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Blinking Light Patterns as Artificial Subtle Expressions in Human-Robot Speech Interaction

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***Abstract*— Users' impressions of blinking light expressions used as artificial subtle expressions have been investigated. In a preliminary experiment, thirteen blinking patterns were used for investigating participants' impressions of their agreeableness. The highest and lowest valued blinking patterns were identified and used for a speech interaction experiment. In this experiment, 52 participants tried to reserve hotel rooms with a spoken dialogue system coupled with an interface robot using a blinking light expression. A sine wave, a random wave, a rectangular wave, and a no-blinking condition were used as artificial subtle expressions to express a robot's internal state of "processing" or "recognizing". The results of a questionnaire showed the conditions did not significantly differ in terms of agreeableness, but the sine wave and the rectangular wave were evaluated as "more useful" than the no-blinking condition. Results of factor analyses suggested that the rectangular wave provides a comfortable impression of the dialogue.**

I. INTRODUCTION

The research area of human robot/agent interaction deals with smooth communications between inventions and humans. Inventions that can communicate with people can improve our daily life and business processes. Some researchers have tried to develop robots and agents that can behave in a human-like manner [1], [2]. Specifically, some researchers have focused on subtle changes in inventions' behavior that is similar to changes in humans' behavior. People usually communicate with each other verbally, but nonverbal information, such as facial expressions, gaze directions, and gestures, also plays an important role [3]. People can easily understand others' internal states from such nonverbal information [4]. Even subtle changes in nonverbal information influence human communications. Such expressions are called subtle expressions [5]. Ward [6] reported that the subtle inflections of pitch information in speech reflect one's emotional states even when contradicted by the literal meanings of the words spoken. Cowell & Ayesh [7] and Song et al. [8] have tried to recognize subtle facial expressions because people do not always make clear facial expressions in real situations.

On the basis of such subtle changes in these social signals, some researchers have tried to implement humanoid robots and life-like agents for smooth communication with subtle expressions. Bartneck & Reichenbach [9] investigated the effect of the geometrical intensity of a synthetic facial expression for developing synthetic characters. Sugiyama et al. [10] created a humanoid robot that can slightly change its behaviors on the basis of recognition of its situation. Kipp & Gebhard [11] developed a dexterous avatar agent that can slightly change its facial expression in accordance with the user's gaze direction. However, implementing subtle expressions requires many joints and complicated control systems for robots and life-like agents, making implementation very expensive.

We found that simple expressions from artificial agents, like a blinking LED or beeping sounds, played a similar role to subtle expressions made by humans. For example, smooth turn taking was achieved in human-robot speech interaction by a robot conveying an internal state of recognizing the user's utterances with a small blinking LED [12], [13]. An agent communicated its attitude to users by making inflected beeping sounds [14]. A robot communicated confidence levels of its advice to users by adding inflected beeping sounds [15], [16]. On the basis of the results of these studies, we proposed "artificial subtle expressions (ASEs)" as intuitive notification methodology for describing artificial agents' internal states to users.

The advantages of ASEs are low cost implementation and intuitive notification without previous knowledge. Moreover, ASEs made by a blinking LED gave users better impressions of dialogue with a robot and the robot itself [13], [12]. However, how expression patterns affect user impressions

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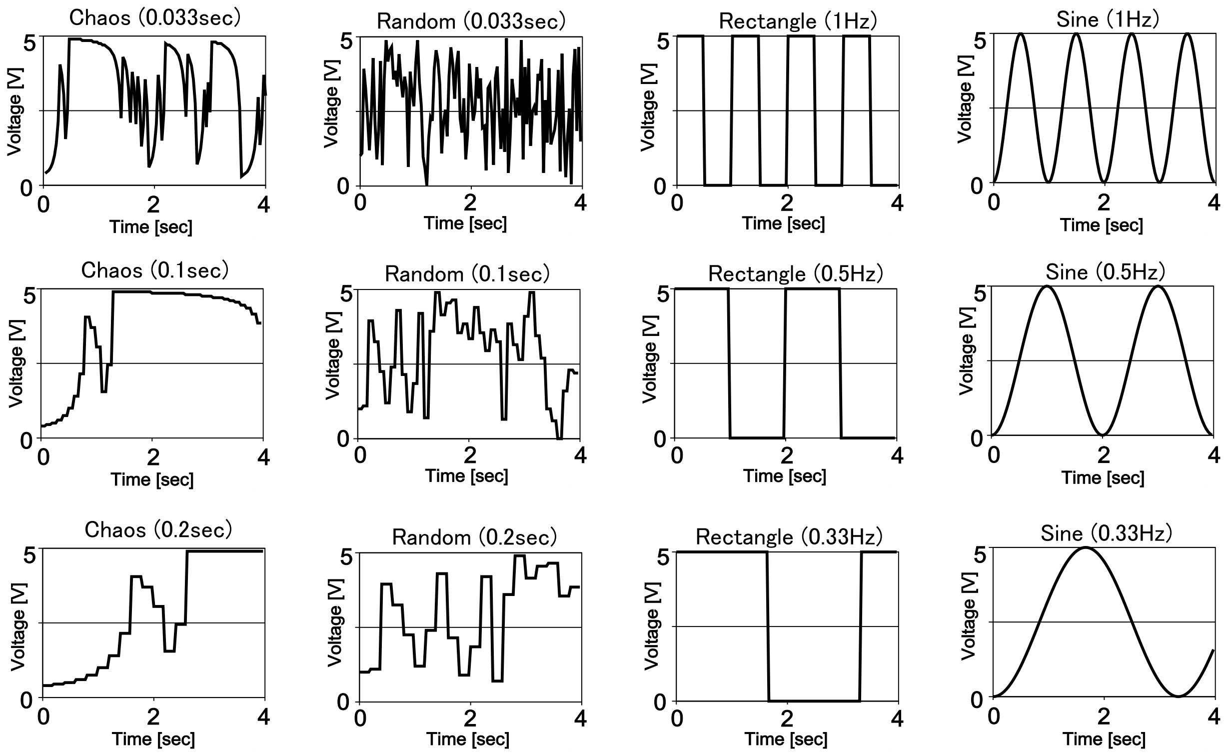

Fig. 1. LED blinking patterns

is not clear. In this study, we focused on ASEs made by a blinking LED and investigated the relationship between LED blinking patterns and user impressions.

II. Experiment of Blinking Pattern Evaluation

We conducted an evaluation experiment for users' impressions of LED blinking patterns without speech interaction.

A. Method

We investigated the relationship between user impressions and blinking patterns by using a small LED. The patterns we used were thirteen waves: three intermittent chaos waves, three random waves, three rectangular waves, three sine waves, and always-on. Figure 1 shows twelve of the patterns used in our experiment (always-on is left out). The vertical axes are proportional to the voltages input to the LED. The LED was charged from 0V to 5V with a 10 KΩ register connected in series. Intermittent chaos waves and random waves have parameters of update time. For example, an intermittent chaos wave with a 0.033-sec update time is described as "Chaos (0.033 sec)" in the figure. Rectangular waves and sine waves have parameters of frequency. For example, a rectangular wave with 0.5-Hz frequency is described as "Rectangular (0.5 Hz)" in the figure.

Figure 2 shows the experimental environment of the investigation. A red LED 4 mm in diameter was fixed in the center of a black board. Participants' visual fields were restricted with the black boards so that they could concentrate on the LED blinking. They were requested to give their impressions of LED patterns by pushing an evaluation button. Luminance of the room was 187 LUX near the LED.

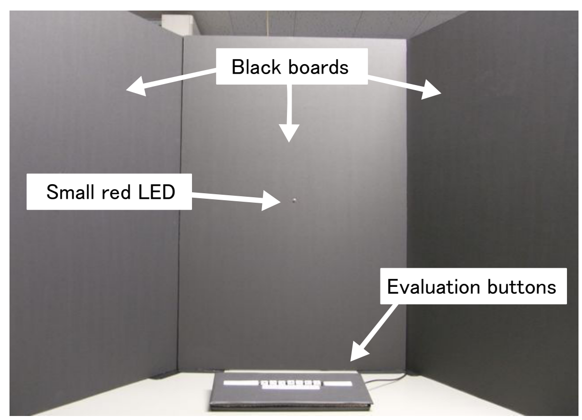

Fig. 2. Experimental environment

Participants selected a number from 1 to 7 on the basis of seven-level Likert items after a LED pattern was shown. Number 1 meant "bad feeling", and 7 meant "good feeling". Blinking time was 4 sec in each condition. Before an LED pattern appeared, a short notification sound was played. LED patterns were shown in a random order, and each pattern was shown three times from the random set; 39 LED blinking patterns were provided for a participant. The participants were 16 males, mean age 23.5 (S.D. = 1.7).

TABLE II

RATED ITEMS OF IMPRESSION OF LED AND RESERVATION SYSTEM

item	sine (0.5 Hz)		rectangle (15 Hz)		random (0.033 sec)		no-blinking	
	Mean	S.D	Mean	S.D.	Mean	S.D	Mean	S.D.
good feeling–bad feeling (for the LED)	4.58	0.79	4.31	1.18	4.23	0.60	—	—
useful–useless (for the reservation system)	4.69	1.11	4.77	1.54	3.62	1.45	3.00	1.73
hope to use–hope not to use (for the reservation system)	3.69	1.49	4.46	1.85	3.92	1.71	3.23	1.92
the time the robot took to began to reply to them	3.23	1.75	2.92	1.31	2.77	1.63	4.35	2.83

TABLE I

RATED VALUES OF LED BLINKING PATTERNS

Blinking patterns	Mean	S.D
Sine (0.33Hz)	5.04	1.35
Sine (0.5Hz)	5.65	0.77
Sine (1Hz)	4.73	0.98
Rectangle (0.33Hz)	4.17	0.78
Rectangle (0.5Hz)	4.63	0.91
Rectangle (1Hz)	4.40	1.17
Chaos (0.033sec)	2.15	0.95
Chaos (0.1sec)	3.00	0.61
Chaos (0.2sec)	3.23	0.77
Random (0.033sec)	1.88	1.42
Random (0.1sec)	1.96	0.69
Random (0.2sec)	2.63	0.88
Always-On	4.17	1.46

Fig. 3. Experimental environment and robot with embedded LED

B. Experimental Results

Table I shows the results of LED pattern evaluations. The higher the value, the better the feeling. The sine wave (0.5 Hz) had the highest value, and the random wave (0.033 sec) had the lowest value.

III. EXPERIMENT OF HUMAN-ROBOT SPEECH INTERACTION

On the basis of results of the Blinking pattern evaluations, we investigated the effects on the user impressions in human-robot speech interaction.

A. Method

We conducted a speech interaction experiment between a robot with a small LED and the participants. Participants were requested to reserve hotel rooms by talking with the robot. The spoken dialogue system and the robot (Wow Wee RS-Media) were the same as those in our previous work [17]. The purpose of the experiment was to investigate how LED blinking patterns affect the user impressions of the dialogue and the robot.

A red LED 4 mm in diameter was fixed in the center of the robot's chest, as shown in Fig. 3. When the spoken dialogue system detects an audio signal, the LED on the robot begins to blink. The blinking stopped when the robot began to answer verbally. The role of the LED blinking was to show participants that the robot detects their voices and processes. This prevents utterance collisions between a participant and the robot. Our previous work showed that the LED blinking was able to prevent utterance collisions [13], [12].

The blinking patterns we used in this experiment were a random wave (0.033 sec), a sin wave (0.5 Hz), a rectangular wave (15 Hz), and no-blinking. The random wave (0.033 sec) had the lowest value and the sine wave (0.5 Hz) had the highest value in the experiment of blinking pattern evaluation as described above. The pattern of the rectangular wave (15 Hz) was used in our previous works [13], [12], [17]. The blinking time was a participant's utterance time plus 4 seconds. The robot began to utter 3.6 seconds after it stopped an audio signal from a participant because there was a processing delay for 0.4 seconds.

Participants were requested to sit on a chair and to reserve hotel rooms by talking with the robot placed in front of them. They put on a head phone so that the spoken dialogue system could easily distinguish their voices from the robot's voice and performed five hotel reservation tasks. In each task, they tried to reserve one to three rooms. Reservation procedures such as reserving multiple rooms at a time or reserving a room a few different times were not provided. After the five trials, they answered a questionnaire of their impressions of the LED blinking and the reservation system, the dialogue, and the robot. Participants were 26 males and 26 females. Their mean age was 30.1 (S.D.=9.4), and ages ranged from 19 to 50 years old. The luminance of the room was 475 LUX, and the 1 KΩ register was connected to the LED in series to adjust the luminance of the LED.

B. Experimental results

1) Impressions of the LED blinking and the reservation system: Participants evaluated items to be "good feeling–bad feeling" for the LED, "useful–useless" for the reservation

TABLE III

RATED ADJECTIVE PAIRS FOR IMPRESSION OF DIALOGUE AND FACTOR LOADING MATRIX OF FACTOR ANALYSIS (PROMAX ROTATION, MAXIMUM LIKELIHOOD METHOD)

Adjective pairs		Sine (0.5 Hz)		Rectangle (15Hz)		Random (0.033 sec)		No-blinking		Factors				
Positive	Negative	Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D	1	2	3	4	5
exciting	dull	4.15	1.63	5.15	1.57	4.46	1.76	3.92	1.61	0.95	-0.21	-0.02	0.07	-0.03
interesting	boring	5.54	0.78	5.69	0.95	5.31	1.44	4.77	1.59	0.85	-0.08	-0.05	-0.01	0.03
pleasant	unpleasant	4.15	1.21	4.77	0.93	4.15	1.07	3.92	1.19	0.60	0.28	0.02	-0.03	-0.16
comprehensible	incomprehensible	4.15	1.41	4.69	1.44	3.85	1.63	4.00	1.87	0.54	-0.01	0.28	-0.18	0.08
calm	agitated	3.69	1.18	4.31	1.49	4.08	1.12	3.69	1.49	-0.13	0.95	0.00	-0.01	-0.07
likable	dislikable	3.92	0.86	4.62	1.39	4.00	1.29	3.54	1.90	0.32	0.67	-0.09	0.08	-0.01
lively	lifeless	3.15	0.80	3.38	1.12	3.23	0.73	3.15	1.34	-0.05	0.56	0.38	-0.10	-0.02
good	poor	3.69	0.85	4.31	1.38	3.69	1.03	3.69	1.70	0.18	0.55	0.11	0.02	0.23
leisurely	hurried	4.77	1.30	4.62	1.04	5.31	0.95	4.15	1.46	-0.16	0.49	0.27	0.03	-0.09
soothing	annoying	3.69	1.49	4.85	0.99	3.62	1.19	3.23	1.42	0.10	0.20	0.87	-0.05	-0.21
polite	impolite	4.15	1.14	5.31	0.85	4.23	0.93	4.38	1.19	0.07	-0.21	0.62	0.29	0.05
easy	uneasy	3.38	1.12	3.85	1.46	3.08	0.95	2.92	1.66	-0.05	0.16	0.61	0.09	0.13
smooth	rough	3.31	1.25	4.15	1.52	2.77	1.42	2.69	1.65	-0.04	0.25	0.57	-0.08	0.13
warm	cold	3.00	1.22	4.23	1.24	3.54	1.39	3.23	1.36	-0.04	-0.01	0.04	1.04	-0.11
informal	formal	3.15	1.14	3.92	1.66	3.54	1.39	2.77	1.59	0.05	0.27	0.16	0.46	0.19
relaxed	tense	3.31	0.63	3.46	1.27	3.23	0.73	3.69	1.65	0.01	0.04	-0.17	-0.06	0.88
casual	serious	3.38	0.96	4.00	1.35	3.31	0.85	3.69	1.44	-0.09	-0.19	0.32	-0.06	0.52

system, and "hope to use–hope not to use" for the system. They also answered the time the robot took to began to reply to them. Table II shows the results of the questionnaire. Participants evaluated items on a seven-level Likert scale (1: strong agreement with a negative adjective, 4: neutral, 7: strong agreement with a positive adjective). We performed ANOVA for each item, which showed significant differences in the "useful–useless" ($F_{3,48} = 4.428, p < .01$). The items were compared by the Tukey HSD method multiple times, which showed significant differences between the sine wave and the no-blinking ($p = .026$) and between the rectangular wave and no-blinking ($p = .018$).

2) Impressions of the dialogue: Table III shows the results of participants' ratings for the dialogue. The adjective pairs in the table are translated from Japanese words that we used in the questionnaire. The ratings are based on a seven-level Likert scale (1: strong agreement with a negative adjective, 4: neutral, 7: strong agreement with a positive adjective).

We performed factor analysis (promax rotation and maximum likelihood method) for the impression of the dialogue. Five factors were extracted from evaluated items by a scree plot. In the factor analysis process, we excluded the low-value-factor loading item "light–dark". We interpreted the factors on the basis of our previous work [18]. The first factor was named the *excitement* factor, the second the *calmness* factor, the third the *comfort* factor, the fourth the *relaxation* factor, and the fifth the *warmness* factor. Table IV shows the correlation between factors.

We calculated the factor scores by using a regression method. Table V shows the factor scores and the results of ANOVAs for the impression of the dialogue. The ANOVAs found a significant difference in the third factor (comfort). Multiple comparisons with the Tukey HSD method between conditions found differences between rectangle and no-blinking ($p = .027$) and between rectangle and random ($p = .078$). This suggests that the rectangular wave provides a comfortable impression for users because the scores of the rectangular wave are higher than those of the no-blinking condition and random wave.

TABLE IV

CORRELATION BETWEEN FACTORS OF IMPRESSION OF THE DIALOGUE

Factors	1	2	3	4	5
1	1.00	0.60	0.40	0.42	0.28
2	0.60	1.00	0.66	0.52	0.49
3	0.40	0.66	1.00	0.50	0.38
4	0.42	0.52	0.50	1.00	0.43
5	0.28	0.49	0.38	0.43	1.00

TABLE V

FACTOR SCORES OF THE IMPRESSION ON THE DIALOGUE

Factor	Blinking pattern	Mean	S.D	$F_{3,48}$	p
1. Excitement	sine	-0.061	0.725	1.880	0.146
	rectangle	0.477	0.772		
	random	-0.053	0.906		
	no-blinking	-0.363	1.195		
2. Calmness	sine	-0.093	0.650	0.979	0.410
	rectangle	0.346	0.980		
	random	0.027	0.809		
	no-blinking	-0.279	1.278		
3. Comfort	sine	-0.115	0.951	3.372	0.026
	rectangle	0.674	0.801		
	random	-0.201	0.796		
	no-blinking	-0.358	1.043		
4. Warmness	sine	-0.362	0.918	2.072	0.116
	rectangle	0.532	0.937		
	random	0.016	1.012		
	no-blinking	-0.186	1.003		
5. Relaxation	sine	-0.080	0.621	0.297	0.827
	rectangle	0.141	1.142		
	random	-0.153	0.389		
	no-blinking	0.093	1.249		

3) Impression on the robot: Table VI shows the results of participants' ratings for the robot. The adjective pairs in the table are also translated from Japanese. The ratings are based on a seven-level Likert scale as well as the ratings for the dialogue.

We performed factor analysis (promax rotation and maximum likelihood method) for the impressions of the robot. Four factors were extracted from evaluated items by a scree plot. In the process of the factor analysis, we excluded the

TABLE VI

RATED ADJECTIVE PAIRS FOR IMPRESSIONS OF THE ROBOT AND FACTOR LOADING MATRIX OF FACTOR ANALYSIS (PROMAX ROTATION, MAXIMUM LIKELIHOOD METHOD)

Adjective pairs		Sine (0.5 Hz)		Rectangle (15 Hz)		Random (0.033 sec)		No-blinking		Factors			
Positive	Negative	Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D	1	2	3	4
excited	cool	3.46	1.20	4.00	0.82	3.54	1.05	3.85	1.21	0.79	-0.10	-0.12	0.10
polite	impolite	4.15	0.69	4.85	1.14	4.00	0.71	4.85	1.52	0.78	-0.30	0.42	0.27
friendly	unfriendly	4.08	1.38	4.38	1.33	3.77	1.09	4.00	1.29	0.73	0.19	0.01	0.01
innocent	wicked	4.31	0.63	4.62	0.77	4.15	0.80	4.15	0.90	0.68	-0.01	0.09	0.00
pretty	ugly	4.31	1.03	4.54	0.78	4.08	0.76	4.08	0.86	0.67	-0.12	0.11	-0.19
accessible	inaccessible	3.54	0.88	3.92	1.32	3.31	0.95	3.62	1.56	0.61	0.25	0.02	-0.25
sociable	unsociable	3.38	0.96	4.38	1.26	4.00	1.22	3.54	1.27	0.50	0.20	-0.09	-0.12
aggressive	defensive	4.31	0.63	5.00	0.82	3.92	0.76	3.85	1.34	0.49	0.37	-0.24	0.12
active	inactive	3.92	0.76	4.85	0.69	4.31	0.85	3.62	1.19	0.48	0.40	-0.20	0.18
broad-minded	narrow-minded	3.92	0.76	4.38	0.77	4.31	0.95	4.15	0.99	0.48	0.15	0.19	-0.45
careful	careless	5.08	0.76	4.69	0.75	4.85	0.99	4.85	1.21	-0.39	0.07	0.38	0.32
patient	irritable	4.69	0.85	4.31	0.95	4.92	1.50	4.62	1.12	-0.07	0.80	0.22	-0.17
confident	unconfident	4.69	0.95	4.92	0.86	4.85	1.46	4.69	1.11	-0.09	0.66	0.20	0.23
kind	unkind	4.08	0.95	3.92	1.00	4.15	0.69	4.31	0.95	0.17	0.36	0.12	0.01
modest	boastful	4.31	0.85	4.31	0.95	4.38	0.65	5.00	1.00	-0.28	0.29	0.79	0.11
respectful	disrespectful	4.31	0.85	4.69	1.25	4.54	0.97	4.85	1.63	0.36	-0.09	0.76	-0.20
discreet	indiscreet	4.15	0.80	4.92	1.75	4.62	0.96	4.92	1.04	0.07	0.29	0.58	0.14
impressive	unimpressive	5.23	1.09	6.00	1.00	4.62	1.26	5.38	1.04	0.21	0.25	0.02	0.59
serious	frivolous	5.00	1.00	5.00	1.15	4.31	0.85	5.38	1.45	-0.18	-0.03	0.11	0.48

TABLE VII

CORRELATION BETWEEN FACTORS OF IMPRESSIONS OF THE ROBOT

Factors	1	2	3	4
1	1.00	0.34	0.01	-0.19
2	0.34	1.00	-0.12	0.18
3	0.01	-0.12	1.00	0.08
4	-0.19	0.18	0.08	1.00

TABLE VIII

FACTOR SCORES OF THE IMPRESSION ON THE ROBOT

Factor	Blinking pattern	Mean	S.D	$F_{3,47}$	p
1. Friendliness	sine	-0.169	0.821	1.635	0.194
	rectangle	0.521	0.931		
	random	-0.214	0.631		
	no-blinking	-0.098	1.268		
2. Credibility	sine	-0.054	0.590	0.505	0.681
	rectangle	0.216	0.780		
	random	0.074	1.142		
	no-blinking	-0.220	1.068		
3. Humility	sine	-0.205	0.495	1.879	0.146
	rectangle	-0.227	0.947		
	random	-0.094	0.556		
	no-blinking	0.509	1.364		
4. Virility	sine	0.007	0.846	1.469	0.235
	rectangle	0.266	0.645		
	random	-0.398	1.050		
	no-blinking	0.147	0.796		

low-value-factor loading item "responsible–irresponsible". We also interpreted the factors on the basis of our previous work. The first factor was named the *friendliness* factor, the second the *credibility* factor, the third the *humility* factor, and the fourth the *virility* factor. Table VII shows the correlation between factors, none of which were high-value factors.

We also calculated the factor scores by using a regression method. Table VIII shows the factor scores and the results of ANOVAs for the impressions of the robot. The ANOVAs found no significant difference between blinking patterns. This suggests that the LED blinking patterns do not significantly affect the impressions of the robot.

IV. DISCUSSION

The results of the speech interaction experiment suggest that the rectangular wave provides comfortable impressions in a dialogue. This is possibly due to the reliability of the speech interaction. Participants might consider their words were certainly conveyed to the robot. A 15-Hz rectangular wave is probably effective for users to have this impression in a dialogue. This finding is useful to make users' feel more comfortable in speech interaction with an invention because a simple blinking LED can be easily attached to it.

The characteristics of the 15-Hz rectangular wave were a fast switching blink, a widely changed luminance, and a constant frequency. These might provide people with a feeling that their words are being reliably conveyed because in previous work [18] with rectangular LED blinking people were also given a similar impression during hotel reservation tasks.

The experimental results of the speech interaction also suggest that LED blinking patterns do not significantly affect the impression of the robot. If the speech interaction in hotel reservation tasks required more attention than the robot itself, it is no wonder that the LED blinking had little effect on the robot impression. A previous work with a last-and-first task [12] also used a rectangular wave for LED blinking, and its experimental results showed the LED blinking provided a sincere impression of the robot. The sincere impression of the robot and the comfortable impression of the dialogue seem to be related. This study used hotel reservation tasks that were more complicated than last-and-first tasks. Such a difference should make participants' interests shift to the dialogue from the robot itself because the dialogue is directly connected to their purpose in the given tasks.

The experimental results of the blinking pattern evaluation showed that the sine wave (0.5 Hz) had the highest value and the random wave (0.033 sec) had the lowest value. In contrast, the evaluation values of the sine wave and the random wave in the experiment of the speech interaction were almost the same. These results were likely caused by the difference in tasks. Hotel reservation tasks in the speech interaction experiment might have required more attention than observing the LED in the pattern evaluation experiment because the participants were required to reserve hotel rooms. Therefore, they would not have been as conscious of their impressions of the LED and so gave them almost the same ratings. How tasks affect impressions needs to be analyzed.

In our previous works, we used the 15-Hz rectangular wave for LED blinking. The effects of blinking patterns were investigated in this study, and the results suggested that the rectangular wave was effective for giving participants better impressions of the dialogue. Such a wave form of LED blinking will be effective in tasks requiring speech interaction. However, effectiveness of the LED blinking will be potentially affected by contexts because it is an abstract expression and can be interpreted differently by users. The meanings conveyed by the LED blinking in different contexts need to be investigated.

V. Conclusion

In this paper, we described the investigations into users' impression given by blinking light expressions used as artificial subtle expressions (ASEs). In the preliminary experiment of blinking pattern evaluation, thirteen blinking patterns were used for investigating participants' impressions of the agreeableness (good feeling-bad feeling) of the artificial subtle expressions. The highest valued blinking pattern was the sine wave (0.5 Hz), and the lowest valued one was the random wave (0.033 sec). In the speech interaction experiment, 52 participants engaged in hotel room reservation tasks with a spoken dialogue system coupled with an interface robot using a blinking light expression. A sine wave (0.5 Hz), random wave (0.033 sec), rectangular wave (15 Hz), and no-blinking condition were used as artificial subtle expressions to express the robot's internal states of "processing" or "recognizing". The results of a questionnaire showed that the blinking patterns and the sine wave did not significantly differ in terms of agreeableness, and the rectangular wave was evaluated as more useful than the no-blinking condition. The results of the factor analyses suggest that the rectangular wave gives participants a comfortable impression of the dialogue.

We focused on ASEs made by a blinking LED and investigated the relationship between blinking patterns of a LED and user impressions. The advantages of ASEs are low cost implementation and intuitive notification without previous knowledge. Our findings in this study are useful to improve users' feeling in speech interaction with an invention because a simple blinking LED can be easily attached to it. We will address an investigation on conveying meanings of the LED blinking in different contexts to resolve the remaining issues.

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