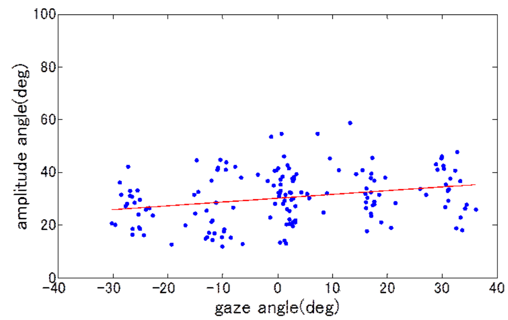

Fig. 12. Results of amplitudes of right forearm and gaze: Subject B

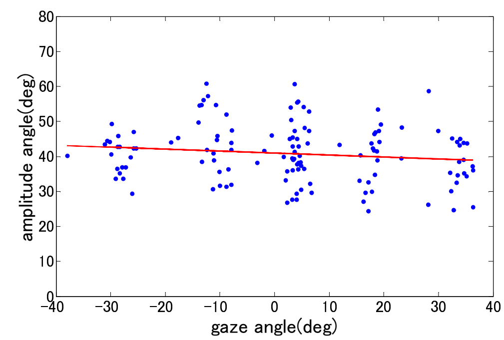

Fig. 13. Results of amplitudes of left forearm and gaze: Subject F

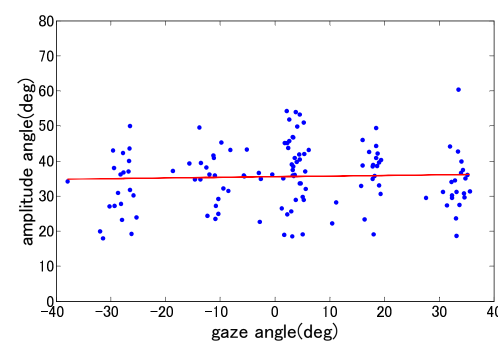

Fig. 14. Results of amplitudes of right forearm and gaze: Subject F

V. CONCLUSION

In this paper, we introduced our preliminary analysis of gait changes that correspond to gazing directions. We constructed

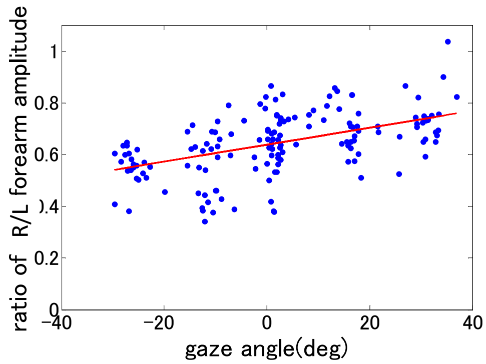

Fig. 15. Results of ratios of both amplitudes: Subject B

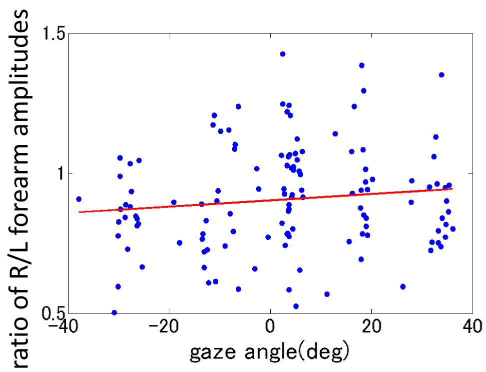

Fig. 16. Results of ratios of both amplitudes: Subject F

TABLE III. CHANGE RATES OF RATIOS OF BOTH AMPLITUDES: R/L

	ratio
Subject A	**0.0011**
Subject B	**0.0033**
Subject C	**0.0012**
Subject D	**0.0015**
Subject E	0.0008
Subject F	**0.0011**
Subject G	**0.0014**
Subject H	**0.0029**
Subject I	**0.0099**

an immersive walking environment that consisted of multiple screens/projectors and a treadmill. In this environment, we measured subject gait and gaze by a motion capturing system and an eye tracker, respectively. We described the environment and its calibration required to obtain both gait and gaze in common coordinates.

After the calibration, we performed our experiment. Its results confirmed that arm swing is affected by gaze direction and identified a tendency to decrease the amplitude of the opposite arm to the gazing direction. These results suggest the possibility of gaze estimation based on gait.

Future works will scrutinize our obtained data and use such additional conditions as moving gaze targets.

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