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Control of Automatic Door by Using Kinect Sensor

Xuanang Feng, Yuina Yazawa, Eisuke Kita
Department of Complex Systems Science
Graduate School of Information Science
Nagoya University, Furo-chou, Chikusa-ku, Nagoya 464-8601, Japan
Yi Zuo
Institute of Innovation for Future Society
Nagoya University, Furo-chou, Chikusa-ku, Nagoya 464-8601, Japan

***Abstract*—The purpose of this study is to control opening and closing of the automatic door for pedestrian approach to the door by using Kinect sensor. Distance between them and the door, moving direction and velocity of them are estimated by Kinect sensor. Direction of their bodies and faces determine moving direction of them. Once they are approaching the door, time to when the door opens is calculated from the distance between them and the door. The validity of the control by using algorithm of the door is discussed in four experiments for 10 examinees.**

I. Introduction

The record mentions origin of the automatic door that people opened and closed a temple door by steam in Greece era [1]. The number of installed automatic door has been increasing since Tokyo Olympics in 1964 in Japan. It is estimated that more than 2 million automatic doors are operating in Japan now. Because the automatic door controls big and heavy door, it enables people to pass the door without opening that by themselves when holding luggage in both hands or when using cart. Therefore, in particular, the automatic door is adopted at the place where there are a lot of pedestrian such as commercial facilities like shops and accommodation facilities and public facilities. So far there are many automatic doors that control main body by detecting supersonic wave and infrared reflection wave change that an approach object emits. However the automatic door does useless movement by this system when pedestrian and objects don ' t intend to pass the door go through detective area. Therefore some studies are reported about action detection and prediction of them in front of the automatic door. Miyake et al. [2] acquired consecutive images around the automatic door by CCD camera that put on above the door and detected objects coming out in the images. Then they detected its movement direction and size and controlled the door depending on movement direction that they estimated. Tomizawa et al. [3] suggested automatic door that controls opening and closing timing of the door depending on their walking speed by measuring the angle facing body central location, movement speed and front direction of them who there is around the door by using some laser range finder (LRF). Yoshida et al. [4] made feature vector by analyzing walk movement of five pedestrians using Kinect made by Microsoft Corporation. They mention the method to classify walk movement of five pedestrian in the cause. In these methods, there may be difficult to control the door when they can use only lateral images of pedestrians and cannot estimate movement vector because they estimate movement direction by movement vector of them. In addition, there may be difficult to cope with sudden turns of them enough if there is little frequency to estimate movement direction. Therefore this study shows that automatic door system controls opening and closing of the door depending on approach intention of them using Kinect made of Microsoft Corporation. This method controls opening and closing of the door for only them with approach intention in appropriate timing by judging the intention and movement direction from joint direction and coordinate of them using frame information of them coming close to the door by using Kinect. It is possible to estimate the movement direction when it is impossible to estimate movement vector by images because we estimate movement direction by joint direction. In addition, we can support sudden change of movement direction to some extent. The constitution of this article is as follows. After having described a suggestion system in Chapter II, this show the pedestrian experiment in Chapter III. Chapter IV show the summary of this study.

Fig. 1. Kinect sensor [5].

II. Control system of automatic door

A. Kinect sensor

Kinect for Windows Sensor [5] to use in this study (after: Kinect) is a gesture input game device of the non-contact type released from Microsoft in 2010 (Fig. 1). Kinect equips

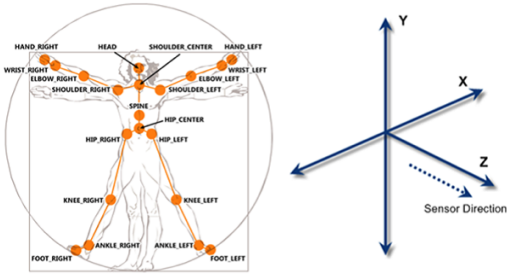

Fig. 2. The joint position obtained from Kinect [6].

TABLE I
THE CLASSIFICATION OF PEDESTRIAN ORIENTATION.

Classification	Shoulder Tracking	Head Orientation
Front	Both	$[225°, 315°]$
Side	Single	$[135°, 225°], [315°, 45°]$
Back	Both	$[45°, 135°]$

RGB camera and depth sensor and then has a processor performing human body recognition using it. Furthermore, the sound recognition function with microphone array is also equipped with Kinect. It is one of characteristics that Kinect is cheap whereas normal depth cameras are very expensive. Kinect for Windows SDK is software development kit released by Microsoft in June 2011. SDK can use and get data from various sensors equipped with. Fig. 2 shows joints that can be acquired by Kinect.

B. Abstraction of the system

The purpose of this study is to control opening and closing of the automatic door depending on speed for only pedestrian passing to the door. Therefore, we use the body direction, walking speed and shoulder width of them. It is determined whether they passes the door by its body direction, and arrival time is calculated by walking speed and shoulder width.

1) Judgement of opening and closing control depending on pedestrian body direction: Fig. I shows relation of angle and body direction when walking direction of pedestrians is classified in every $45°$. TABLE I shows relation number of shoulder joint points that Kinect can recognize and head angle when direction where head faces is running direction. Therefore, depending on this, we determine opening and closing of the door in the following:

- In the case of Front in TABLE I, pedestrian are determined that approaching the door, and it is opened.
- In the case of Back in TABLE I, pedestrian are determined that go away the door, and it is closed.
- In the case of Side in TABLE I, pedestrian are determined that pass over the door, and it is closed or does not move.

2) Beginning time of opening door: First, the door is closed. It should open the door before the pedestrian arrive at it so that he can pass. Kinect is equipped the door. Z_0 is distance between Kinect and them when Kinect recognizes them for first time. Z is distance between Kinect and them when recognizes again 1 second later. X_r is their right shoulder coordinate. X_l is their left shoulder coordinate. Following equation shows their walking speed.

$$V = Z_0 - Z. \tag{1}$$

Following equation shows t_0 that the time they reach the door assuming that they walk in constant speed.

$$t_0 = \frac{Z}{V}. \tag{2}$$

Following equation shows their shoulder width.

$$W = |X_{\mathrm{r}} - X_{\mathrm{l}}|. \tag{3}$$

The necessary opening width of the door is calculated by adding W_{margin} to W, where W_m is shoulder width's correction value that is caused by elements such as muscle or clothes [3]. V_{m} is opening and closing speed of the door. Following equation show necessary time to open $W+W_{\mathrm{margin}}$.

$$t = \frac{W + W_{\mathrm{margin}}}{V_{\mathrm{m}}}. \tag{4}$$

If it is $t < t_0$, the door is started to open after $t_0 - t$. However, it is necessary to start to open the door immediately if it is $t > t_0$. Therefore, following equation shows Δt that is the time before beginning to open the door.

$$\Delta t = \begin{cases} t_0 - t & (t_0 > t). \\ 0 & (t_0 \leq t). \end{cases} \tag{5}$$

3) Control algorithm of automatic door: The flow of opening and closing control of the door is in the following:

1) Kinect recognizes pedestrian.
2) Their approaching direction is determined according to TABLE I.
3) In the case of Front in TABLE I, following control is done so that they are determined to approach the door.
   a) Z_0 is measured.
   b) 1 second later, Z, X_{r} and X_{l} are measured.
   c) Δt is calculated by eq (5).
   d) The door is opened Δt seconds later.
4) In the case of Back in TABLE I, the door is closed so that they are determined to go away it.
5) In the case of Side in TABLE I, the door is closed or non-control so that they are determined to pass over it.

III. EXPERIMENT

A. Experimental condition

Subjects are 10 adults, and they are named A to J. TABLE II shows characteristic such as sex, age and clothes of them. Distance between Kinect and them is 0.5m to 6.0m, and Kinect is equipped at 1.5m in height from the ground (Fig. 3). In this study, LEGO Mindstorms NXT 2.0 simulates opening

TABLE II
EXAMINEES.

Person	Sex	Age	Height (cm)	Brightness of clothes
A	Male	26	178	Bright
B	Female	24	173	Bright
C	Male	23	168	Dark
D	Male	24	171	Dark
E	Female	24	145	Dark
F	Male	25	165	Dark
G	Female	21	165	Dark
H	Female	22	155	Dark
I	Male	23	167	Dark
J	Male	24	185	Dark

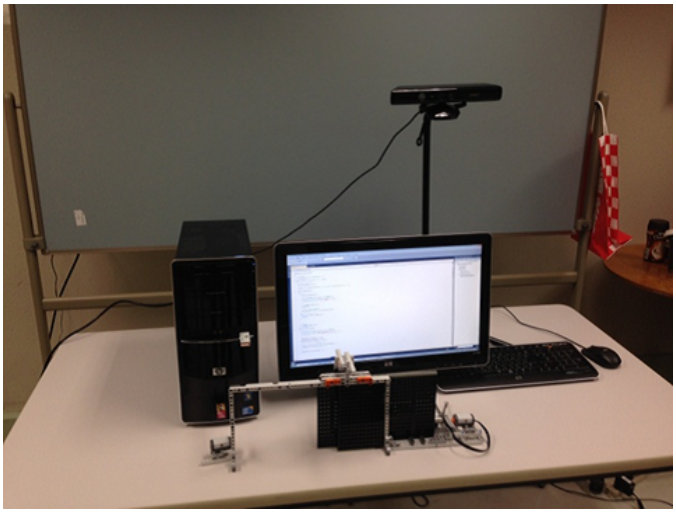

Fig. 3. Experiment environment.

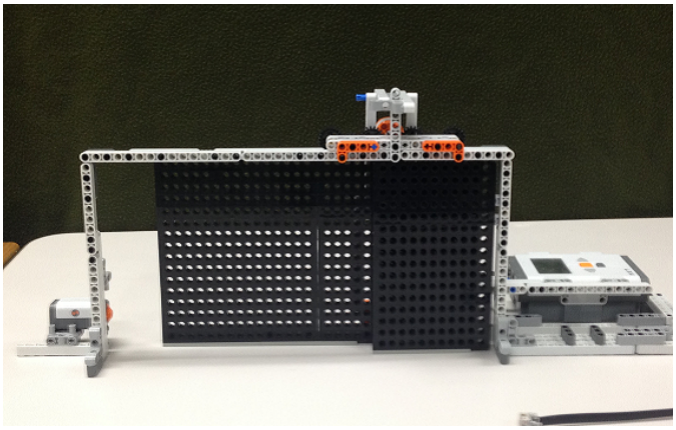

Fig. 4. Automatic door model.

and closing control of the door (Fig. 4). LEGO Mindstorms [7] was jointly developed by LEGO Corporation and MIT. In this study, Mindstorms NXT released in 2006 is used. A microprocessor is incorporated in NXT and can let a robot do autonomy movement by downloading programs [8].

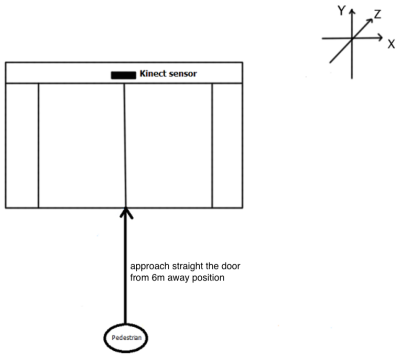

Fig. 5. Experiment 1 : Pedestrian behavior.

TABLE III
EXPERIMENT 1 : RESULT.

Person	Correct	Error	Relevance ratio
A	50	0	100%
B	50	0	100%
C	50	0	100%
D	50	0	100%
E	50	0	100%
F	50	0	100%
G	50	0	100%
H	50	0	100%
I	50	0	100%
J	50	0	100%
Total	500	0	100%

B. Experiment 1

The experiments that pedestrian walk straight to the door from 6.0m away at different speed are performed for 50 times every speed (Fig. 5). Because conventional automatic doors are opened after they approach to sensor recognition area, it cannot be opened before they arrive at when they walk fast. In the case, they may stop in front of the door. TABLE III shows experiment results. “Error” is the numbers of delaying of opening the door, and “Relevance rate” is the rate of opening the door appropriately for them. By TABLE III, it is known that the door is opened at the speed of adjusting to their walking speed after it recognizes in 100%.

C. Experiment 2

The experiments that the pedestrians walk a straight line at 0.6m from the door that is parallel to the door are performed for 50 times every subject (Fig. 6). In this case, conventional automatic doors open because they are opened when they approach to sensor recognition area in 100%. TABLE IV shows experiment results. “Error” is the numbers of opening the door, and “Relevance rate” is the rate of judging they don’t pass the door. By TABLE IV, it is known that the door judges that they don’t pass the door in 96.2% accurate rate, and there is little case the door is opened and closed.

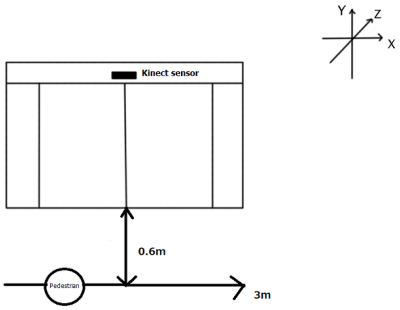

Fig. 6. Experiment 2 : Pedestrian behavior.

TABLE IV
EXPERIMENT 2 : RESULT.

Person	Correct	Error	Relevance ratio
A	48	2	96%
B	47	3	94%
C	48	2	96%
D	50	0	100%
E	49	1	98%
F	48	2	96%
G	48	2	96%
H	47	3	94%
I	48	2	96%
J	48	2	96%
Total	481	19	96.2%

D. Experiment 3

The experiments that pedestrian pass over the door are performed. Then, they walk a straight from the front direction of the door, and changes direction 90° left or right side during 1.0 second at 0.5m from the door (Fig. 7). In this case, because conventional automatic doors are opened after they approach to sensor recognition area, the door have mistake in 100%. TABLE V shows experiment results. "Error" is the numbers of opening the door, and "Relevance rate" is the rate of judging they don't pass the door. By TABLE V, it is known that the door judges in 94.0% accurate rate that they don't approach to the door.

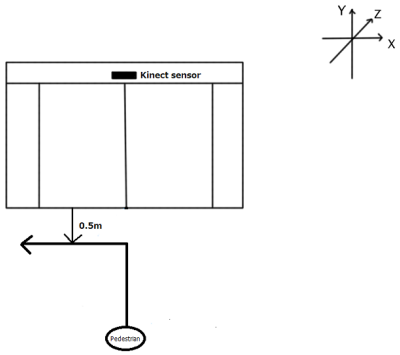

Fig. 7. Experiment 3 : Pedestrian behavior.

TABLE V
EXPERIMENT 3 : RESULT.

Person	Correct	Error	Relevance ratio
A	46	4	92%
B	44	6	88%
C	47	3	94%
D	50	0	100%
E	47	3	94%
F	48	2	96%
G	47	3	94%
H	48	2	96%
I	46	4	92%
J	47	3	94%
Total	470	30	94.0%

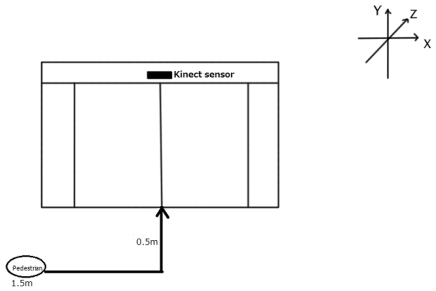

Fig. 8. Experiment 4 : Pedestrian behavior.

E. Experiment 4

The experiments that pedestrian close in front of the door from right or left side are performed. Then, they walk a straight from front direction of the door, and changes direction 90° left or right side during 1.0 second at 0.5m from the door (Fig. 8). TABLE VI shows experiment results. By TABLE VI, it is known that the door judges that they approach to the door in 94.6% accurate rate.

TABLE VI
EXPERIMENT 4 : RESULT.

Person	Correct	Error	Relevance ratio
A	47	3	94%
B	45	5	90%
C	47	3	94%
D	50	0	100%
E	49	1	98%
F	47	3	94%
G	46	4	92%
H	48	2	96%
I	47	3	94%
J	47	3	94%
Total	473	27	94.6%

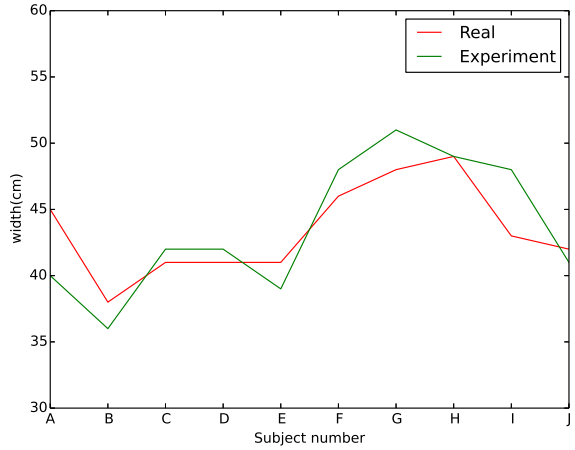

Fig. 9. The width of pedestrians.

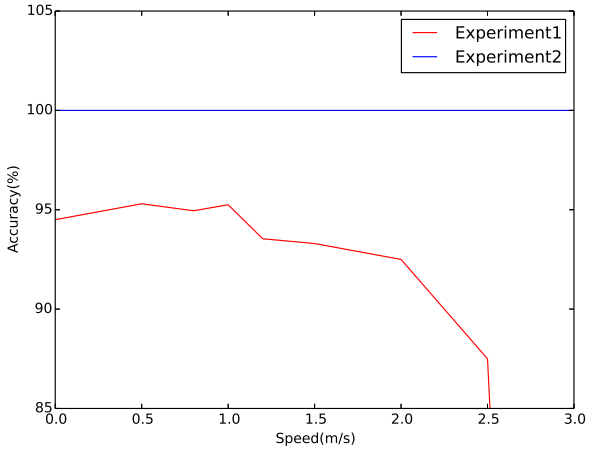

Fig. 10. The relationship between accuracy and speed of pedestrians.

F. Consideration for the experiment result

Comparing the results every subjects, accurate rate of subject B (woman, height: 173cm, clothes: white shirt) turns out slightly lower than others. Kinect has a fault to lose precision when it recognizes something in the bright environment. Therefore, it is thought that Kinect cannot judge pedestrians well because of white clothes. Fig. 9 shows a comparison between real shoulders width and shoulders width measured by Kinect. It is known that joint positions estimated by Kinect may be different from real joint positions. Then, Fig. 10 shows measurement precision of walking speed measured by Kinect in experiment 1 and experiment 2 to inspect influence that walking speed give for experiments. Precision is good for all speed in experiment 2, however that of experiment 1 is different every walking speed. Precision remains in comparison with an existing experiment results from 0m/s to around 1.2m/s which is human normal walking speed. However, it is possible to support the subjects who come straight close from the front direction of the door, while it is impossible to do them running parallel to the door. It is because they went out of the detection range instantly.

IV. Conclusion

This study shows that control of the automatic door performed opening and closing at appropriate timing. It judged the approach intention of the pedestrians around the door by the sensor. Walking speed and direction of them are predicted by the joint direction and shoulder width of them that are detected by Kinect, and control of the door is judged. We done experiment that they straight close to the door and that they pass over the door and that they change the walking direction just before the door. First case had 100% accurate rate, the second had 96.2% and the third had 94.3%. For the above reasons, it is known that Kinect judges passage of them appropriately. In this experiments, LEGO Mindstorm was used to simulate the automatic door instead of the door itself. The future prospects are to examine using the real size door and to set of Kinect depending on it.

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