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MOTION DESIGN OF INTERACTIVE SMALL HUMANOID ROBOT WITH VISUAL ILLUSION

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Abstract. *This paper presents a novel method to express motions of a small human-like robotic avatar that can be a portable communication medium: a user can talk with another person while feeling the other's presence at anytime, anywhere. The human-like robotic avatar is expected to express human-like movements; however, there are technical and cost problems in implementing actuators in the small body. The method is to induce illusory motion of the robot's extremities with blinking lights. This idea needs only Light Emitting Diodes (LEDs) and avoids the above problems. This paper presents the design of an LED blinking pattern to induce an illusory nodding motion of Elfoid, which is a hand-held tele-operated humanoid robot. A psychological experiment shows that the illusory nodding motion gives a better impression to people than a symbolic blinking pattern. This result suggests that even the illusory motion of a robotic avatar can improve tele-communications.*
Keywords: Tele-communication, Nonverbal communication, Portable robot avatar, Visual illusion of motion

1. **Introduction.** Current advanced technologies of information media allow us to connect with distant people in various modalities. We can talk with other people in a face-to-face-like manner using the video chat function of a mobile phone at anytime, anywhere. The progress of the communication technologies may symbolize people's aspiration to have natural communication (like face-to-face conversation) with people in distant locations. The current communication media rely on video and sound information; however, a more human-like interface is expected to bring more natural communication. Our final goal is to achieve a tele-communication in which people feel as if they were conversing in a natural fashion with someone directly in front of them.

Recent studies have tried to use tele-operated robots as communication media (robotic avatar) to achieve more natural tele-communication. The tele-operated robot can convey not only the speaker's image and voice but also his/her physical information through the physical entity of a robot. It is important to transfer the speaker's physical information since nonverbal information like a gesture has a large weight in human-human communication [1, 2]. The gestural motions can be transferred through a video; however, Kuzuoka *et al.* [3] have shown that gestural motions expressed by the physical body of a robotic

Figure 1. Cell phone-type tele-operated android robot "Elfoid"™

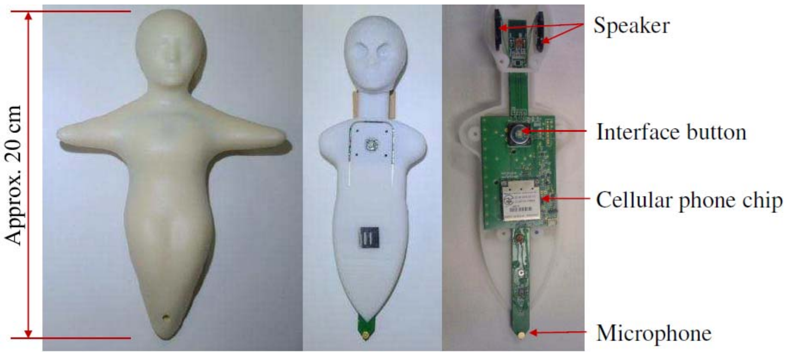


Figure 2. Elfoid: skin (left), plastic case (center), and communication module (right)

avatar fosters smooth tele-communication. Some other studies have tried to improve tele-communication by transferring the speaker's gestural motions through a tele-operated robot [4, 5]. Furthermore, small (cell phone-size) robots have been developed to be a portable communication medium in that the speaker can talk with another person while feeling the other's presence at anytime, anywhere [6, 7].

We have also developed a portable tele-operated android "Elfoid" (Figures 1 and 2) equipped with cell phone capability as a novel communication medium. It is designed to transfer a speaker's voice (and motions, in the future) using the cell phone networks. We expect that people can talk with one another while feeling the other's presence at anytime, anywhere. The users seem to strongly expect that Elfoid can make movements of the head and arms since its head and arms are clearly recognized as a human's head and arms. It should, therefore, produce gestural motions synchronized with the speaker's motions to express his/her presence. However, it is hard to implement a number of actuators in the small body because of space and energy cost problems.

If Elfoid makes users perceive an illusory motion of its limbs by means of light, sound, vibration, and so on, it can support natural interaction without embedded actuators for moving the limbs. Based on this approach, this paper proposes a method to induce a user's illusory perception of motions by Elfoid with blinking of LEDs embedded in its body. Some studies have shown that subtle expressions of facial and bodily movements, which serve an important role in interpersonal communication, improve smoothness of human-robot/human-agent communication [8, 9, 10]. We think the illusion of subtle motion on the robot avatar also improves interpersonal communication through a tele-operated robot. This paper reports design of a blinking pattern of LEDs to induce an illusory nodding motion, which is an important nonverbal expression in face-to-face communication. We first design four blinking patterns and find the best pattern with respect to the facility to perceive illusory motion and its naturalness. We then reveal that the blinking pattern improves tele-communication through a tele-operated robot by evaluating the effect of the illusory nodding motion on human impression.

2. **Robotic Platform: Elfoid.** Elfoid has been developed as a cellular phone that conveys operator presence (Figure 2). Its main feature is a human-like shape: human-like head, arms, and legs but no hands and feet. Its skin is fashioned from urethane gel and resembles and feels like human skin. It has a communication module inside that is covered with a plastic case to enable us to talk with other persons. Instead of an actual Elfoid system, in this paper, we used a full-scale blown-molded mock-up model made of polyvinyl chloride (PVC) to embed the LEDs.

3. **Design of Illusory Motion with Blinking Lights.** The influence of nodding motions has been investigated in face-to-face interaction. Matarazzo *et al.* [11] showed that the head nodding of interviewers significantly increases the duration of interviewee's speech. Analysis of the relationship between voice and body movement has revealed that the head nodding of human listeners has a strong relation with their body movement [12]. Some studies with artificial agents have reported the effectiveness of nodding movements on collaboration in virtual space [13] and in the real world [14]. Matsubara and Ueda showed that head nodding by a robot eases the frustration of humans who complain to the robot [15]. This paper also focuses on the head-nodding motion of Elfoid and evaluates the effect of the illusory nodding motion of Elfoid on human impressions of how it eases the frustration of a person who is talking with another person through Elfoid.

Multiple white LEDs are embedded in Elfoid's body to illuminate the surface of the body parts from the inside. The blinks of the LEDs are remotely controlled through the control box, which is set up outside Elfoid. We induce a perception of illusory head motions by sequentially changing the illumination.

Two different illumination patterns are considered as possible implementations based on human cognition: biological motion and illusion of motion from shadow. Studies of biological motion [16] have revealed that humans perceive a human's motion in a display of movement of structured point lights. A biological motion expressed by embedded LEDs might provide an illusion of motion since Elfoid has a human-like body. Studies of the visual illusion of motion have reported that humans perceive movement of a still object when its shadow moves [17]. This might be applicable to human gestures because human movement changes the shaded areas of the human body; for example, the shadow on the lower part of the face appears and disappears when nodding. By controlling the shifting of the shaded parts of Elfoid's body with blinking LEDs, we might be able to evoke illusory motions of its head.

We then designed the following patterns (the locations of LEDs are shown in Figure 3).

- Pattern BP (Figure 4(a)): LEDs 1 and 2 are lit in the sequence of 1(i) - 2(ii) - 1(i) to express the biological motion (i.e., a motion of point lights) of the forehead. This motion takes about 500 msec. Other LEDs (3, 6, 9, 10, 13, 14, 15, 16) are also lit during the nodding motion to express human body shape (iii). Every LED expresses a point light.
- Pattern SD (Figure 4(b)): LEDs 1 to 5 are lit at first (i). LEDs 2 and 3 are gradually turned off (ii) and then gradually lit again (i). The motion takes about 500 msec. To widen the shadow area, diffusion filters are attached to all LEDs. This pattern expresses the shadow shift when looking down and up; the shadow on the lower part of the face appears (ii) and disappears (i). Other LEDs (6, 7, 8, 11, 12, 13) are also lit during the nodding motion to illuminate the body parts as well as Pattern BP. In this pattern, the upper body part is highlighted and the lower body part is shaded.

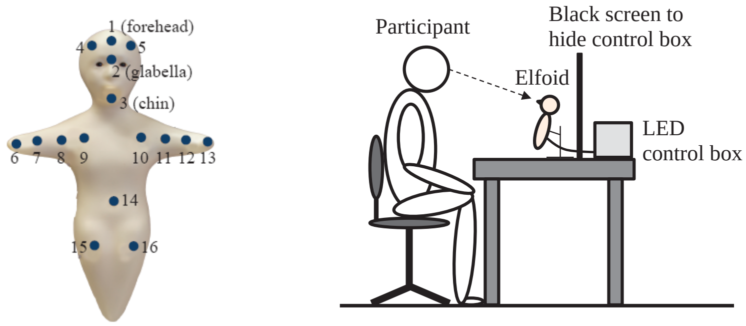
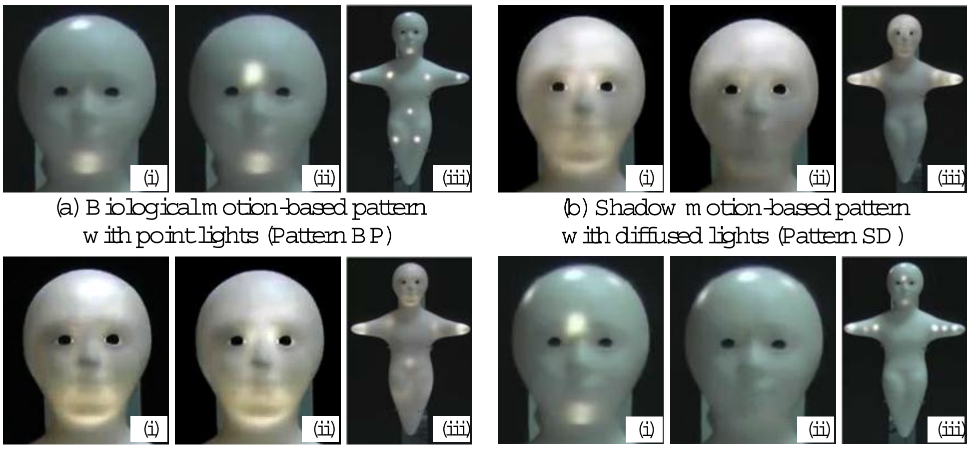


Figure 3. Experimental setup: designs of LED locations (left) and experimental scene (right)



(a) Biological motion-based pattern with point lights (Pattern BP)

(b) Shadow motion-based pattern with diffused lights (Pattern SD)

(c) Biological motion-based pattern with diffused lights (Pattern BD)

(d) Shadow motion-based pattern with point lights (Pattern SP)

Figure 4. Designed illumination patterns

In addition, we designed two patterns by switching the diffuse and point lights.

- Pattern BD (Figure 4(c)): This is the same as Pattern BP except that diffused lights are used.
- Pattern SP (Figure 4(d)): This is the same as Pattern SD except that point lights are used.

4. **Evaluation of Designed Patterns.** We conducted subjective experiments to find the patterns that participants perceive as illusory-nodding motions more naturally and more quickly among all patterns.

4.1. **Procedures of experiment.** First, we evaluated the ease of perceiving the illusory-nodding motion (experiment 1). Before the experiment, we instructed the participants that Elfoid's blinking lights denote its nodding motion. Twenty-three people (fourteen men and nine women) who had never interacted with Elfoid participated in the experiments. The average age of all participants was 21.4 (SD = 2.2). They observed the blinking patterns of Elfoid, which was fixed on a table (the right figure in Figure 3). They adjusted the height of the chair to view Elfoid's face from the front. We maintained the illumination condition in the room throughout experiments 1 and 2. We continuously repeated the blinking pattern and showed it to participants until they perceived the illusion of nodding. They were asked to subjectively decide their perception of the illusion and to notify the experimenter when they perceived it. We measured the length of time before they perceived the illusion. If they did not perceive it within five minutes, the measurements were stopped. Participants tried four patterns in random order.

We then evaluated the subjective impression of the perceived illusory motions (experiment 2). Fifteen of the participants (nine males and six females) in experiment 1 took part in experiment 2 (average age = 21.7, SD = 2.4). They were presented with paired comparisons for the subjective naturalness of the illusory nodding motion (total six pairs). For each pair, they separately observed two stimuli (one stimulus consisted of two consecutive noddings of one blinking pattern) and responded as to which nodding pattern was more natural. Note that they did not need to observe Elfoid's blinking LEDs before the experiment because they had already recognized illusory head nodding in experiment 1. They were allowed to repeatedly observe the nodding patterns. When they failed to observe a difference in the naturalness or did not perceive the illusory-nodding motion, they answered "no difference". The order of the pairs was randomly changed for every participant.

4.2. **Results.** Figure 5 shows the length of time before the participants perceived the illusory-nodding motion measured in experiment 1. When a participant did not perceive it, no data were plotted. The measured values vary widely. Analysis of the time difference with ANOVA revealed that there was no significant difference between the patterns. However, it can be seen that the participants tended to perceive the illusory motion of pattern SD more quickly than the other patterns. Therefore, we also tested the time difference between SD and the others using a Wilcoxon signed rank test, since their normality cannot be assumed by the Shapiro-Wilk test. In this test, the case of no paired data was omitted from the test. It showed that the SD time is significantly smaller than BD ($T(n = 16) = 0$, $p < 0.01$), SP ($T(n = 12) = 14$, $p < 0.05$) and BP ($T(n = 9) = 0$, $p < 0.01$).

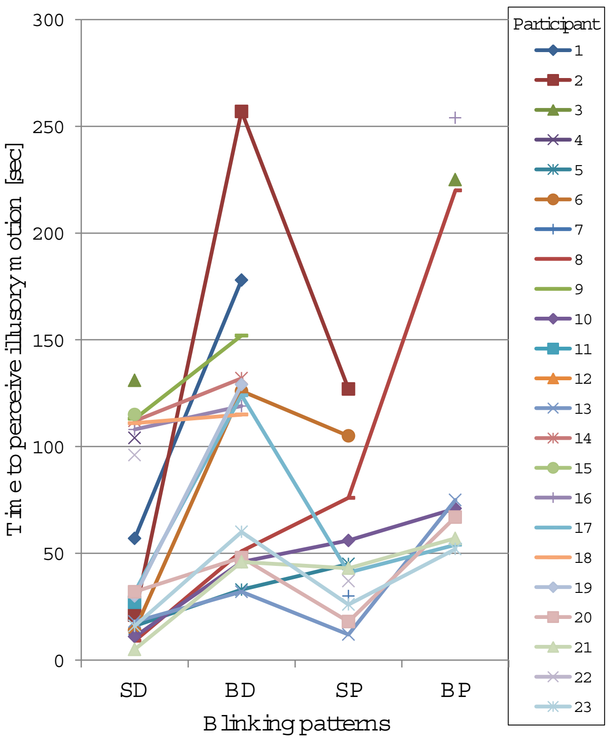


FIGURE 5. Time to perceive illusory-nodding motion

Table 1. Paired comparison of naturalness of nodding motions expressed by blinking patterns. The more natural pattern is shown in each box. Symbol "=" stands for no difference between the two.

Participant	SD - BD	SD - SP	SD - BP	BD - SP	BD - BP	SP - BP
1	BD	SD	SD	BD	BD	BP
2	=	SD	SD	BD	=	SP
3	SD	SD	SD	SP	BD	BP
4	=	=	=	=	=	=
5	SD	SD	SD	SP	BD	BP
6	SD	SD	SD	BD	BD	SP
7	SD	SD	SD	SP	=	SP
8	SD	SD	SD	SP	=	=
9	SD	SD	SD	BD	=	=
10	SD	SD	SD	SP	BD	SP
11	=	=	SD	=	=	=
12	=	SD	SD	BD	BD	=
13	SD	SD	SD	=	BD	=
14	BD	=	=	BD	BD	BP
15	SD	SD	SD	SP	BP	BP

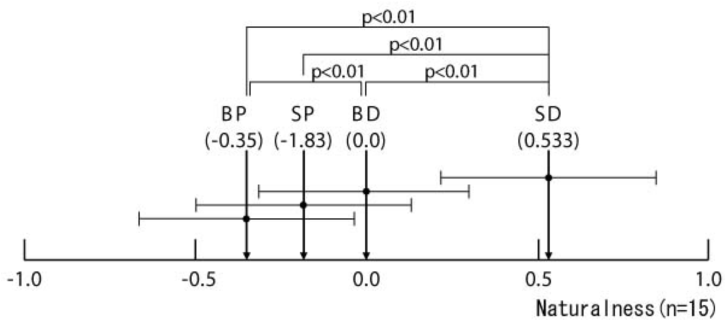


Figure 6. Scale value of subjective naturalness of blinking patterns (yardstick test, 99% confidence interval $\boldsymbol{Y(4, 42, 0.01) = 0.316}$)

Table 1 shows the paired comparison results of experiment 2. The more natural pattern is listed in each box. When there was no difference, we put "=". Scheffe's paired comparisons test with Nakaya's modified model [18] showed a significant effect of the blinking patterns ($F(3, 42) = 32.3$, $p < 0.01$). Figure 6 shows the scale value to express the subjective impression of naturalness obtained by the yardstick method. SD is significantly more natural than BD, SP, or BP ($p < 0.01$), and BD is significantly more natural than BP ($p < 0.01$).

These results suggest that the pattern SD makes us perceive illusory motion of head nodding more naturally and more quickly. Therefore, we use the pattern SD as the illusory motion pattern in later experiments.

5. **Evaluation of Effect of Illusory Head Nodding.** Since we selected a model that shows the best nodding performance in terms of naturalness of the motion and time to perceive the illusion, we tested whether the model gives an impression that resembles actual head nodding.

(a) Turning on LEDs (b) Turning off LEDs

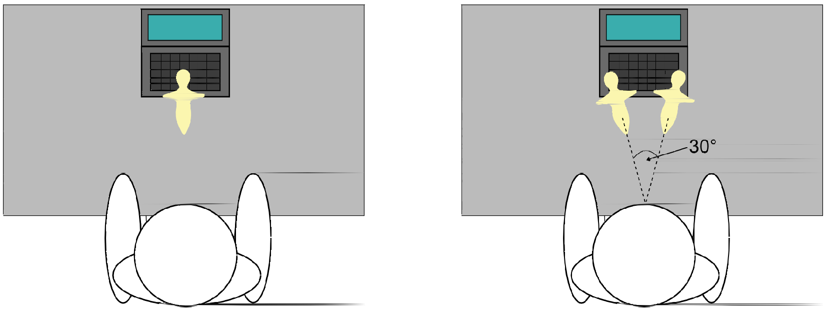
FIGURE 7. No-nodding case. LEDs on the left and right side of Elfoid's head (4 and 5 in Figure 3) are blinked.

5.1. **Working hypothesis.** Recent studies have revealed that when a user complains to a robot the satisfaction rating improved by increasing the frequency of the robot nods [15]. Although this result suggests the advantage of the head-nodding behavior of robots, perhaps illusory head nodding could be replaced with an LED that blinks simply, as described in the concept of ASE [19]. Therefore, we hypothesize that the frustration of participants who complain to Elfoid will be eased more if Elfoid presents illusory head nodding than if its LEDs blink simply. We evaluated the performance of illusory head nodding with grumbling situations where the participants complained about a difficult customer. The performances of different blinking LEDs were measured by rating the easing of frustration based on a previous study [15].

5.2. **Design of blinking pattern.** We used the pattern SD to create the illusory motion of head nodding. The entire configuration was the same as the first and second experiments except that LEDs on the body (6, 7, 8, 11, 12, 13) were turned off in this experiment. For comparison, we designed a simple blinking model that is not supposed to create the illusory motions (see Figure 7). The blinking pattern was achieved with diffused lights that were symmetrically placed on the left and right sides of Elfoid's head. We call the pattern SD the illusion model and the simple blinking pattern the no-illusion model. The other configurations, such as number of LEDs, blinking frequency, and light intensity, are the same among all models.

5.3. **Experimental procedure.** First, the blinking patterns of the illusion and no-illusion models were presented to the participants in order to habituate them to the patterns (Figure 8(a)). Each pattern was repeated for three minutes.[1] These patterns were presented in random order. The participants were informed that the blinking pattern gives the illusion of head nodding for the illusion model, while for the no-illusion model the blinking pattern expresses the internal state of the operator (experiment A). This instruction was needed so that the participants clearly perceived the illusion. However, this instruction may give the participants the impression of the no-illusion model being bad, since it does not express a motion but the other does. We then prepared a different instruction condition in which the participants were informed that both of the blinking patterns give the illusion of head nodding, even though it was a misleading instruction (experiment B). The subsequent procedure is identical to both experiments A and B.

[1]The time interval was determined based on the fact that the SD model needed 131 seconds to make the participants perceive the illusion in the first experiments.



(a) Instruction and free talk phases (b) Grumbling task

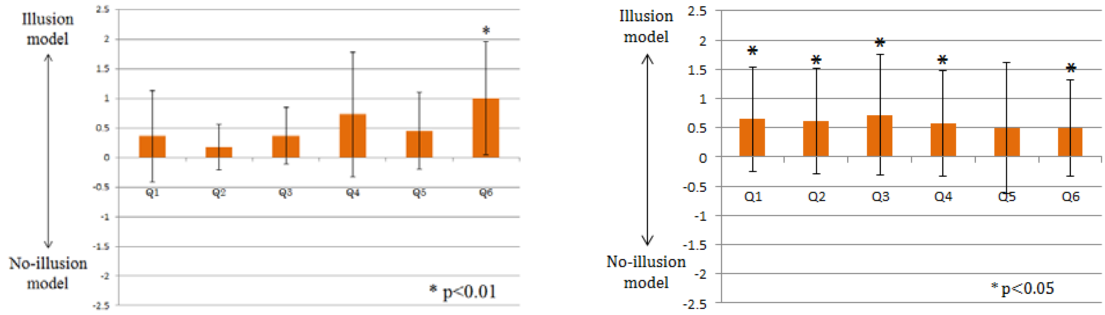
FIGURE 8. Experimental setting

Next, the participants had a three-minute conversation on a given topic with an experimenter through Elfoid to become accustomed to conversation with it (Figure 8(a)). During the conversation, the experimenter blinked the LED in synchronization with her/his nodding. The experimenter did not know which model s/he was operating remotely. The order of presenting the models was changed randomly. After the conversation, the same procedure was followed with the other model.

After that, the participants read a scenario for a role-playing game, where a customer is complaining through a monitor to a participant who plays a shop clerk. The participants selected appropriate answers to the customer's questions from several options for dealing with difficult customers, although all options just increased the customer's anger. This process was expected to increase the participants' frustration. After the role play was finished, they were asked to complain to two Elfoids at the same time, as shown in Figure 8(b): one is the illusion model and the other is the no-illusion one. These Elfoids were randomly placed on the left or right side for every participant. The participants were informed that each Elfoid was operated by two different experimenters, though both Elfoids were actually operated by one experimenter, who blinked the LEDs when s/he nodded. Note that the operator did not talk to the participants. The participants only evaluated the Elfoids from the blinking patterns. After they grumbled to the Elfoids, they completed questionnaires. We also interviewed them about their impression of the Elfoids to collect more detailed information about their feelings.

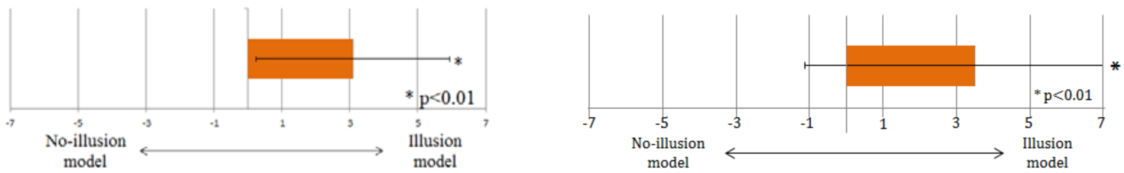
5.4. **Evaluation.** We evaluated the extent of the easing of frustration with subjective measures based on one proposed by Matsubara and Ueda [15]. Six questions were asked of the participants: (Q1) Which Elfoid made you feel better? (Q2) Which Elfoid gave a satisfying feeling? (Q3) Which Elfoid was more fun? (Q4) Which Elfoid was more friendly? (Q5) To which Elfoid could you say everything you wanted to say? (Q6) Which Elfoid showed empathy?

The participants were asked to answer which Elfoid on the left or right side was appropriate for each question and then rated how strongly they felt on a three-point scale. If they selected the illusion model, the point was used as a score. A negative value was scored if the no-illusion model was selected. For example, when a participant selected the right Elfoid, which was the no-illusion model, and gave it two points, the score was -2. If the participants failed to find any difference between the two Elfoids, we gave a score of zero.



(a) Experiment A (b) Experiment B

Figure 9. Averages and standard deviations of scores for each question



(a) Experiment A (b) Experiment B

Figure 10. Average and standard deviation of sum of scores for all questions

5.5. **Result.** Sixteen people (9 men and 7 women) participated in experiment A and 19 people (16 men and 3 women) participated in experiment B. We removed some participants from the analysis because they reported that they could not perceive the illusory head nodding. Thus, the data of 11 participants (6 men and 5 women, average age was 21.7 (SD = 2.7)) in experiment A and 14 participants (12 men and 2 women, average age was 20.9 (SD = 1.7)) in experiment B were analyzed.

Figure 9 shows the average scores for each question in experiments A and B. The negative scores indicate that the no-illusion model was selected. The illusion model received a higher average score than the no-illusion one. We tested whether the average score of each question exceeded zero. We used a t-test if the normality could be assumed by a Shapiro-Wilk test, and a Wilcoxon-test if the normality could not be assumed. For experiment A, we found significant difference for Q6 (Which Elfoid showed empathy?) ($p < 0.01$). In experiment B, we found significant difference for Q1 (Which Elfoid made you feel better?) ($p < 0.05$), Q2 (Which Elfoid gave a satisfying feeling?) ($p < 0.05$), Q3 (Which Elfoid was more fun?) ($p < 0.05$), Q4 (Which Elfoid was more friendly?) ($p < 0.05$), and Q6 (Which Elfoid showed empathy?) ($p < 0.05$).

The extent of the easing of frustration varied among individuals. This is because it is not always true that persons have the same feeling when they complain to others. The average score of all questions will help us evaluate the overall effect of illusory motion on the ease of frustration. Therefore, we also tested whether the sum of all the scores exceeded zero. The sum of scores is shown in Figure 10. We found that the sum of the scores significantly exceeds zero in experiment A ($p < 0.01$ with t-test) and in experiment B ($p < 0.01$ with Wilcoxon-test). These results show that the illusion model significantly eased participant frustration compared with the no-illusion model. In particular, the participants felt greater empathy from the Elfoid with the illusion model.

6. **Discussion.** Before the experiment evaluating the four designed blinking patterns, we expected that the biological motion-based patterns could create illusory motions since people generally perceive a human-like motion from a biological motion. However, the shadow motion-based pattern with diffused lights is a more natural pattern for recognizing nodding motions than the biological motion-based one. One possibility for its low performance is that the point-light motion was not continuous but intermittent, while the original biological motion is expressed as a continuous change of lights. However, in preliminary experiments, we confirmed that we can recognize nodding motions when only the light pattern is presented in a dark room. Therefore, the projection of the light pattern to the surface of Elfoid disturbs the perception of biological motions.

Although the result of experiment 2 evaluating the blinking patterns shows that the pattern SD can produce a natural nodding motion, it is a concern whether this result really reflects the illusory motions. It still remained a possibility that the participants merely perceived the blinking lights as a sign of nodding. The experiment 1 result indicates that the participants more easily perceived the illusory motion of pattern SD than the other patterns. Additionally, almost all of the participants (22 of 23) announced that they perceived the illusory motion for pattern SD (other patterns: 16 in BD, 12 in SP, and 9 in BP). If they perceived the blinking lights as a sign, we inferred that there was no large time difference among the four patterns, since before the experiment they knew that the blinking lights expressed nodding motions. Furthermore, almost all of the participants (14 of 15) in experiment 2 admitted in interviews after the experiment that they felt that Elfoid's face actually moved. These results suggest that the participants perceived the illusory motions especially for pattern SD with a mechanism that resembles the illusory motions from shadows [17]. The natural impression of pattern SD might come from the illusory motion rather than the blinking pattern.

The results of the experiment to evaluate the effect of illusory nodding showed that grumbling to the illusory nodding pattern eased the participants' frustration more than grumbling to the simply blinking pattern, even though a previous study reported that a blinking LED gave positive impressions to people [20]. It was also revealed that the illusory nodding has the effect regardless of the instruction about the blinking pattern. These results imply that robot avatars with human-like appearance should express non-verbal information, including facial expressions and gestures, as humans do because it is intuitively understandable. This corresponds to the fact that humans anticipate a robot's ability based on its appearance [21, 22]. Our proposed method has the potential to achieve human-like gestures on portable robot avatars without any actuators.

It is inferred that the illusory motions do not have the same effect as actual ones, though we have not compared the two. As described above, it is hard to implement a number of actuators in the small body. For example, Tsumaki *et al.* [23] have developed a cell phone-size humanoid robot, but its servomotors are located outside the body and therefore the portability is decreased. The proposed method to induce the illusory motion using LEDs will be useful for improving tele-communication while avoiding the technical and cost problems of implementing actuators inside the small robot body.

We think the proposed method is applicable to different devices. The method enables us to cheaply implement a capability to express motions on, for example, human-like figures. For example, if we develop a human-like-shaped cell phone holder with our technology, users can easily have a humanoid robotic avatar using their cell phones and sense the presence of a partner in cell phone communication. Furthermore, our technology is useful for humanoid toy robots since it can make for rich interaction with users by cheap devices.

As described above, existing studies have shown that subtle expressions of face and body are important in human-robot communication [8, 9, 10]. Our results revealed that subtle expressions are also important in communication through a tele-operated robot. This suggests that the capability to express subtle motions on a robotic avatar should be carefully designed so as to foster smooth tele-communication.

The results of the grumbling experiment showed that the illusory nodding gives a better impression on not only empathy (Q6) but funniness (Q3) and friendliness (Q4). This paper has tested only a situation where participants grumble; however, it is expected that the effect on funniness and friendliness would improve tele-communication in other situations. In particular, the strong effect on empathy would support tele-communication where back-channel feedback frequently appears.

It should be pointed out that the participants needed instruction and about two minutes to perceive head-nodding motions in our experiment. One might consider this as a crucial problem for practical use. However, many participants reported that they could perceive the illusory motion easily once they had perceived it the first time. Therefore, that is not a problem for practical use because illusory motion is always recognizable for users after short training.

Nevertheless, a well-designed structure should be explored so that people can strongly perceive illusory motions without any instruction because long instruction time is needed as the number of illusory motions increases. The research on optical illusions might help us build a design principle for illusory motion of human gestures. Another solution might be to integrate other sensory information. For example, vibrations synchronized with illusory head-nodding motions might improve the perception of head nodding.

Our proposed method should also be applicable to other gestures such as shaking the head or hands, even though we focused on a head-nodding motion here. For example, we now think that it is possible to induce an illusion of head-shaking motion by implementing a change of shadow on the sides of Elfoid's nose. Implementation of other gestures remains as challenging future work.

7. **Conclusion.** We proposed a method that enables users to convey nonverbal information, especially their gestures, through a portable robot avatar based on illusory motion. We achieved the illusion of head nodding with blinking lights for a human-like mobile phone called Elfoid. The comparison between the illusions of head nodding and biological motions presented with LEDs showed that illusions allowed people to perceive head nodding motions more naturally and more quickly. We also tested whether the illusory motion of head nodding provided more positive effects than just blinking lights. The results of the experiment where participants grumbled to Elfoid showed that grumbling with illusory head nodding eased the participants' frustration. Our approach is noiseless and has low energy requirements, while servomotors consume more energy and make noise, which might disturb smooth communication. We hope this approach provides a new idea for achieving a portable robot avatar that allows us to feel the presence of a person who is communicating through it.

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