Primary Analysis of Human's Gait and Gaze Direction Using Motion Sensors

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***Abstract*—On estimating gaze direction of a walking human from images captured by conventional surveillance cameras, his/her head and eyes region in the images are not very helpful; they are usually low resolution, and often hidden by self-occlusion. Way of walking, on the other hand, is more easy to observe because it looks much larger in the images, and is expected to be influenced by gaze direction. Considering this, we analyze the relation between gaze direction and gait by putting multiple motion sensors on his/her body. From the analysis we find arm swing is affected by gaze direction, and this fact supports the possibility of gaze direction estimation from the way of walking.**

I. Introduction

Generally speaking, gaze action of a human is closely related to his/her attention, intention and emotion. If we can easily obtain gaze information by conventional surveillance cameras surrounding him/her, it would be very effective for several applications such as security, marketing analysis, and so on.

However, in fact, it is difficult to extract gaze information directly from images, because regions corresponding to his/her head and eye are usually small and so with low resolution. Moreover, these regions are often hidden by self-occlusion.

Considering this difficulty, we propose a novel strategy for estimating gaze direction. In this strategy, we assume that way of walking should be influenced by his/her attention. Since a region of his/her whole body is much larger than that of the head or eye and there have been several tools for gait analysis [1], [2], [3], [4], [5], it is expected that the strategy will work better than the direct gaze extraction as long as the assumption is fulfilled.

In this paper, therefore, we analyze the relation between gaze direction and gait as a primary investigation about the assumption. For the analysis, we put multiple motion sensors on his/her body. From the analysis we find arm swing is affected by gaze direction, and this fact supports the possibility of gaze direction estimation from the way of walking.

As a related work, Sigal *et al.* reported that gait of a human is affected by his/her mental state (*e.g.* happiness or sadness) [6]. Intuitively speaking, the way of walking would be influenced more by the attention than by such the mental state. Considering this, our discussion is thought to be reasonable.

Fig. 1. Motion sensor IMU-Z.

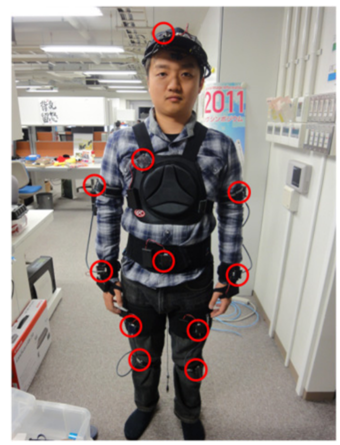


Fig. 2. Sensor positions.

II. Motion Sensor Calibration

In this paper, gait analysis is achieved by measuring poses of body segments. For this pose acquisition, we use a motion sensor IMU-Z of ZMP Corp., which contains three dimensional acceleration and gyro sensors, and compass in its small case shown in Fig. 1, and transmits sensory data to a computer via Bluetooth connections. As shown in Fig. 2, we put the sensors on eleven segments:

- Head
- Chest
- Waist
- Right/left upper arms
- Right/left lower arms
- Right/left upper legs
- Right/left lower legs

The sensor outputs parameter values of the three dimensional acceleration, gyro, compass. Sensor calibration is needed to estimate the pose of the body segments from these raw values. The following sections describes steps of the calibration.

A. Offset Measurement

Measurement of each parameter of a sensor contains error specific to each sensor. Though it is usually small, it causes

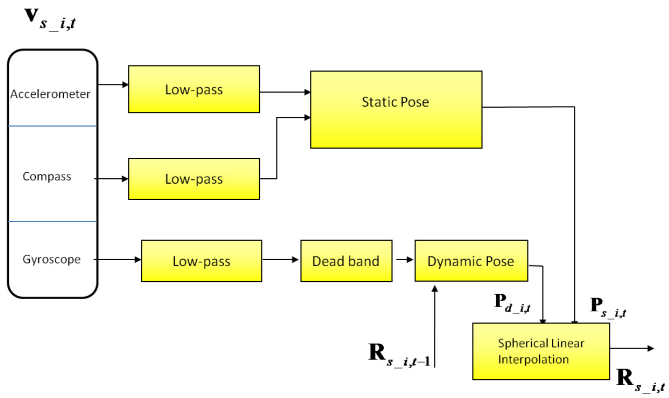


Fig. 3. Integration of parameters.

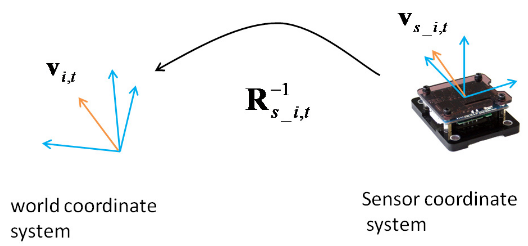


Fig. 4. Pose of sensor.

large error in pose estimation because the estimation is performed by integral operation of the measurement. For precise pose estimation, the error should be preliminarily obtained and considered as the offset. The offset is simply obtained by capturing data in known poses; located horizontally on a flat floor, for example.

B. Pose in Global Coordinate

After the offset is considered, the pose $R_{s\_i,t}$ at t of i-th sensor in the global coordinate is estimated by integrating the acceleration, gyro and compass measurememts. The global coordinate is defined by North and East directions and the gravity direction. This integration process is described in Fig. 3.

After this process, measurement $\boldsymbol{v}_{s\_i,t}$ of the sensor can be transformed into that in the global coordinate $\boldsymbol{v}_{i,t}$ by the following equation:

$$\boldsymbol{v_{i,t}} = R_{s\_i,t}^{-1}\boldsymbol{v_{s\_i,t}}, \tag{1}$$

as described in Fig. 4.

C. Pose of Body Segment

Since the sensor is put freely on each body segment, we do not know transformation from the sensor pose to that of the body segment R_{reset_i}. As a result, we do not know the segment pose from the sensory data (Fig. 5).

To solve this problem, we define several poses $R_{l\_i,t1}, \cdots, R_{l\_i,tk}$ whose parameters in the global coordinate

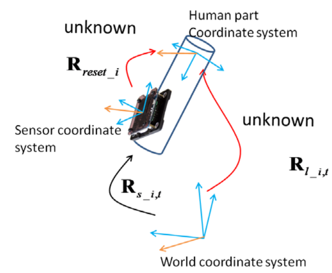


Fig. 5. Pose of body segment.

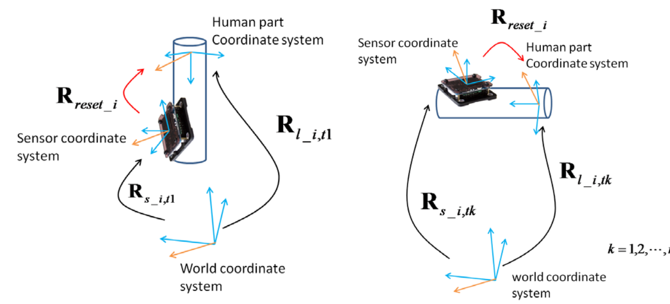


Fig. 6. Known poses.

are known, and ask a human to take the poses as shown in Fig. 6. By capturing the sensory data and estimating their pose $R_{s\_i,t1}, \cdots, R_{s\_i,tk}$, we can get the following equations:

$$\begin{aligned} R_{l\_i,t1} &= R_{reset\_i}R_{s\_i,t1} \\ &\vdots \\ R_{l\_i,tk} &= R_{reset\_i}R_{s\_i,tk} \end{aligned} \tag{2}$$

From these equations we obtain R_{reset_i}, so that we can obtain the pose of the body segment from the sensory data after that.

D. Normalization about Human's Direction

On analyzing human's gait, the pose of the body segment should be described independent from his/her direction. So the pose of each body segment obtained in the previous section is normalized by time average of that of waist, which well corresponds to the human's direction.

III. Experiment

A. Environment

We use an outdoor environment as shown in Fig. 7 for experiments. A target for gazing is a baloon located on a tripod stand so as that its height is similar to a human. A human walks straight along the paths while gazing at the target. There are several paths to prepare the wide range of gaze directions. We collect data of seven people. Each human walks all paths five times.

B. Result — Range of Swing

Fig. 8 shows relation between gaze direction and peak-to-peak of right lower arm swing of a certain subject. Red points denote obtained data, and green line denotes a regression line of the data. We can see that the peak-to-peak of *right* arm

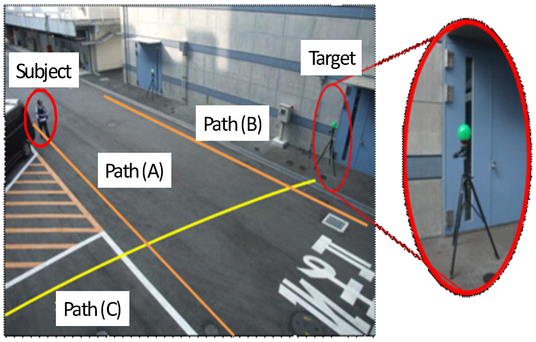
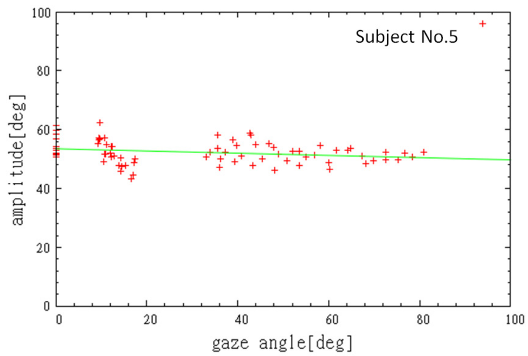
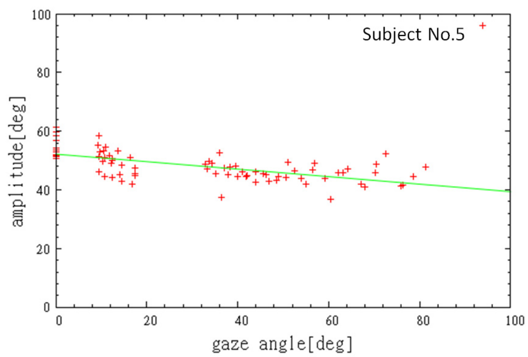


Fig. 7. Experimental environment



Gazing at target in right side.



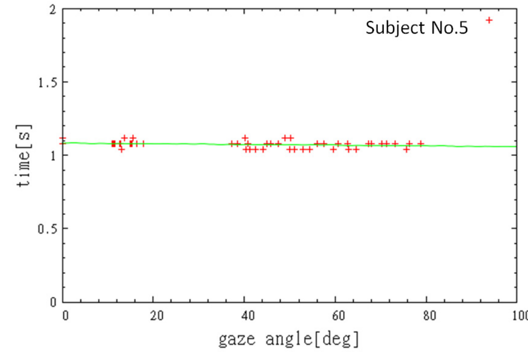
Gazing at target in left side.

Fig. 8. Peak-to-peak of arm swing.

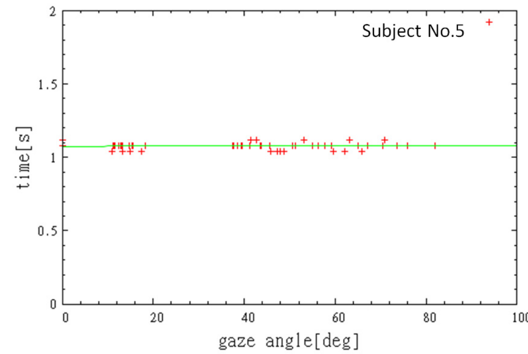
gets smaller as the gaze direction gets larger when the target is located in *left* side. TABLE I shows the corresponding results about the all people. A value of each cell denotes the gradient of the regression line. From the results, we find a interesting tendency that *the peak-to-peak of arm swing gets smaller according to gaze direction when a human gazes at the opposite side*.

In addition to this results, we also analyze forward/backward peaks separately. TABLE II and TABLE III show the corresponding results. It is confirmed that they indicate similar tendency to TABLE I.

Among all the tables, results of subjects 1 and 2 do not fulfill the tendency. We think it is because of their characteristics.



Gazing at target in right side.



Gazing at target in left side.

Fig. 9. Pitch of gait

TABLE IV
AVERAGE RATE OF CHANGE OF GAIT CYCLE FOR GAZE DIRECTION

	Subject No.						
gaze direct	1	2	3	4	5	6	7
left	0.000	0.000	0.001	0.000	0.000	0.001	0.000
right	0.000	0.000	0.001	0.000	0.000	0.001	0.001

It should also be noted that the tendency is fulfilled only in arm swing. We do not find similar tendency in leg motion.

C. Result — Pitch of Gait

Fig. 9 shows relation between the gaze direction and pitch of gait of a certain subject. Red points denote obtained data, and green line denotes a regression line of the data. We can see that the pitch seems to be constant. To confirm this tendency, we calculate gradients of the regression lines of all subjects as shown in TABLE I. From the results, it is confirmed that the pitch is constant independent from the gaze direction.

D. Result — Phase of Gait

Fig. 10 shows a time series of arm swing of a certain subject. In this section, we investigate whether the shape of the curve (phase) might change or not according to the gaze direction. For this investigation, we first extract four feature points from each pitch of the curve; upper/lower peaks and zero-crossings. We then measure four kinds of time intervals as shown in the figure, and analyze relation between each interval and the gaze direction.

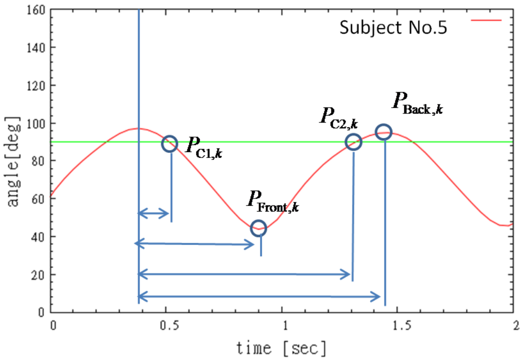


Fig. 10. Analysis of phase

As a result of this analysis, we do not find any relation; the intervals are constant independent from the gaze direction.

IV. Conclusion

In this paper, we proposed a novel strategy for estimating human's gaze direction from images of conventional surveillance cameras. This strategy relies on the assumption that the way of walking should be influenced by his/her attention. We thus performed the experiments to confirm whether the assumption is fulfilled or not. In the experiments, gait data of multiple subject were captured by motion sensors, and analyzed. As a result, we found that arm swing is affected by gaze direction; the arm swing gets smaller as the gaze direction gets larger. This fact is interesting, and supports the possibility of gaze direction estimation from the way of walking.

Future work contains design and implementation of gaze direction estimation method considering the analysis in this paper. Experimental evaluation in various situations is also needed.

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TABLE I

GRADIENT OF REGRESSION LINE: PEAK-TO-PEAK OF ARM SWING

parts	gaze direct	Subject No. 1	2	3	4	5	6	7
Right	: left	-0.141	0.032	-0.096	-0.039	-0.011	-0.118	0.078
Upper arm	: right	-0.255	-0.018	-0.044	-0.017	0.026	-0.075	0.051
Left	: left	0.135	0.029	-0.035	-0.108	-0.025	-0.005	0.017
Upper arm	: right	-0.063	-0.031	-0.142	-0.168	-0.015	-0.045	-0.026
Right	: left	-0.205	0.035	-0.199	-0.117	-0.128	-0.259	-0.016
front arm	: right	-0.297	-0.045	-0.085	-0.047	-0.038	-0.186	0.019
Left	: left	0.175	0.056	-0.043	-0.013	-0.008	-0.075	-0.007
front arm	: right	-0.118	-0.066	-0.267	-0.096	0.003	-0.145	-0.090
Right	: left	-0.148	-0.022	-0.312	-0.015	-0.046	0.121	-0.118
upper leg	: right	-0.051	-0.074	-0.006	-0.039	-0.051	0.048	-0.286
Left	: left	-0.137	0.095	-0.028	—	0.006	0.043	-0.187
upper leg	: right	-0.230	-0.195	-0.040	—	-0.008	-0.006	-0.211
Right	: left	-0.063	-0.045	-0.043	-0.030	-0.002	-0.062	-0.084
lower leg	: right	-0.037	-0.007	-0.032	-0.004	-0.001	-0.066	-0.052
Left	: left	-0.039	-0.026	-0.078	—	-0.018	-0.079	-0.079
lower leg	: right	-0.036	-0.043	-0.062	—	-0.041	-0.071	-0.014

TABLE II

GRADIENT OF REGRESSION LINE: FORWARD PEAK OF ARM SWING

parts	gaze direct	Subject No. 1	2	3	4	5	6	7
Right	: left	0.084	0.016	0.040	0.032	0.051	0.010	-0.073
Upper arm	: right	0.103	0.045	0.011	0.023	0.039	-0.015	-0.001
Left	: left	0.034	0.008	0.072	0.104	0.076	0.002	0.033
Upper arm	: right	0.078	0.066	0.084	0.147	0.048	0.012	0.028
Right	: left	0.144	0.013	0.149	0.092	0.079	0.060	0.019
front arm	: right	0.197	0.052	0.046	0.041	0.011	0.014	0.016
Left	: left	-0.043	0.001	0.071	0.013	0.039	0.002	0.022
front arm	: right	0.128	0.061	0.154	0.053	0.049	0.027	0.011
Right	: left	0.153	0.088	0.087	0.067	0.045	0.040	0.110
upper leg	: right	0.090	0.026	0.008	0.053	0.021	0.028	0.045
Left	: left	0.099	0.089	0.102	—	0.021	-0.003	0.197
upper leg	: right	0.099	0.044	0.089	—	0.065	0.029	0.128
Right	: left	0.130	0.022	0.041	0.037	0.023	0.079	0.103
lower leg	: right	0.108	0.026	0.028	-0.000	-0.009	0.056	0.054
Left	: left	0.033	0.029	0.031	—	-0.003	0.026	0.014
lower leg	: right	0.058	0.039	0.022	—	-0.000	0.028	0.008

TABLE III

GRADIENT OF REGRESSION LINE: BACKWARD PEAK OF ARM SWING

parts	gaze direct	Subject No. 1	2	3	4	5	6	7
Right	: left	-0.049	0.056	-0.068	-0.009	0.041	-0.109	-0.005
Upper arm	: right	-0.138	0.024	-0.042	0.002	0.064	-0.082	0.037
Left	: left	0.173	0.047	0.031	-0.000	0.052	0.001	0.042
Upper arm	: right	0.026	0.034	-0.059	-0.013	0.031	-0.033	-0.005
Right	: left	-0.064	0.051	-0.052	-0.024	-0.048	-0.209	0.019
front arm	: right	-0.094	0.008	-0.029	0.005	-0.026	-0.161	0.034
Left	: left	0.129	0.064	0.025	0.002	0.036	-0.061	0.018
front arm	: right	0.017	-0.002	-0.111	-0.036	0.048	-0.110	-0.080
Right	: left	-0.012	0.075	-0.241	0.044	0.017	0.164	0.022
upper leg	: right	0.010	-0.063	-0.016	0.013	-0.022	0.090	-0.217
Left	: left	-0.040	0.179	0.081	—	0.020	0.038	0.009
upper leg	: right	-0.140	-0.128	0.054	—	0.053	0.019	-0.095
Right	: left	0.065	-0.023	-0.011	0.004	0.022	0.017	0.035
lower leg	: right	0.070	0.012	-0.012	-0.006	-0.001	-0.000	0.012
Left	: left	-0.007	0.004	-0.046	—	-0.023	-0.055	-0.066
lower leg	: right	0.024	-0.002	-0.036	—	-0.042	-0.044	-0.006