Around Me: A System with an Escort Robot Providing a Sports Player's Self-Images

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ABSTRACT

Providing self-images is an effective approach to identifying sports players' body movements that should be corrected. Traditional means providing self-images, however, such as mirrors and videos, are not effective in terms of mobility and immediacy. In this paper we propose a system, Around Me, providing self-images through a display attached to an escort robot that runs in front of the user. This system captures the user's posture from the front and recognizes his/her position relative to the robot. The user's movements are synchronized with the robot's movements because the robot's movements are determined by the user's location. In this research we developed an experimental prototype specialized for assistance in jogging. In pilot studies we observed that the ability of Around Me to provide real-time images is potentially able to encourage the user to improve his/her jogging form, which is essential for performance and for injury prevention. In addition, compared with the robot running in front of the user with one following behind the user, we clarified the frontal robot's characteristics: the robot can control the jogging speed, and the user needs to adjust the robot's steering and the distance between the robot and him/her as he/she requires. Then we found indications that Around Me can, with various jogging support functions, encourage the user to practice jogging with ideal form.

Author Keywords

Sports Assistance, Self-Images, Escort Robot, Jogging.

ACM Classification Keywords

H.4 Information Systems Applications: Miscellaneous

INTRODUCTION

One of the ways we can improve our actions is by self-monitoring our body movements, recognizing problems that should be corrected, and changing our movements for the better. In our daily lives, we can find several situations where people do this: people rehearsing presentations; medical personnel rehabilitating patients or assisting elders; and people practicing sports such as baseball, dance, or golf. Especially in sports, using self-images is regarded as an effective way to improve a player's abilities [1] and they are often used by amateurs as well as professionals [2].

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AH '14, March 07 - 09 2014, Kobe, Japan

http://dx.doi.org/10.1145/2582051.2582094

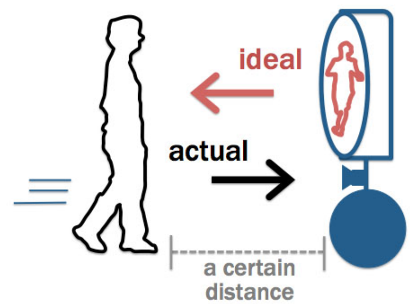

Figure 1. The system of providing user's self-images interprets user's actual body movements and returns the user the way how he/she should make his/her movements ideal. The self-images can help users improve various actions.

In general, we can obtain our self-images in two ways, via mirrors and videos, but each way has disadvantages. Mirrors cannot move by themselves. Therefore we must adjust our location many times to obtain appropriate self-images, and we cannot use mirrors while running. On the other hand, we cannot check videos in real time, and self-monitoring our body movements as they occur is important if we want to improve our actions effectively [3]. People are often taught by sports trainers who watch their body movements and give advice about problems that should be corrected. Trainers thus substitute their guidance for self-images. Although excellent trainers can give us quite useful tips, the time trainers are available is limited and can be expensive. It is necessary to develop a system providing a user's self-images without these disadvantages.

We think that a system providing self-images for the purpose of improving the user's body movements as he/she requires must satisfy the four requirements described below.

- Mobility to adjust the location where the system acquires the user's images and provides them to the user. The self-images must be easy to watch and must include the body parts that the user needs to observe.

- Time efficiency with regard to the interval between acquiring the images and providing them. Seeing and modifying movements on the spot is effective [3].
- Continuous usability. Completing the improvement of a user's actions takes a long time.
- No encumbrance disturbing the user's body movements. The system should not inhibit the user's actions.

One of the related systems, called Flying Sports Assistant, provides the user's self-images captured from the back by a camera on an unmanned aerial vehicle (UAV) [4]. The user obtains self-images through a head-mounted display (HMD) that the user wears. The components of Flying Sports Assistant are a posterior robot and an HMD. Providing self-images from an out-of-body view reportedly contributes to the effects of sports training.

We propose a novel system, Around Me, which provides user's self-images through an escort robot accompanying the user. The robot captures and provides the user's self-images accurately and helps him/her improve his/her body movements continuously. Consequently, the system will enable the user to change actual actions to ideal actions. We can consider that this system interprets user's actual body movements and returns the user the way how he/she should make his/her movements ideal (Fig. 1).

We classify escort robots into three types according to whether they run in front of the user, alongside the user, or behind the user. The types differ with regard to the minimum required system components and the viewpoints from which the robot captures self-images.

- *Running in front of the user:* The system needs a frontal robot equipped with a display. The viewpoint from the front is suitable for observing the whole form and recognizing how each body part moves with the others.
- *Running alongside the user:* The system needs a side robot and an HMD, or it needs a side robot and a frontal robot equipped with a display. The viewpoint from the side is suitable for recognizing the user's angle of forward inclination.
- *Running behind the user:* The system needs a posterior robot and an HMD, or it needs a posterior robot equipped with a camera and a frontal robot equipped with a display. The viewpoint from the back is suitable for recognizing the user's raising the feet upward.

We think that presenting self-images through a display is less cumbersome than presenting them through an HMD and that no cumbersomeness is quite significant because cumbersomeness disturbs a sports player's essential body movements. An HMD also occupies part of the player's field of vision and this prevents him/her from recognizing his/her surroundings in order to avoid danger. We therefore decided to use a display and, as an initial step, developed an experimental prototype of a robot that runs in front of a user and to which a display is attached so we could evaluate how effective the system is at providing self-images. We also used the prototype to investigate characteristics of the frontal robot.

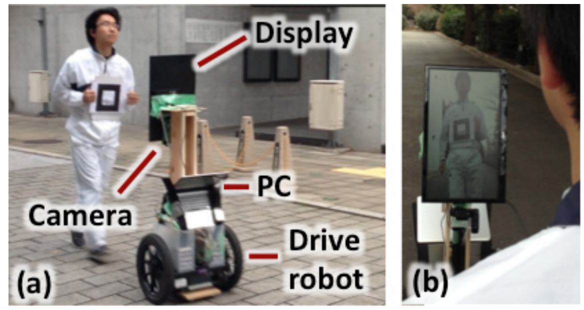

Figure 2. (a) Around Me consists a two-wheel-drive robot, a display, a camera, and a PC. This prototype is designed for assisting a jogger. A user can recognize and improve his/her body movements while jogging. (b) The display shows the user's self-images continuously.

We considered possible applications for Around Me, such as jogging assistance, walking rehabilitation for elders, and helping people practice martial arts (karate, kendo, and boxing). In this research we selected jogging assistance because it was an application suitable for evaluating the versatility and mobility of our system. Jogging includes basic human behaviors, such as walking and running, and we can improve a variety of actions if we combine these behaviors or properly configure each of the parameters that shape the behaviors. Conducting jogging studies thus verifies a kind of versatility. Moreover, jogging speed is not beyond the moving speed of most people, and therefore we can estimate the system's mobility through jogging studies. We focused on the assistance of jogging and developing a prototype that provides self-images continuously while the user is jogging (Fig. 2(a)(b)). This is a platform delivering to joggers useful information through the display, such as tips about their pace and running form.

In order to clarify differences between Around Me and Flying Sports Assistant, we compare them in Table 1. As the table shows, Around Me can be regarded as an improvement over Flying Sports Assistant in terms of continuous use (see "Operable Time"), no encumbrance (see "Wearable Device"), and extensibility to add new system components (see "Withstand Load"). As Around Me is superior to Flying Sports Assistant in these terms, our research on Around Me has made a significant contribution.

AROUND ME

Around Me, which runs in front of a user, captures his/her posture and provides self-images through a display. It maintains a certain distance between the user and the robot, and it keeps the robot facing the user at all times. The system consists of a two-wheel-drive robot based on Selfi (which is produced by FIT Inc [5]), a display, a camera, and a PC (Fig. 2(a)). The camera captures the user's posture, and then the PC recognizes the user's position relative to the robot and controls the rotation of each wheel accordingly. The captured user's self-images are shown to the user on the display (Fig. 2(b)).

Table 1. Comparison between Around Me and Flying Sports Assistant

System	Position	Provision	Operable Time	Wearable Device	Withstand Load
Around Me	Front	Display	60 min	AR marker	33.81 kg
Flying Sports Assistant	Back	HMD	12 min	HMD	0.50 kg (at most)

System Behavior

Maintaining an appropriate position relative to the user is important for two reasons: one is that the display needs to be located where the user can watch self-images easily and accurately, and the other is that the robot must create a suitable relationship between itself and the human. We therefore developed the function of maintaining a certain distance while running.

Research on the relationship between humans accompanied by robots has indicated that the space between them is one of the most effective elements determining what relationship is created. Walters [6, 7] suggested that the distance from the robot to the human influences how familiar the relationship becomes, and he classified the relationship according to the distance. Some research on escort robots also focused on the space between the person and the robot. Luis [8], for example, addressed the issue of keeping appropriate space naturally while a robot walks beside a person, and Gockley [9] developed the algorithm needed for a robot following a person from the back to keep a suitable space. Thus the space between a person and a robot running alongside or behind that person has been researched previously. Comparatively little research, however, has been done on the relationship or the space between a person and a robot that runs in front of that person. Although Ho [10] attempted to develop the algorithm needed for a frontal robot to accurately move as a user intends, that research focused on the accuracy of the frontal robot's movements. Newly, we reveal what relationship a robot that runs in front of a person can create between itself and that person.

Around Me moves to control its position relative to the user. Fig. 3 shows the rules of the robot's movements. The user wears an AR marker that enables Around Me to recognize the user's location, and Around Me runs in accordance with user's running causing the user to become farther from or nearer to the robot and moving left or right. If the distance between the user and the robot is from 150 to 170 cm, the robot keeps standing at the same position. The speed of the robot increases when the robot-to-person distance decreases, and it decreases when this distance increases. In addition, the robot moves to the left and the right in order to keep facing the user so that it can capture and display accurate self-images.

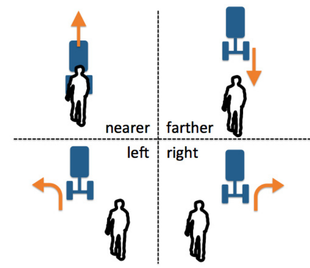

Figure 3. If the user gets farther from the robot, the robot's advance speed increases. If the user comes nearer to the robot, its retreat speed increases. As the user positions the robot right, the robot curves to the right. As the user positions the robot left, the robot curves to the left.

Table 2. Basic specifications of the prototype

Dimensions (DWH) [mm]	435, 525, 1433
Weight [kg]	76.19
Maximum Advance Speed [km/h]	6.07
Maximum Retreat Speed [km/h]	2.27
Operable Time [hour]	1.00 (at least)
Running Range [km]	10.15
Withstand Load [kg]	33.81
Perceptible Angle [degree]	54.20

Function Evaluation

We investigated whether a prototype could be used as a system providing accurate self-images. The basic specifications of the prototype are listed in Table 2.

Maintenance of a Certain Distance

We conducted an experiment in order to evaluate the ability of the prototype to maintain a definite distance between the user and the robot and accompany the user in a real outdoor environment. As a result, we found that the prototype could run with a jogger on a test path at a campus of the University of Tokyo (Fig. 4(a)). This test path is generally on paved roads for about 1.1 km. Fig. 4(b) shows that the robot could maintain a certain distance while the user was jogging even though the user stopped several times for the safety of pedestrians. We thus confirmed that the prototype could maintain a certain distance between the robot and the human continuously and was able to accompany a jogger in an outdoor environment.

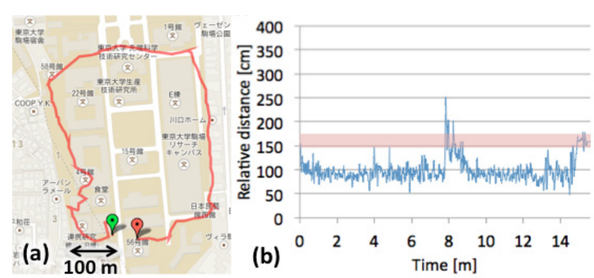

Figure 4. (a) The prototype could run with a jogger on a 1.1-km test path at a campus of the University of Tokyo. (b) The prototype continuously kept a certain distance, about 100 m, for a quarter of an hour. The colored band on the Y-axis (150 to 170 cm) shows the distance within which the robot stops. Around 8 minutes later, the user stopped for the safety of pedestrians in the area.

Following the User's Movements

We evaluated how quickly the prototype could follow changes in the user's moving. In an environment equipped with a motion-capture system, we measured the locations of the robot and a user on which we put motion-capture markers. Fig. 5 shows how the user's and robot's position coordinates and the relative distance between them changed when the user repeatedly (four times) started to advance, turned back, passed the start point, retreated, turned forth, and came back to the start point. We asked the user to do this task so that we could evaluate the prototype's ability to follow a jogger. Consequently, we confirmed that the prototype could follow the user sufficiently. As Fig. 5 shows, there was about a 2.30-second difference between time when the user first turned back and time when the robot first turned back. This difference is the delay time for the robot following the user's quick movements. We can regard this delay time as a time which we do not need to mind in using Around Me. We observed that the changes of the user's and robot's position coordinates and the relative distance between them properly moved together.

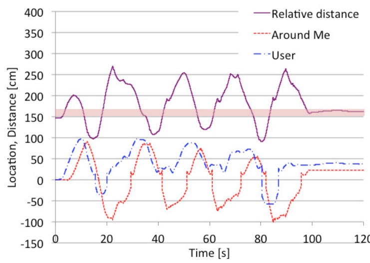

Figure 5. Changes of user's and robot's position coordinates and the relative distance between them properly moved together. The colored band on the Y-axis (150-170 cm) shows the distance within which the robot stops. As we can see from the difference between the time when the user first turned back and time when the robot first turned back, the delay time for the robot following the user's quick movements is about 2.30 sec.

Measurement of Perception Angle

To measure the angle within which Around Me could perceive a person, we attached motion-capture markers to the robot and a person and measured perception angles in the environment equipped with the motion-capture system. When we conducted this experiment, we made the prototype remain stationary even though the system was turned on. The person first walked in an area where Around Me could recognize him/her and then walked in an area where Around Me could not. Fig. 6 shows a graph in which all of the recorded plots are overlaid. We found that the prototype could recognize a person within about 54.20 degrees. This perception angle was no problem in using the prototype in this research, but if necessary we can increase it by attaching to the robot a wide-angle camera or additional cameras.

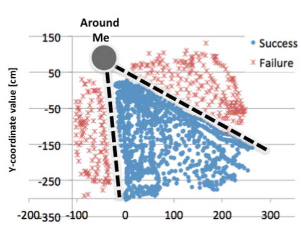

Figure 6. The prototype could recognize a user within about 54.20 degrees.

Abilities Supporting the Robot Movements

The robot movements described in the previous section are supported by two abilities as follows.

Control of the Robot's Speed

The control of the robot's speed is based on an inverted pendulum function. The inverted pendulum function receives real angle data, which means the inclination of the robot itself, and virtual angle data, which the user's position relative to the robot is converted into. The robot uses the real-angle data to keep its body perpendicular to the ground and uses the virtual-angle data to determine the speed needed to maintain a certain distance between itself and the user. Because we use the inverted pendulum function as the control function for the robot's speed, the robot's body is highly stable. Thus, the robot does not fall forward or backward and it is easy for the user to watch his/her accurate self-images on the display. The robot is able to maintain both an upright posture and a certain distance between the robot and the user at all times.

Recognition of User's Position

In this experimental prototype, we use an AR marker to recognize the user's position. The user wears the marker on the front of his/her chest when using our prototype. This technique has the advantage that the prototype can interpret the user's body's turning direction easily and the disadvantage that the prototype has a slight possibility of misrecognizing some other thing as the marker. We therefore implemented an error-detection function that makes the robot stop when the detected marker has an improper shape or when the marker moves too fast. In case we meet an environment where the robot often misrecognizes, we can improve our solution to this problem by using another technique, such as a particle filter [4, 11].

SYSTEM EVALUATION

This system has two roles: obtaining the user's self-images and showing the user's self-images. We evaluated each role in order to examine the effectiveness of the proposed system, Around Me.

User Study 1: Obtaining User's Self-images

To evaluate how appropriately Around Me obtains user's self-images as an escort robot, we conducted a study of comparing an frontal escort robot (FER), which runs in front of the user, with a posterior escort robot (PER)(Fig. 7(a)), which follows behind the user.

Experimental Methods: Eight graduate students, 23-31 years old (mean: 26.6 years, standard deviation (SD): 2.40 years), 6 male and 2 female, participated in this study. They first ran about 30 m with an FER and then ran the same distance with a PER. They were then asked to answer seven questions on a 5-point Likert scale (5 indicates positive and 1 indicates negative). The questions are listed in Table 3. Furthermore, we measured the running time and the distance between the user and the robot while jogging.

Results & Considerations: Fig. 8 shows the number of participants (0 to 8) who answered each point in the 7 questions. The distance between a user's position and the center of the robot's stop distance (160 cm from the user) is shown in Fig. 7(b). The verbal free feedbacks about the FER were the following: "Because I myself have to control the robot, I feel an attachment to the robot." and "As the robot stays in front of

Table 3. The seven questions in User Study 1

Q1	Did you need to control the robot?
Q2	Did the robot's following you and moving with you make you feel uncomfortable?
Q3	Did the robot encumber you while jogging?
Q4	Did the marker you wore disturb you?
Q5	Did the robot prevent you from seeing your surroundings well enough for jogging?
Q6	Did you feel endangered because the robot always stayed with you?
Q7	Did you feel familiar with the robot?

me, I can make assumptions that I will deal with some accidents of the robot well. I feel a sense of safety." The verbal free feedbacks about the PER included the following: "Because I cannot see the robot, I do not feel familiar with it. I can notice no connection with the robot."

The responses to Q1 in Fig. 8 indicated that users thought the FER required them to control it and PER did not. Fig. 7(b) shows that the user could maintain a certain distance when accompanied by the FER because the user paid attention to the speed of the robot, whereas the user did not try to maintain the distance to the PER because the robot was behind the user. Thus PER had to maintain the distance by itself. In this study, however, the PER failed to follow the user at the certain distance because the parameters corresponding to the robot speed were misconfigured. Moreover, as Fig. 7(b) shows, the running time for 30 m was 27.13 sec with the FER and 22.51 sec with the PER. This result shows that a user running with an FER depends on the robot's pace but a PER relies on the user's pace.

The responses to Q2, Q3, and Q4 showed that this system did not encumber or disturb a user and thus that he/she could use this system comfortably. In Q5, we did not confirm that the system prevents the user from seeing the frontal view for jogging. The responses to Q6 indicated that a user feels safer when accompanied by an FER than when accompanied by a PER. Since the issue of safety is the key to admitting the system as a usable device, the user should be accompanied by an FER.

The responses to Q7 revealed that an FER is capable of creating a familiar relationship between a user and the robot. This is because an FER requires the user to control the robot and he/she can confirm that the robot follows his/her movements in real time. We also confirmed the Spearman's rank correlation coefficient between Q1 and Q7 is about 0.50, which means there is an exact correlation between them.

In summary, we confirmed that an FER can obtain self-images without disturbing the user and retain the exact effect of providing self-images because it does not encumber a user, does not prevent him/her from moving and does not produce a sense of danger due to the robot. An FER requires the user to control the robot, but this creates a familiar relationship between the user and the FER. As shown in Table 4, we clarified that the differences between an FER and a PER are the rights to manipulate the speed and to control the distance and steering, and the presence or absence of a familiar relationship between the robot and the user.

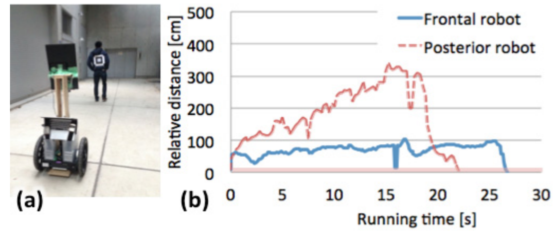

Figure 7. (a) Image of the study in which the user was accompanied by the posterior robot. (b) The X-axis is the running time for 30 m, and the Y-axis is the distance between the user's position and the center of the robot's stop location (160 cm from the user). When accompanied by the frontal robot, the user maintained a certain distance, whereas the posterior robot tried to follow him/her. The running time was 27.13 s with the FER and 22.51 s with the PER.

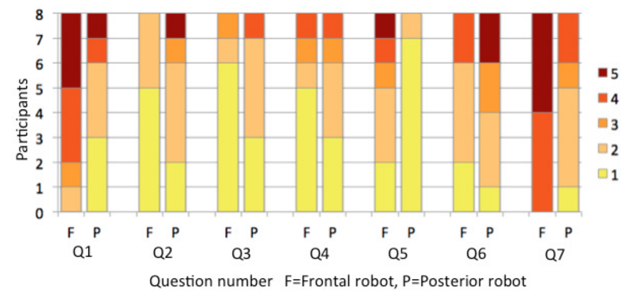

Figure 8. This shows the number of participants (0 to 8) who answered each scale point in the 7 questions. In the scale, 5 indicates positive and 1 indicates negative. We can see the proportions of positive and negative responses to each question. The frontal robot made users feel more required to control and more familiar than the posterior robot did.

User Study 2: Showing User's Self-images

We conducted a study to examine the effectiveness of showing user's self-images.

Experimental Methods: The same students participated in this study, ran about 90 m with the FER, and answered 4 questions to evaluate in the same scale used in the previous study. The questions are listed in Table 5. Each question corresponds to the process of a behavior that the user undertakes in order to improve his/her body movements.

Results & Considerations: The results obtained with the 4 questions are shown in Table 6, which shows the mean, SD, percentage of positive responses (=4 or 5 on a 5-point Likert scale) and percentage of negative responses (=1 or 2) to each question. The verbal free feedbacks were the following: "As I get used to running with Around Me, I can pay sufficient attention to my self-images on the display." and "I can observe my body movements, for example, which shoulder rises, and can make my form better while jogging."

The responses to Q1 in Table 6 point out that users could pay satisfactory attention to the screen and that the system was able to assist users through the display. Almost all the users could accomplish the process of Q2, but whether the user accomplished the process of Q3 depended on the individ-

Table 4. Characteristics of the frontal robot and the posterior robot

Robot Type	Distance & Steering	Speed	Familiar Relationship
Frontal	User	Robot	Yes
Posterior	Robot	User	No

Table 5. The four questions in User Study 2

Q1	Did you pay attention to the screen?
Q2	Could you quickly notice that Around Me displayed you?
Q3	Could you see your small body movements?
Q4	Did you try to improve your body movements after seeing your self-images?

Table 6. User Study 2 question results on a scale from 5 to 1

	Mean	SD	Positive % (=4,5)	Negative % (=1,2)
Q1	4.50	0.98	7/8	1/8
Q2	4.50	0.98	7/8	1/8
Q3	3.38	1.07	4/8	3/8
Q4	3.75	0.96	5/8	1/8

ual user. The feedbacks indicate that whether a user can pay attention to the images is determined by the user's learning level of this system. Furthermore, The responses to Q4 show that users felt more inclined to improve their form through self-monitoring and tried to modify their body movements. To sum up, we confirmed this system can show users' self-images on the display and encourage the users to improve body movements such as their jogging form.

JOGGING SUPPORT FUNCTIONS

We describe jogging support functions that are provided through the display while jogging. We focused on encouraging a jogger to improve his/her form. In jogging, the form is essential for performance and for injury prevention.

Robot's Guidance

Fig. 9 shows functions with which the robot itself guides a user. We implemented two functions. One is a function that recognizes the front and rear points of the user's inclination and then guides him/her in order to keep his/her posture vertical (Fig. 9(a)). Amateur joggers should continuously make their posture vertical [12]. The other is a function that displays the standard lines for a user to interpret his/her form accurately on the spot. The lines are a horizontal line at the height of the user's shoulders and a vertical line at the center of his/her torso (Fig. 9(b)). Without the standard lines, some users cannot accurately perceive their form by themselves. We also designed three additional functions. One of these is a function that draws the user's bone lines through body joints (Fig. 9(c)). These lines make him/her interpret changes of the whole form clearly. Another is a function that zooms in the user's body parts that should be observed (Fig. 9(d)). With this function, a user is able to recognize smaller body movements. The third additional function we designed semi-transparently overlays the most appropriate user's form on the self-image (Fig. 9(e)). The constant display of the ideal form helps the user adjust his/her body movements in detail.

Remote Instructor's Guidance

Fig. 10(a) shows a function with which remote instructors guide a user through the display. The instructors draw things such as lines, arrows, and circles and write words. They then continuously provide the user useful tips in real time without accompanying the user. Because this enables an instructor to teach multiple joggers at the same time, it possibly becomes

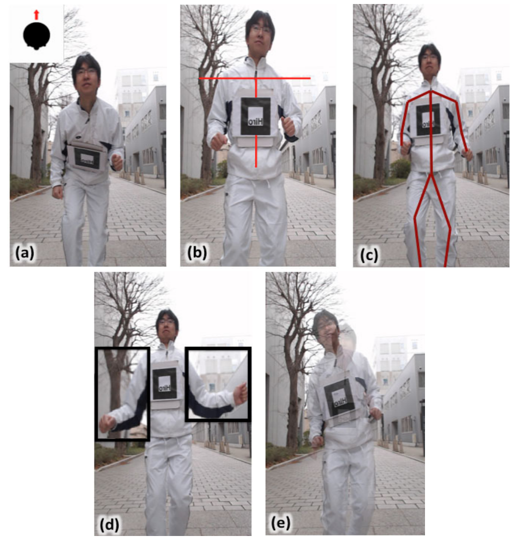

Figure 9. These are functions with which the robot itself guides a user. (a) Inclination of body. (b) Standard lines. (c) Bone lines. (d) Zoomed-up body parts. (e) Semitransparent ideal form overlay.

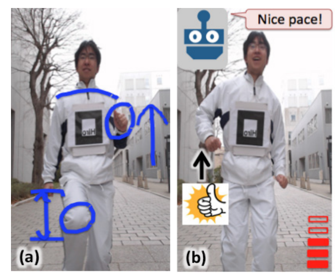

Figure 10. (a) Remote instructors provide useful tips on the display in real time. (b) This motivates a jogger to practice harder and makes him/her feel as if the robot were a jogging partner.

easier for more joggers to obtain the guidance of a skillful instructor.

Enhancement of Motivation

Fig. 10(b) shows the function that can encourage a user to improve his/her form ambitiously and motivate him/her to practice harder. For this support function, we utilize the FER's advantage: the characteristic that the FER creates a familiar relationship between the robot and the human. When using this function, a user interacts with the robot as if it were a jogging partner. Grather [13] indicated that assistance by systems that have hardware bodies makes a jogger more motivated than does assistance by systems that consist only of software. Moreover, he suggested that a jogger's need to control the robot should be beneficial for the encouragement to the jogger. Thus, this function of motivating a user is suited for Around Me.

DISCUSSIONS

System Design

Autonomous Level for Control of the Robot

We can classify the autonomous level for control of the robot into two types: indication and autonomy. Indication means that the user determines the system's position relative to him/her, and autonomy means that the system follows the user autonomously and determines the relative position by itself. In systems that use indication, the user must pay sufficient attention to the control of the robot, and self-images can become images that the user requires, whereas in systems that use autonomy, self-images cannot become images that the user requires. In systems that use autonomy, on the other hand, the user can focus on only his/her action without paying attention to the control of the robot.

The control type that Around Me uses is indication. This is because we will eventually develop a system that moves around a user intentionally. In terms of safety, we do not need perfect autonomy if the system is used only in wide open sites like our campus. If necessary, we can raise the autonomous level. Ho [10] has already developed the function of a frontal robot's moving autonomously to the position where a user is about to go. Furthermore, by obtaining GPS map information, the system can move completely independently of a user.

Selection of Media Providing the Training Information

People can receive information from systems enabling them to recognize and improve their body movements with five senses: hearing, sight, touch, smell, and taste. The systems mainly use the person's hearing or sight, which do not require the use of special devices. In a system used in practicing skiing, Hasegawa [14, 15] provided both aural and visual information. Taking this research into consideration, the advantage of visual information is that a user can understand the whole condition intuitively. The disadvantage is that length of time the user can receive the information is sometimes not long enough for the user to recognize his/her body movements. On the other hand, the advantage of aural information is that a user can recognize it quickly. The disadvantages are that converting original information into understandable sounds is too difficult and that the system needs not to provide information about the whole condition but only quite focused information because a user cannot interpret many sounds provided at the same time.

We thought that Around Me for jogging should provide visual information because the whole condition is indispensable if a user is to improve form while jogging. Thus, Around Me provides self-images through the display. Some users, however, cannot recognize the point that should be corrected and control the robot at the same time. In order to resolve this problem, we also will consider the possibility of sometimes combing sound information with the displayed images.

Improvement for Practical Use

We clarified what aspects of the experimental prototype should be improved for practical use.

Increase the Top Speed: We should increase the top speed of the prototype because the prototype has the possibility of not leading a person because its top speed is only 6.07 km/h. The causes of this problem are the limited stability of the robot's body and the limited power of the robot's motor. With regard to the former cause, the higher the top speed gets, the lower the stability gets. There is a trade-off relation between the speed and the stability because of Newton's first law. With regard to the latter cause, we can replace the motor with a more powerful one.

Enhance the Perception Accuracy: As described earlier in this paper, the prototype uses an AR marker to recognize the location of the user. Although this has advantages, there are more accurate techniques that could be used for this purpose. Thus we will implement, for example, a particle filter [4, 11] in the system for general use.

Getting More Safe: Although we have already developed an emergency-stop function, we did not design a function interpreting external environments and detecting something dangerous. In our studies, the system ran only in a wide open campus where everybody allows our research. If we use it in the general public, we should equip it with structures for quickly judging the safety of the current situation. We can raise the degree of danger management's perfection by using the contributions of previous research, such as research on obstacle avoidance [16, 17].

RELATED WORK

When the development of systems providing self-images started, all of the systems were fixed ones without movable structures. The ALIVE system [18] is a big display in which virtual things are overlaid on a user's self-image. Although its main contribution is to immerse the user in a world that mixes real things with virtual things, the applications for education and training with self-images were introduced as effective methods. Magic Mirror [19, 20] is a screen that provides user's self-images and overlays them on a wide range of useful information. This system has a variety of applications, such as assistance of collaborative work and trying on clothes virtually.

As shown in the Introduction, Flying Sports Assistant [4] is a general and movable system providing self-images. It is used for various sports played on the ground. Floating Eye [21] obtains self-images by using a balloon equipped with a camera and provides them to the user through a specialized helmet-style display. However, the balloon is hard to control and the user's movements are restricted by the cable connecting him/her to the balloon. Among the systems specialized for a specific sport, Swimoid [11] is focused on swimming. The robot, which swims under the user, obtains the user's self-images and provides them from below through a display. This system can solve a problem that it is difficult for instructors to directly give helpful tips to a swimmer in the water. In addition, Augmented Ski [14, 15] is a system in which a user is equipped with a long stick that has a camera attached to the end and wears an HMD providing self-images captured from the back.

Among the above research into providing self-images, our research is positioned as shown in Fig. 11, where the X-axis represents mobility and the Y-axis represents adaptability, which is advantageous because an adaptable system can assist a user in versatile cases including a variety of sports. Around Me is positioned in the high-adaptability and high-movability area colored in red. As shown in Table 1, Around Me is an improvement over Flying Sports Assistant. In addi-

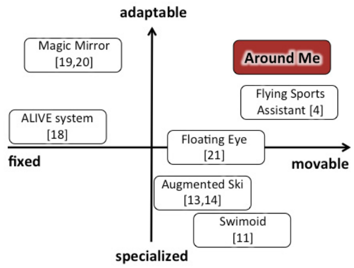

Figure 11. Position of our research relative to other relevant research. The X-axis represents the proposed systems' mobility, while the Y-axis represents their adaptability. In those two terms, we can confirm that our research contribution is unique and high.

tion, there is no other system obtaining self-images that uses a robot running in front of a user on the ground and that provides them through a frontal display. Therefore, we regard our research contribution as unique and high.

CONCLUSIONS

We proposed a system, called Around Me, that provides a user's self-images through a display attached to a robot running in front of the user. We developed an experimental prototype of Around Me and conducted studies in order to evaluate the effectiveness of providing self-images with Around Me. We clarified the robot running in front of a user can obtain his/her self-images without disturbing his/her movements. Comparing the robot running in front of the user with one following behind the user, we found that the advantage of the frontal robot is that the user determines the robot's steering and the distance between the user and the robot, while the jogging speed is manipulated by the robot. We then evaluated the effectiveness of showing user's self-images and found that Around Me can encourage the users to improve their body movements (e.g., jogging form). We also found that the system can, with seven support functions on the display, help a user practice jogging. In the near future, we will implement a system consisting of multiple robots moving around a user while obtaining and providing self-images separately corresponding to the user's intention.

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