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Social Navigation Model based on Human Intention Analysis using Face Orientation

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Abstract— **We propose a social navigation model that allows a robot to navigate in a human environment according to human intentions, in particular during a situation where the human encounters a robot and he/she wants to avoid, unavoid (maintain his/her course), or approach the robot. Avoiding, unavoiding, and approaching trajectories of humans are classified based on the face orientation on a social force model and their predicted motion. The proposed model is developed based on human motion and behavior (especially face orientation and overlapping personal space) analysis in preliminary experiments. Our experimental evidence demonstrates that the robot is able to adapt its motion by preserving personal distance from passers-by, and approaching persons who want to interact with the robot. This work contributes to the future development of a human-robot socialization environment.**

I. Introduction

In the near future, robots are expected to work and coexist in the same environment as humans. Examples of robots' expected capabilities are avoiding collisions and providing service to humans. The problems of human collision avoidance have been researched for a decade now; however, humans do not always intend to avoid the robot. Sometimes, they also want to interact when they need a service from the robot. Therefore, the ability of robots to behave according to human intentions, especially when they want to avoid or approach a robot is important.

In the early period of human collision avoidance research, Murakami *et al.* [1] discussed the study of collision avoidance between an autonomous wheelchair and human. The wheelchair robot motion planning strategy is based on rough observation of the human face, i.e., whether the human notices the robot. Tamura *et al.* [2] proposed a collision avoidance model in which a predicted human trajectory is considered as human intention to avoid or unavoid a robot.

Lately, the human-robot interaction (HRI) concept is discussed together with the collision avoidance problem. By considering HRI factors (such as proxemics, human gaze, and posture) involved in human path prediction, a robot motion can become more socially acceptable. Most research pays attention to how to integrate these factors via a number of different models [3], [4], [5], [6]. For example, Lam *et al.* [4] have focused on the harmonious coexistence between humans and robots in navigation tasks. Predefined harmonious rules and sensitive fields of humans and robots were used for robot path planning. Hence, the robot was able to move autonomously to complete a given task and also behave like a human during its operation. Recently, Garrell *et al.* [7] proposed multiple robots navigation model that cooperatively guiding group of people in urban area.

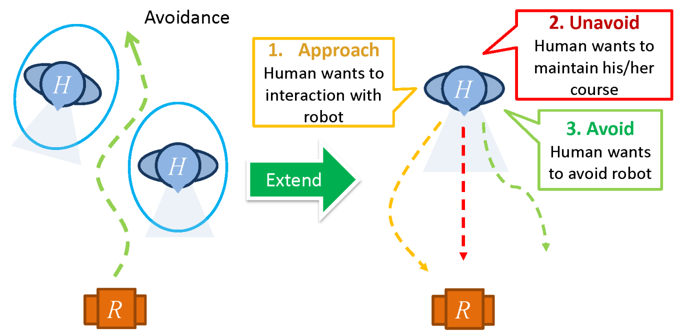

Fig. 1. (left) Social force model for human collision avoidance (right) Social Navigation Model; during human-robot confrontation, a robot is able to move according to human intention, (1) he/she wants to avoid the collision with a robot by changing lanes, (2) he/she wants to keep moving in the same direction, so the robot has to avoid him/her or (3) he/she wants to approach the robot and interact with it.

In general social context, a robot has to avoid the collision and sometime approach to person who want to socialize with a robot. This idea is presented in Fig. 1. How can we enable a robot to navigate according to a situation where humans want to avoid, unavoid or approach the robot ?. Up to now, very few studies have taken this topic into consideration. Yamaoka *et al.* [8] proposed a model for a robot to properly adjust its motion when presenting information to human. Satake *et al.* [9] discussed robot strategies to approach appropriate humans in public space from human trajectories analysis. Shi *et al.* [10] also proposed a robot behavior model to initiate a conversation with a human. However, these works still do not consider the case when humans approach the robot.

In this study, we introduce a social navigation model (as local navigation) which allows a robot to smoothly navigate in an environment where humans want to avoid, unavoid, or approach the robot. Usually, a robot and a human move in different directions to avoid a collision. In contrast, they get closer when they intend to interact with each other. These behaviors can be viewed as a repulsive and attractive force, respectively. We use face orientation to model these forces, as gaze (face orientation) is considered to be a guide of human attention/intention [11]. We also consider body

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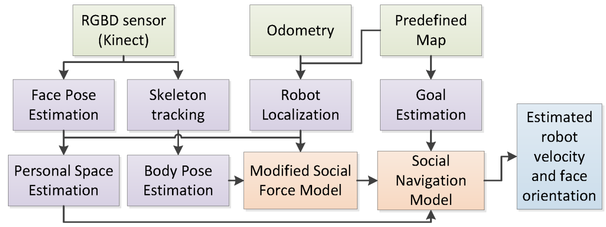


Fig. 2. The overall blocking diagram of proposed system.

pose together with face orientation, to create a modified social force model [12], [13] for human motion prediction. Human avoiding, unavoiding and approaching trajectories are classified within the range where social space and personal space are concerned. With the proposed model, our robot responds smoothly to human motion. Furthermore, the robot is able to behave like a human by providing the human with face orientation in the intended direction before changing its direction when avoiding collisions, and maintaining a proper distance when it was approached by human.

II. System Architecture

A robot that understand human intentions requires several modules to operate together. Fig. 2 shows the overall diagram of our proposed system. To obtain the skeleton information, we use a RGBD sensor (Kinect). The face orientation and body pose of the human during motion are estimated according to our previous work [13].

We also take into consideration the concept of personal space [14], which prevents uncomfortable feelings when humans plan to avoid or interact with a robot. Lam *et al.* [4] discuss different types of personal space in different situations and assume an egg-shaped personal space while moving, due to the safety assumption that a human should have a long and clear space while moving. Scandolo *et al.* [15] use personal space in their social cost map model for socially acceptable path simulation. In this study, the personal space during human motion according to time step, t, is modeled as an ellipse:

$$\begin{bmatrix} x(\theta_{rt}) \\ y(\theta_{rt}) \end{bmatrix} = \begin{bmatrix} x_t \\ y_t \end{bmatrix} + \mathbf{R} \begin{bmatrix} m_a \cos(\theta_{rt}) \\ m_i \sin(\theta_{rt}) \end{bmatrix} \tag{1}$$

where $\mathbf{R} = \begin{bmatrix} \cos(\vartheta_t) & -\sin(\vartheta_t) \\ \sin(\vartheta_t) & \cos(\vartheta_t) \end{bmatrix}$ is the rotation matrix. $x(\theta_{rt})$ and $y(\theta_{rt})$ are the points on the personal space distributed by angle, θ_{rt} (varying from 0-2π). m_i and m_a are the minor and major axe which depend directly on v_x and v_y. The direction of the personal space is estimated by the face orientation, ϑ_t. The characteristics of a human which are applied to modified social force model for motion prediction, are stated as $\mathbf{H} = \begin{bmatrix} x_t & y_t & v_t & \rho_t & \vartheta_t \end{bmatrix}^T$. (x_t, y_t) are the x and y position of the human and v_t is human velocity. ρ_t and ϑ_t are the body pose and face orientation angle with respect to the world coordinate. The calculated velocity of human, current robot position, goal position, and personal space are input to the social navigation model to estimate robot velocity and its face orientation.

III. Robot Motion Planning Based on Human Intention

For a robot to design its motion, it has to understand human motion properly. In this study, we define 3 types of human motion as follow:

- *Avoid* : humans want to avoid the collision with the robot by themselves.
- *Unavoid* : humans do not avoid the robot and expect the robot to avoid them.
- *Approach* : humans want to interact with the robot.

To classify these types of motion correctly, we integrate the high-level perception of humans, including body pose, face orientation and personal space during motion to a modified social force model. For a robot to smoothly respond to human motions, we use the social navigation model in motion planning.

A. Modified Social Force Model (MSFM)

We employ the social force model [12], [16] to predict human motion. A human, H_i, is modeled as a particle i with a mass, m. He/she walks with an intended velocity, v, in a desired direction, $\mathbf{d}$. In the social force model at each time step, their motion is described by the superposition of 2 types of force:

1) Attractive force to the goal: With an internal motivation to the goal, a human adapts his/her velocity $\mathbf{v}$ to an intended direction by

$$\mathbf{F}^{goal} = m\frac{v\mathbf{d} - \mathbf{v}}{\tau} \tag{2}$$

where τ is the rate of change required by the human for adapting the current velocity to the intended direction. We use the body pose of a human as a representation of the intended direction for human motion prediction [17].

2) Repulsive force from others: Based on the influences from the object and the other humans present in the environment, a human has to adapt his/her direction according to these disturbances, which are modeled as the repulsive force between human , $\mathbf{F}^{human}$ and object, $\mathbf{F}^{object}$. Both $\mathbf{F}^{object}$ and $\mathbf{F}^{human}$ are the result of a combination of social repulsive forces, $\mathbf{f}_{social}$, and physical repulsive forces, $\mathbf{f}_{physical}$. A physical repulsive force $\mathbf{f}_{physical}$ is formulated as

$$\mathbf{f}_{physical} = k_{ph}(r_{i,A} - d_{i,A})\mathbf{v}_{i,A} \tag{3}$$

where k_{ph} represents the physical constant of the physical force. A can be a person/an object encountered in the environment. Other humans and objects are modeled as particles with radii r_i and r_A. $d_{i,A}$ is the distance between the two entities. $r_{i,A}$ is the summation of their radii. Vector $\mathbf{v}_{i,A}$ indicates the direction from A to H_i. Social repulsive forces are described as :

$$\mathbf{f}_{social} = k_{so}e^{(\frac{r_{i,A} - d_{i,A}}{s_A})}\mathbf{v}_{i,A}w(\gamma) \tag{4}$$

Influences from social repulsive forces are limited to the field of view of humans, therefore the anisotropic term,

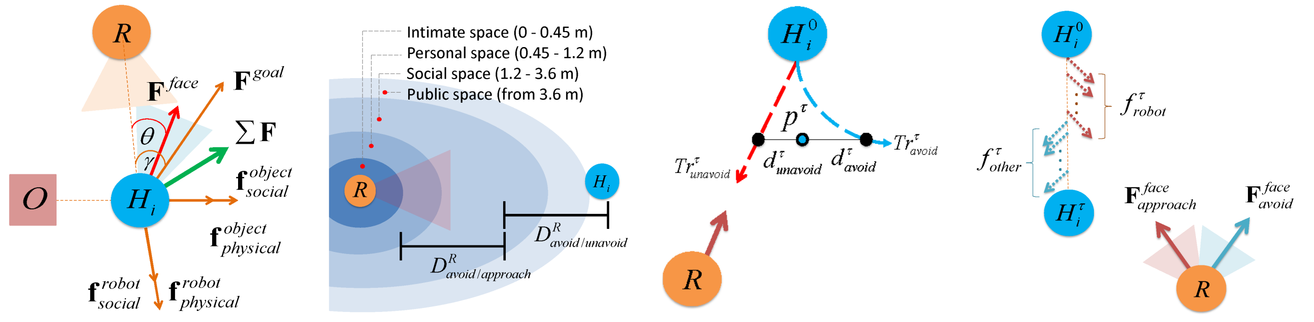


Fig. 3. (a) The modified social force model, (b) avoid/unavoid and avoid/approach range, (c) avoid and unavoid motion classification, and (d) direction of the force due to face orientation depends on the probability of approaching or avoiding derived, from face orientation.

$w(\gamma) = \lambda + (1-\lambda)\frac{1+\cos(\gamma)}{2}$, defined by constant, λ, is introduced in the equation. γ is the angle between other humans and intended direction. k_{so} is the magnitude and s_A is the range of the force.

3) Modification based on Face Orientation: Typically, face orientation points to human intention/attention [11]. In a face-to-face confrontation, if humans want to talk to the person who walks pass by, they will look at him as a sign to start the conversation [11]. On the other hand, if humans do not know each other or do not want to start a conversation, they will look in the direction that they want to go to show their own intentions. This is a natural human mechanism and is modeled as a social force based on face orientation, $\mathbf{F}^{face}$:

$$\mathbf{F}^{face} = FSe^{\left(\frac{r_{i,A}-d_{i,A}}{s_A}\right)}\mathbf{v}_{i,A}w(\theta) \tag{5}$$

FS refers to the strength of the force. The exponential growth of the force depends on the range of the force, s_A, distance, $d_{i,A}$, and the sum of their radii, $r_{i,A}$. The term $\mathbf{v}_{i,A}$ is the face orientation vector of H_i related to A, and describes the orientation of the force. The angle between the face orientation vectors is denoted by θ. Therefore, the resulting force is modeled as :

$$\sum\mathbf{F} = \mathbf{F}^{goal} + \mathbf{F}^{object} + \mathbf{F}^{human} + \mathbf{F}^{face} \tag{6}$$

We use $\mathbf{v}$ to predict the human path which is derived from $\frac{d}{dt}\mathbf{v} = \frac{\sum\mathbf{F}}{m}$ in every time step. An illustration of all forces is shown in Fig. 3(a). The force due to face orientation has a relative effect on the social repulsive force. A high value of force due to face orientation makes the human tracking path fluctuate, while a low value yields no effect. The appropriate face parameter was set to be less than the social repulsive force.

B. Social Navigation Model

The Social navigation model (SNM) is developed from the concept of social force model. In SNM, the human's intentions to avoid, unavoid or approach a robot are determined based on face orientation and human predicted path. As presented in Fig. 3(b), there are two types of range to be considered; $D^R_{avoid/unavoid}$ is the range where a robot considers whether humans intend to avoid or unavoid a robot and $D^R_{avoid/approach}$ is the range where a robot considers whether humans intend to approach or avoid robot. The values of all parameters in this section are discussed in a preliminary experiment with humans (Sec. IV-A).

1) Avoid/unavoid range: $D^R_{avoid/unavoid}$ is considered when a human and a robot are in the same lane only. We use the concept of avoiding or unavoiding probability based on predicted path [2], as presented in Fig. 3(c). Next position (p^τ) on the human predicted path is used as a reference. d^τ, which is the distance from p^τ to $Tr^\tau_{(un)avoid}$ (avoid or unavoid trajectory) is derived as:

$$d^\tau_{(un)avoid} = \left\|Tr^\tau_{(un)avoid} - p^\tau\right\| \tag{7}$$

Hence, the total distance, d^τ_{total}, is defined as

$$d^\tau_{total} = d^\tau_{avoid} + d^\tau_{unavoid} \tag{8}$$

We can find the probability of a human performing an unavoidance motion $\mathrm{P}^\tau_{unavoid}$ or avoidance motion P^τ_{avoid} by

$$\mathrm{P}^\tau_{unavoid} = 1 - \frac{d^\tau_{unavoid}}{d^\tau_{total}} \tag{9}$$

$$\mathrm{P}^\tau_{avoid} = 1 - \frac{d^\tau_{avoid}}{d^\tau_{total}} \tag{10}$$

If $\mathrm{P}^\tau_{avoid} > \mathrm{P}^\tau_{unavoid}$, the robot remains in the same lane. The robot changes the lane when $\mathrm{P}^\tau_{avoid} < \mathrm{P}^\tau_{unavoid}$. As a result, in both cases, the robot and human will be in a different lane. This robot behavior is safe and comfortable for humans in a passing by situation, since humans prefer a bigger distance and they feel more relaxed when the robot leaves the way open from them [18].

2) Avoid/approach range: Next, the robot starts considering human intention to approach in the range of $D^R_{avoid/approach}$, which is derived as

$$D^R_{avoid/approach} = D^H_{avoid/approach} + v_{r,h}t \tag{11}$$

where $D^H_{avoid/approach}$ is the range that humans normally start avoiding each other. $v_{r,h}$ is the relative velocity of the human with respect to the robot.

Within this range, the robot considers both the predicted path and the face orientation as signs of human intentions. The visualization of this force is presented in Fig. 3(d).

We consider the duration of face orientation towards the robot from the first observation time to time τ as f^{τ}_{robot}, and the duration of the face orientation to others as f^{τ}_{other}. Hence, the total duration is defined as

$$f^{\tau}_{total} = f^{\tau}_{robot} + f^{\tau}_{other} \tag{12}$$

From the duration of face orientation towards any target object, we define the probability that the human will approach ($\mathrm{Pr}^{\tau}_{approach}$) or avoid ($\mathrm{Pr}^{\tau}_{avoid}$) at time, τ, based on the following two equations :

$$\mathrm{Pr}^{\tau}_{approach} = \xi \left[\frac{f^{\tau}_{robot}}{f^{\tau}_{total}} + \left(1 - \frac{d^{\tau}_{approach}}{d^{\tau}_{total}} \right) \right] \tag{13}$$

$$\mathrm{Pr}^{\tau}_{avoid} = \xi \left[\frac{f^{\tau}_{other}}{f^{\tau}_{total}} + \left(1 - \frac{d^{\tau}_{avoid}}{d^{\tau}_{total}} \right) \right] \tag{14}$$

Note that $d^{\tau}_{unavoid}$ is treated as $d^{\tau}_{approach}$ and ξ is the normalized factor. We use this condition to adapt the direction of the force $\mathbf{F}^{face}_{avoid/approach}$ in the SNM. Different from the MSFM applied to human, the force due to face orientation applied to the robot is derived as

$$\mathbf{F}^{face}_{avoid/approach} = FSe^{\left(\frac{r_{i,R} - d_{i,R}}{s_R}\right)} \mathbf{v}_{i,R} w(\theta) \tag{15}$$

where the force can be adapted as

- *Attractive force*, FS : when $\mathrm{Pr}^{\tau}_{approach} > \mathrm{Pr}^{\tau}_{avoid}$
- *Repulsive force*, $-FS$: when $\mathrm{Pr}^{\tau}_{approach} < \mathrm{Pr}^{\tau}_{avoid}$

If $\mathrm{Pr}^{\tau}_{approach} > \mathrm{Pr}^{\tau}_{avoid}$, the subgoal of the robot is created in front of the human with an appropriate distance ($d_{interact}$) for the human to feel comfortable when interacting with the robot. The robot remains in the same lane when $\mathrm{Pr}^{\tau}_{approach} < \mathrm{Pr}^{\tau}_{avoid}$.

IV. Experiment and Results

In this section, we present preliminary experiments between humans and human-robot experiments. Preliminary experiments focused on how humans avoid collisions and approach each other. Human-robot experiments were conducted to analyze and verify our proposed method. We used a one-way repeated-measure analysis of variance (ANOVA) to analyze errors.

A. Human-Human Experiment

We observed humans motion and behavior in preliminary experiments while they were approaching and avoiding each other. There were 6 participants in the experiment. Two tracks were prepared: face-to-face confrontation (left side of Fig. 4) and different lane passing-by situation (right side of Fig. 4). All pairs of participants performed both tasks. For each pair of participants, two tasks, approaching and avoiding, were conducted. Five trials were performed in each task. In each experiment, only a participant decides to approach, unavoid or avoid other human. The human position, body pose, face orientation and relative distance were tracked simultaneously by 2 kinect sensors at the start/goal line. The personal space of the human was adapted using face orientation.

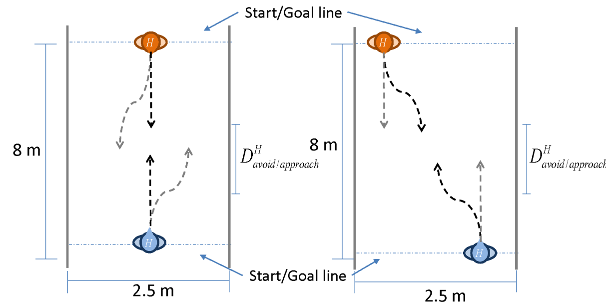


Fig. 4. Preliminary experiment setup of (left) face-to-face confrontation and (right) different lane passing-by.

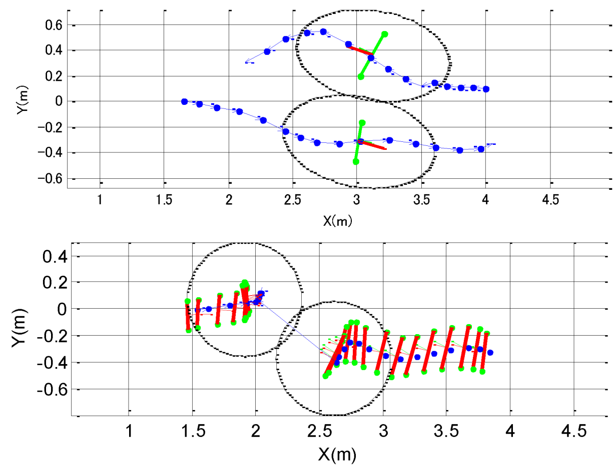
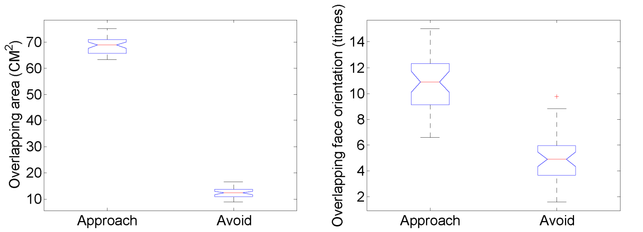


Fig. 5. The results about personal space overlapping in the case of (upper) avoiding and (lower) approaching case.

The graphical results at the moment of avoiding and approaching are presented in Fig. 5. Obviously, the overlapping area of the personal space between humans clearly distinguishes these two behaviors. During an avoiding motion (upper graph in Fig. 5), the participants do not have any interest to interact with each other. Therefore, there is a small overlapping area of the personal space during motion. As presented in Fig. 6(a), the average overlapping area during the avoiding motion is found to be only 12.72 cm^2. On the other hand, there is an average overlapping area of 69.74 cm^2 while participants were approaching each other.

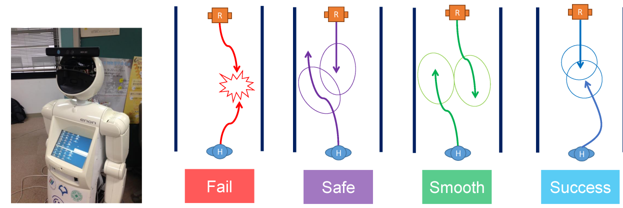
The average number of overlapping face orientations between participants was also be investigated. Fig. 6(b) shows a comparison of the total number of overlapping face orientations when the participants avoid or approach each other. In an approaching case, the average overlapping face orientation is found to be 11.11 times. In contrast, the average overlapping face orientation when participants avoid each other is only 5.56 times.

The results about the overlapping of personal space and



(a) (b)

Fig. 6. (a) Total proxemic overlapping area and (b) total number of overlapping face orientation.



(a) (b)

Fig. 7. (a) Enon robot and (b) the graphical idea used to describe possible cases during navigation. If the robot collides with a human, we consider it as a 'Fail' case. A 'Safe' case is when the robot can avoid a human but there are high overlapping regions of personal space. The robot achieves 'Smooth' collision avoidance when it can avoid a collision with the human and also has a small overlapping region of personal space. Lastly, a 'Success' case refers to the situation when the robot successfully maintains an appropriate distance when it is approached by a human.

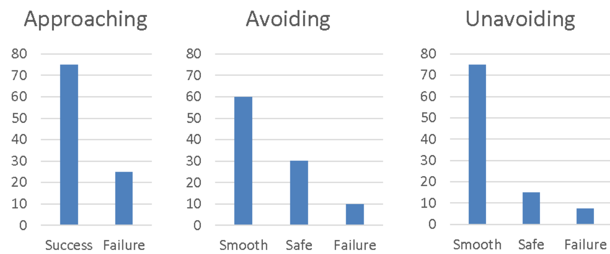


Fig. 8. The success rate of robot motion planning in the case of avoiding, unavoiding and approaching case.

face orientation confirmed a repulsive and attractive force acted between participants while they avoided or approached each other. The duration of overlapping face orientation between humans is directly related to how much humans were going to approach each other. We use these results to develop the social navigation model. Note that the variance of overlapping face orientation in the avoiding case was high, because it was hard for humans to predict whether he/she wants to avoid or unavoid the other during face-to-face confrontation. This information prompted us to create 2 ranges of consideration in the social navigation model.

The average range of avoidance or approach ($D^H_{avoid/approach}$) and the appropriate distance for interaction ($d_{interact}$) between humans are found to be 2.18 and 0.69 meters respectively. Because the maximum walking speed of a human in this experiment was 1.44 m/s, we set $D^R_{avoid/approach}$ to be from 0.45 to 2.5 meters (our system runs at an average of 18 Hz). Therefore, $D^R_{avoid/unavoid}$ was set from 2.5 to 4 meters. These ranges correspond to results obtained through the study of proxemics [14], [19] since they are within the range of personal space to social space.

B. Experiment in Human-Robot Environment

In this section, experiments were conducted in a common human-robot coexisting situation such as a corridor or an office. An Enon humanoid robot (Fig. 7(a)) with a Kinect sensor placed on the head (1.8 meters above the ground) was used in the experiment. Participants were requested to walk toward the humanoid robot. They could choose decide their own trajectory, for example *Avoid*, *Unavoid*, or *Approach*. We chose 5 persons who had random experiences with robots to take part in the experiment. Six trials were performed for each person. The parameters in the SNM were determined by the MSFM simulation [20] and preliminary experiment, with an optimization using Genetic Algorithm [21].

To evaluate the proposed model, we used the criteria [2], [13] presented in Fig. 7(b). The experiment setup was the same as Fig. 4. We conducted 15 experiments each on *avoid*, *unavoid* and *approach* cases. The evaluation results in Fig. 8 show the percentage of success rates of avoiding, unavoiding and approaching cases. We achieved a 75% success rate in an approaching case and a 90% success (smooth+safe) rate in the avoiding and unavoiding cases. 'Fail' case occurred sometime when the system failed to track face and body pose.

During the experiment, most participants who did not want to avoid robot mentioned that they felt relaxed because the robot did not block their way. They also noticed that the robot turned its face away before trying to avoid them. In the approaching case, participants mentioned that the robot moved to them smoothly and maintained a proper distance from them allowing them to use the touch screen on the robot. This suggestion confirmed that the proposed model achieved all 3 possible cases of human behavior.

Furthermore, an experiment in an environment where a robot has to perform different tasks continuously was performed. Fig. 9 shows the situation where the robot has to perform collision avoidance continuously. In this case, none of the participants wanted to avoid the robot (i.e. they expected the robot to avoid them). The result shows that the robot was able to estimate the path of the humans one by one and avoid both of them. Both avoiding motions also satisfy the smooth collision avoidance requirement.

Another experiment was performed in an office environment as presented in Fig. 10. The robot observes the first person and understands his/her intention to unavoid the robot within the avoid/unavoid range, therefore the robot turns its face toward the opposite direction, and steers away from the human. Afterward, a second person is observed. As opposed to the first person, the second person intends to interact with the robot and provides the proper face orientation. Using the proposed model, the robot approaches the human and maintains an appropriate distance.

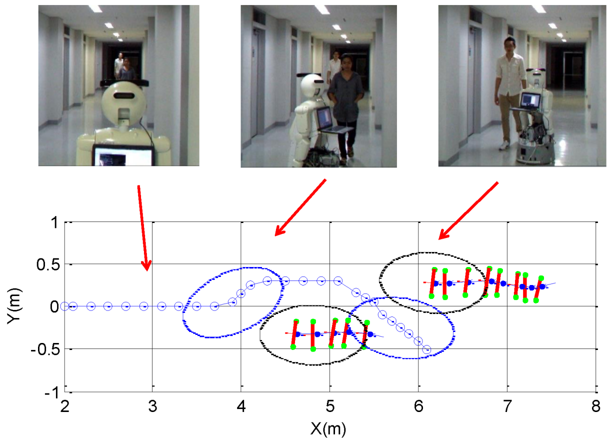


Fig. 9. The experiment result shows that the robot was be able to avoid the collisions continuously when humans do not intend to interact with the robot and expect the robot to avoid the collisions.

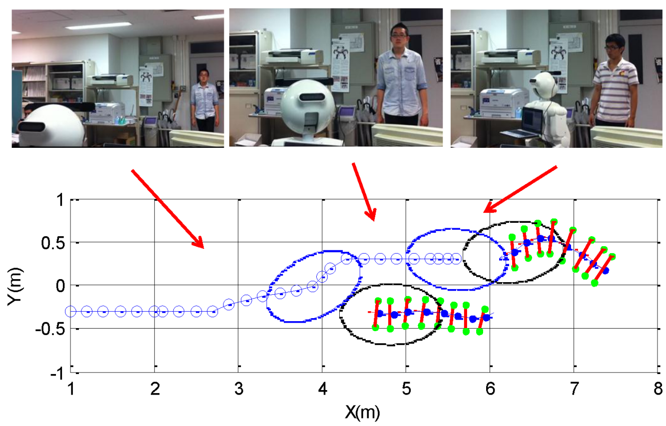


Fig. 10. The experiment results show that the robot was able to avoid the collision with the first person and then interact with the other person based on an analysis of the human face orientation based on the proposed model. Furthermore, the proxemic rule about the personal space estimated by face orientation was also preserved because of a smaller overlapping region during avoidance. Finally, the robot maintained the personal distance when interacting with humans.

V. Conclusion

In this work, we presented a social navigation model that allows a robot to avoid or approach humans by considering human face orientation and predicting human path using a modified social force model. We considered avoiding and approaching behaviors as repulsive and attractive forces between robots and humans. By taking into account the effect of face orientation and personal space during motion planning, not only does the robot achieve safe and smooth collision avoidance, but it is also able to achieve approaching behavior. Experiments were performed in social scenarios, such as when a walking person encounters a robot in a public place. Using the proposed model, the robot was able to use face orientation as an indication for path planning, and preserve the laws of proxemics while avoiding or interacting with the human.

VI. Acknowledgments

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