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Perception of Emotional Expression of Mobile Humanoid Robot Using Gait-Induced Upper Body Motion

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ABSTRACT Humans can express their emotions with not only facial expressions or gestures but also whole-body motion, even while walking, which are essential for our interpersonal relationships and our interaction with others. Communication with people is also considered an important task for robots, however emotional expressions by wheeled mobile humanoid robots when moving has not been well studied. In this paper, we implemented emotional human-like gait-induced upper body motion in a mobile android *ibuki*. We hypothesize that the gait-induced upper body motion with vertical oscillation enhances the human perception of a mobile robot's emotional expressions. *ibuki* is a mobile robot, which has a vertical oscillation mechanism, which enables the robot to move its body with a human gait-induced upper body motion. We ran two experiments in which participants watched videos of *ibuki* moving in a room expressing different emotions - anger, happiness, and sadness –, before answering how they perceived the emotion and their respective confidence level in their answer. Our results show that for motions with vertical oscillation, recognition rates were: 56.0 % for anger, 77.7 % for happiness, and 97.0 % for sadness. We also found that the recognition rate and confidence level of motions expressing happiness with vertical oscillation were higher. Our results play an important role in opening up avenues for more natural ways of interaction between humans and robots. For example, by approaching humans closer while expressing emotions, a robot can naturally provide an opportunity to get started conversation with them.

INDEX TERMS Androids, humanoid robots, mobile robots, human-robot interaction.

I. INTRODUCTION

Humans express their intentions and emotions with facial expressions and gestures [1], even while walking with various gaits (a person's manner of walking). These emotional expressions are thought to contribute significantly to building interpersonal relationships and our interactions with others [2]. Some researchers have previously investigated human intentions expressed through human gait. Frohnwieser *et al.* showed that people gave different allowances of personal space according to differences in walking behavior [3]. Park *et al.* found that human body posture indicated their destination and direction [4].

Human gaits are emotionally expressive, and people may walk in various ways depending on their emotions. People can perceive the emotions from others through their gait. For example, when you see your friend walking with a perceived happy gait, you might ask, "Did something good happen?".

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When you perceive a friend's step as mournful, you might put a comforting hand on her or his shoulder. Many studies have been conducted to investigate the characteristics of emotional gaits [5]–[8]. Karg *et al.* reported that various parts of the upper body, such as the arms and head, express internal states during walking [9]. Michalak *et al.* measured the motions of humans in sad and happy moods, and found that there is a significant difference in vertical upper body movement when expressing these emotions [10].

For human-robot interaction (HRI) in real-world environments, considering the expression of various gaits, including *emotional* gaits, is valuable to build deep human-robot relationships. In the field of bipedal robots, some research has been conducted to realize human-like gaits [11] and further emotional gaits [12], [13]. Destephe *et al.* created emotional gait, which expressed happiness, sadness, and neutral emotion, by using the bipedal humanoid Wabian-2R, and investigated the human perceptions and psychological influences by using a questionnaire survey [12]. Izui *et al.* reported the characteristics of emotional expression based on the human walking motion. They implemented those characteristics on the small humanoid Nao as emotional gaits and investigated the recognition rates of the person who saw gait motions expressing emotions [13].

Since wheel-based motion has moving efficiency and stability on flat ground, it has been actively used for robots operating in real-world environments. However, while some of these mobile robots have a human-like upper body, in most cases, their human-like movements, such as gestures, are realized without wheel-based motion [14]–[16].

In research of a robot's expression with wheel-based motion, Nakata *et al.* investigated a mobile robot's joint angle and velocity parameters based on the Laban theory. They theorized that those parameters are useful in allowing a wheeled robot to express emotions [17]. Granados and Kosuge *et al.* have developed a wheeled dance-teaching robot that has a waist joint that uses a parallel-link mechanism to allow dancing with a human partner. Furthermore, other studies have examined the emotional expression by wheeled humanoid robots [18]. Zecca *et al.* created expressions of emotions based on human data by using a wheeled humanoid Habian. They reported recognition rates for emotional body expressions performed by the standing robot [19]. Tsiourti *et al.* created emotion expressions through five modalities (face, head, body, voice, locomotion) by using wheeled humanoids and confirmed that even a simple locomotion modality can convey a robot's emotion [20].

However, to our best knowledge, the human perception of emotion expressions of wheeled mobile humanoid robots while its moving has not been studied yet. If the robot could express its intentions and emotions while moving, humans could act appropriately according to that information. As a result, robots and humans could achieve orderly interactions by being able to predict and understand each other's behavior in various situations.

To realize an android that can be such a partner to humans in society, we have developed a wheeled mobile android, *ibuki* [21], who is equipped with a mechanism that replicates a human-like upper body motion, which is induced by gait, while moving. The android, which has a human-like appearance and multiple degrees of freedom, is expected to perform natural interactions using rich human-like body expressions. For this purpose, *ibuki* has a vertical-oscillation mechanism (VOM) which creates motion similar to that of the human upper body while moving. With the combination of motions through the VOM and the joints on the upper body, *ibuki* generates human gait-induced upper body motion while moving despite being wheel driven.

In this paper, we implemented in *ibuki* three types of gait-induced upper body motions to express anger, happiness, and sadness. Previous human studies supported the importance of vertical upper body movement for expressions of emotions [10], [22], [23]. Our hypothesis is that gait-induced upper body motion with vertical oscillation enhances human perception of a mobile robot's emotional expressions. Thus, we confirmed whether the presence of *ibuki*'s motion with vertical oscillation enhances the participants' perception in Experiment 1 and whether the congruence of *ibuki*'s motion with vertical oscillation enhances the participants' perception in Experiment 2. As we aimed to implement clearly recognizable expressions of emotions, *ibuki*'s emotional gait-induced upper body motions with and without vertical oscillation were evaluated by participants using two indexes: 1) correct classification of the expressed emotion, and 2) a high level of confidence in their chosen classification. This paper highlights the following key points:

1) We measured three human gait motions (attributed to the emotions anger, happiness, and sadness) and implemented these findings as upper body motions in a mobile android robot. These motions include a vertical movement of the center of mass, induced when humans walk. In this study, our wheeled mobile android is equipped with a VOM, oscillating its body vertically.
2) We found that the emotional expression of happiness using the VOM was well perceived by humans (with higher recognition rates and higher confidence levels) and better than without vertical oscillation conditions.
3) We found that the incongruent (switched vertical motions between different emotions) application of anger/happiness vertical oscillation decreased the recognition rate of happiness/anger emotional expression (significance/marginally significant, respectively). In addition, the emotional expression of happiness using the vertical oscillation for anger decreased the confidence levels; however, the emotional expression of anger using the vertical oscillation for happiness increased the confidence levels.

II. METHODS

In this section, we describe the implementation of gait-induced upper body motion in our mobile humanoid robot using a vertical-oscillation-mechanism (VOM). The movement of this mechanism was based on human center-of-mass (CoM) motion. We also describe how we applied human-motion data to enable *ibuki* to move with emotional expressions.

A. CHILD ANDROID IBUKI

The child-like mobile android (Fig. 1) that we developed called *ibuki*, is 120 cm tall and is comprised of two parts, a mobility unit (lower part) and the upper body, which is designed based on the dimensions of a 10-year-old Japanese boy. The face and hands are covered with silicone skin to have a human-like appearance. An electric motor drives each joint, and mobile batteries are used as the power supply. *ibuki* is mainly used for physical human-robot interaction research - i.e. moving in real-world environments. Because of this, there are no additional sensors and devices equipped for this study.

FIGURE 1. Child-like mobile android ***ibuki***.

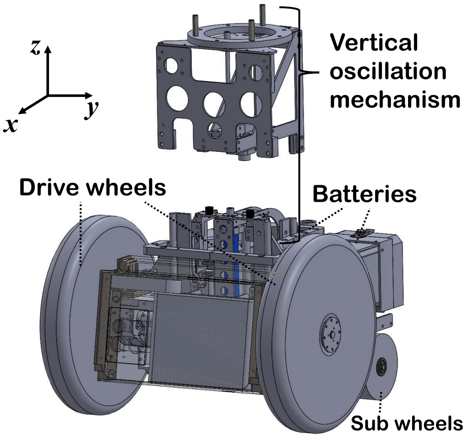


FIGURE 2. Three-dimensional computer-aided design image of the mobility unit.

Fig. 2 shows a three-dimensional computer-aided design (3D CAD) image of *ibuki*'s mobility unit comprised of a wheel unit and the VOM. The wheel unit comprises two driving wheels at the front and two omnidirectional wheels as auxiliary wheels at the rear. The rotation angle of each driving wheel is measured by a magnetic rotary encoder (AEAT-6012, Broadcom).

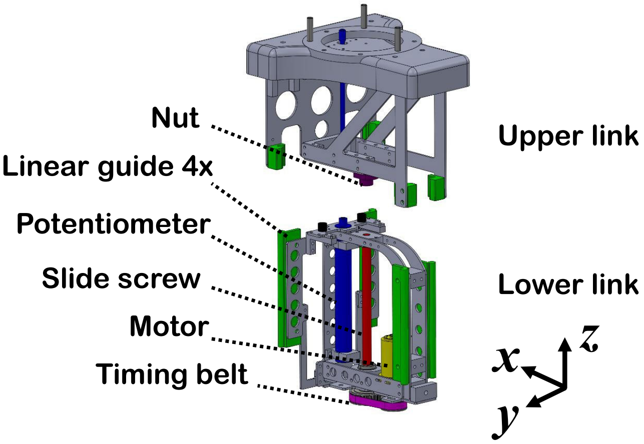


FIGURE 3. Three-dimensional computer-aided design image of vertical-oscillation mechanism.

Fig. 3 shows a 3D CAD image of the VOM. The vertical oscillation is generated by a linear actuator using a motor-driven slide screw. The displacement is measured by a linear potentiometer (LP-150FJ-1K, Midori Precisions).

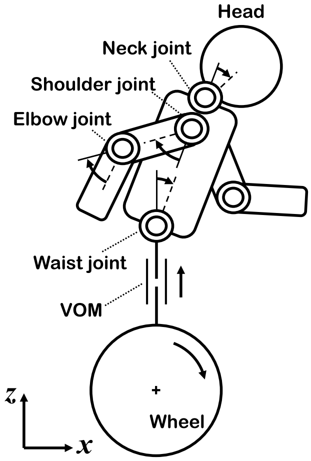


FIGURE 4. ***ibuki***'s joint configuration. Only joints used in our research are shown.

Fig. 4 is a schematic overview of *ibuki*'s joint configuration. Out of 43 joints in the upper body, we used six pitch axis joints (neck, both shoulders, both elbows and waist) in this study. Each joint angle is measured by a potentiometer (SVK3A103AEA01, Murata Manufacturing).

Fig. 5 shows an overview of the control system. The central computer sends reference values to each microcomputer via Ethernet. The angle of each joint is controlled at 100 Hz.

B. GAIT-INDUCED UPPER BODY MOTION GENERATION

When humans walk, all body parts move simultaneously except in particular situations. As the CoM is located near the center of the pelvis, its position is affected by the lower limbs. We modeled the trajectory of the human CoM during walking and controlled the position of the mobile humanoid robot's

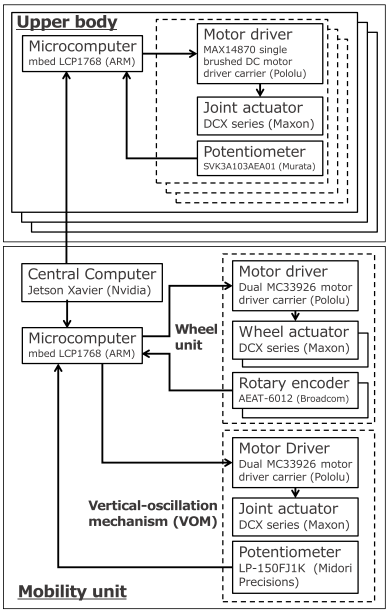


FIGURE 5. System configuration.

apparent-CoM (aCoM) to achieve human gait-induced upper body motion (Fig. 6). The aCoM is essentially the same as the root (null) joint used widely in robot and animation motion generation, but adjusted according to the analogy with characteristics of human walking, which is why we use the term aCoM in this paper.

One gait cycle starts at the heel strike of a foot and continues until the heel strike of the same foot for the next step. Thus, a human moves two steps forward in one gait cycle. In each single support phase, the ankle and knee joints of each support leg flex and then extend, and the pelvis rotates slightly. As a result, the human CoM oscillates twice on the sagittal plane in one gait cycle. The trajectory of the CoM oscillation on the sagittal plane can be modeled as a cosine or cycloid curve (Fig. 6 (A)) [24], [25]. The amplitude is about 40 mm in adult males [26]. Due to the characteristics of the CoM movement, the horizontal moving displacement of the aCoM and the vertical oscillation caused by the gait described above are calculated according to the target gait stride and speed (or frequency). Thus, we can generate the gait-induced upper body motion by controlling wheel angles and VOM displacement based on aCoM (Fig. 6 (B)).

C. IMPLEMENTATION

We chose anger, happiness, and sadness as they are some of the basic human emotional expressions. The purpose of this study is to confirm whether a wheeled android can express emotions by the gait-induced upper body motions while moving. Therefore, we decided to implement emotions that people can express while walking. A previous study has investigated four emotions (anger, happiness, sadness, and fear) and they concluded the perception of fear depends on a specified context [7]. Thus, we decided to exclude fear and used three expressions of emotions: anger, happiness, and sadness in this study.

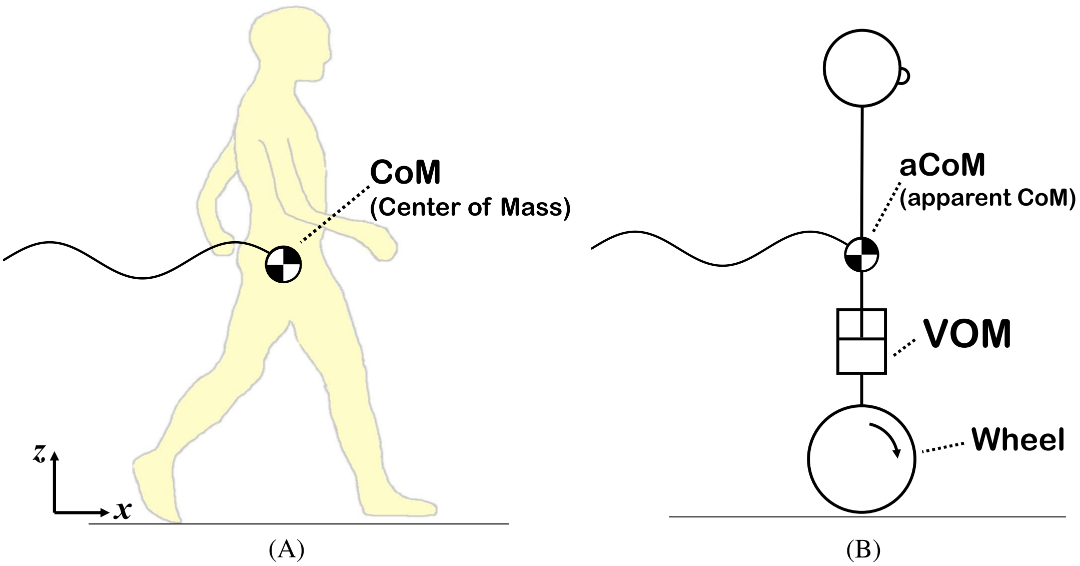
The author filmed himself walking a 5 m distance on a flat floor in our laboratory while expressing these emotions and neutral emotion as a reference. For these expressions, we used [7] as a reference to determine inclination angles of head and torso and walking speeds of the human body. Walking motions were filmed on the sagittal plane of the body for all three emotions, with a camera fixed at 0.9 m in height and 2.6 m away from the middle of the route (filming was repeated three times per emotion).

Joint position time series data was obtained by human pose recognition software Openpose [27]. The sampling rate was 30 Hz and all the data were filtered with a 3 Hz low-pass filter. Reference joint angle values for two gait cycles of the neck, right shoulder, right elbow, and waist in the pitch axis of *ibuki* were calculated from this data. The reference joint angle of the left shoulder $\theta_L(t)$ was calculated by the following equation $\theta_L(t) \;= 2\bar{\theta} - \theta_R(t)$, where $\theta_R(t)$ is the joint angle of the right shoulder and $\bar{\theta}$ is the average angle at all times. The reference joint angle of the right elbow was calculated in the same way. In order to achieve the aCoM trajectory, we obtained the human CoM height $z(t)$ on the waist position. We determined that *ibuki*'s aCoM located at the center of the waist (545 mm height) like in humans. In this case, we could control the height by using the VOM joint displacement $d(t)$. The displacement of VOM $d(t)$ was reduced to 0.71 times by taking the ratio of the height of human and *ibuki*. Due to the limitation of the joint range (maximum was 40 and minimum was -40 mm), we adjusted the average height of a CoM to be $d(t) = 0$. Thus, we calculated the VOM displacement by the following equation: $d(t) \;= 0.71(z(t) \;- \bar{z})$.

Fig. 7 shows comparisons of reference joint values and measured values of three gait-induced upper body motions for each emotion. The upper body is tilted forward for anger and sadness, while in happiness, it is tilted backward. The upper body and neck are tilted forward with a comparatively large angle for sadness. As reported by [10], amplitudes for anger and happiness are larger than that of sadness. The error between the reference and the measured value in Fig. 7 were caused by factors such as the joint friction, dampers installed to reduce unnatural vibrations on the upper body, and the delay due to P-D control for joint angles. Although there was a delay in the entire orbit, we concluded that the difference in waveform between the reference and the measured value was small. Therefore, we conducted the experiments using those motions.

The human walking speed in the traveling direction is not usually constant due to the reaction force on the sole of the foot. However, for a practical and easy integration with other robot systems, the angular velocities of wheels were approximated as a constant speed and we used an average horizontal speed of aCoM except for the neutral emotion.

We filmed *ibuki*'s emotional gait-induced upper body motions by using the motion data above (Fig. 8). The same



(A) (B)

FIGURE 6. Kinematic relationship between (A) human gait and (B) gait-induced upper body motion of mobile humanoid robot equipped with vertical oscillation mechanism.

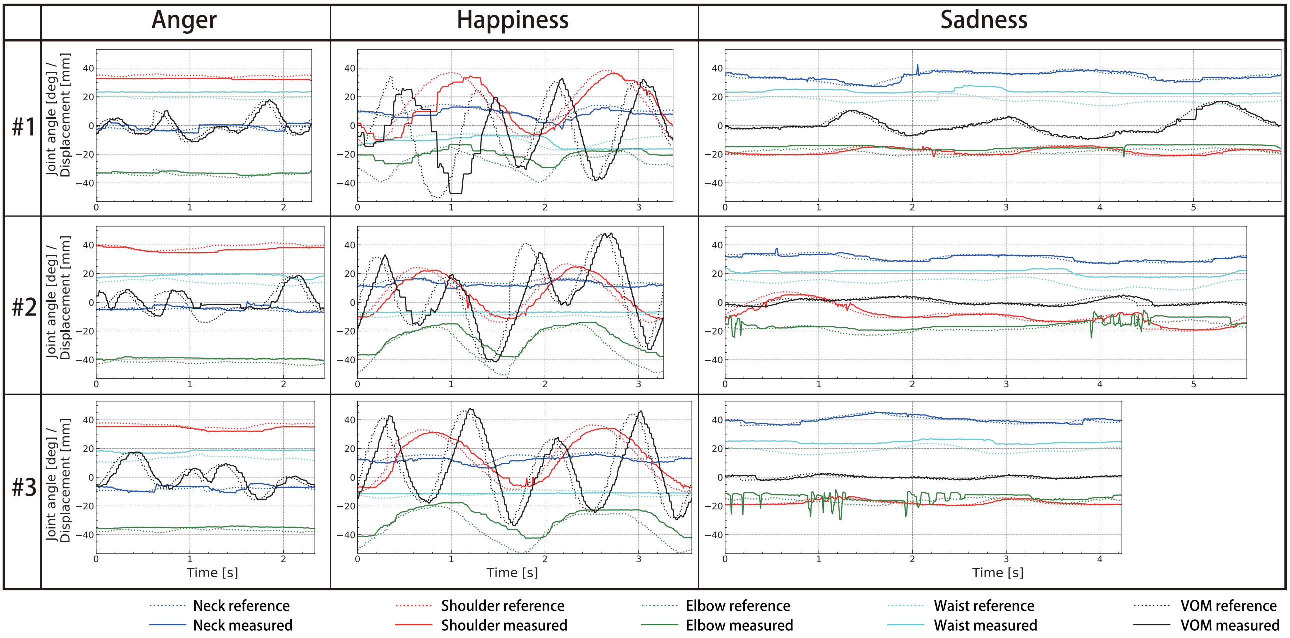


FIGURE 7. Gait-induced upper body motions of anger, happiness, and sadness emotion. The vertical axis represents joint angles [deg] about two cycle gaits of the neck, right shoulder, right elbow, waist, and displacement [mm] of the vertical oscillation. The horizontal axis represents time [s]. The dotted lines show the reference joint angles, and the solid lines show the measured angles (The fluctuation of the measured sensor value was due to the electrical noise.).

shooting environment as for the original human motion data was used. Two cameras were installed at the front and side. The front camera was at a height of 0.9 m, placed in front of the walking route. The side camera was at a height of 0.9 m, placed 2.6 m away from the middle of the walking route. The output of the motor that drives the VOM at happiness motion was insufficient, so in actual shooting, the robot was moved at 1/3 speed, and 3x speed videos were shown to participants, thus mimicking the same speed as humans when walking. *ibuki*'s face was covered with paper to ensure participants did not judge the emotion based on the facial expression.

III. EXPERIMENT 1

The purpose of this research is to investigate the human perception of the gait-induced upper body motions with the VOM to achieve emotional expressions when a wheeled android is moving. In Experiment 1, we investigated whether the presence or absence of the vertical oscillation improves

(A) Anger

(B) Anger of *ibuki*

(C) Happiness

(D) Happiness of *ibuki*

(E) Sadness

(F) Sadness of *ibuki*

FIGURE 8. Representative frames of the original human emotional expressions and *ibuki*'s gait-induced upper body motions expressing emotions. Anger (A) (B), happiness (C) (D), and sadness (E) (F). (A), (C), and (E) also show the results of pose recognition.

the human perception of *ibuki*'s emotional expressions through the gait-induced upper body motions.

A. PROCEDURE

In both Experiment 1 and 2, we recruited all the participants by using Amazon Mechanical Turk. To control the regional influence on the survey, we limited the survey target to North America because it had the largest available pool of participants. In our preliminary survey, we chose participants from other areas and confirmed that the perception result did not have any large changes. Before starting the experiment, we explained the experiments' purpose to all the participants and obtained consent forms. The protocol was approved by the ethics committee for research involving human subjects at the Graduate School of Engineering Science, Osaka University (#R1-6).

Firstly, we checked the recognition rates and confidence levels of side views of the original human gait motions used for *ibuki*. 79 people participated in this survey (29 females and 50 males, average age = 36.2, Standard Deviation (SD) = 10.1). At the beginning of the survey, the neutral emotion gait motion was shown as a reference. After that, a video of the nine original human gait (3 emotions x 3 motions) was displayed on each page in random order one at a time. Each video was looped three times. After each viewing, participants were asked to: 1) Assess which emotion was expressed from four choices: anger, happiness, sadness, and other; 2) Indicate the confidence level of their choice from a range of totally not confident (1) to highly confident (5).

Secondly, we investigated the recognition rates and confidence levels of *ibuki*'s emotion expressions by the gait-induced upper body motions. As we assumed the hypothesis that the presence of a vertical oscillation enhances the participants' perception, we conducted the survey under two condition of emotion expressions with and without the vertical oscillation. The significance level was 5.000 % (the marginally significance level was 10.000 %), the detection power was 90 %, and we conducted the survey with a sample

TABLE 1. Confusion matrix of recognition rates of the original human emotional expressions in Experiment 1. Expressed emotions are shown in columns and selected emotions are shown in rows. Each value indicates the average recognition rate [%].

	Anger	Happiness	Sadness	Other
Anger	**97.0**	1.3	0.4	1.3
Happiness	0.4	**93.2**	0.8	5.5
Sadness	0.0	0.4	**96.2**	3.4

size of 150 participants. We divided the new participants in two different groups: one group of 178 people (76 females and 102 males, average age = 36.3, SD = 9.68) saw the videos with vertical oscillation, and the other group of 177 people (68 females and 109 males, average age = 36.6, SD = 10.6) saw the videos without vertical oscillation.

For both with and without vertical oscillation conditions, we prepared nine videos of *ibuki*'s gait-induced upper body motions, combining three motions per emotion from a side view. To prevent participants from just watching side view motions, we also prepared nine videos from the front view as dummy trials which are not used in the result analysis. In total, each participant watched 18 videos.

Like in the previous survey with the human data, at the beginning of each condition, the gait-induced upper body motion of neutral emotion without vertical oscillation was shown as a reference. For both with and without vertical oscillation conditions, a video was displayed on each page in random order one at a time. Each video was looped three times. After each viewing, participants were asked to: 1) Assess which emotion was expressed from four choices: anger, happiness, sadness, and other, 2) Indicate the confidence level of their choice from a range of totally not confident (1) to highly confident (5).

B. RESULT

For the original human gait motions, the average recognition rates of anger, happiness, and sadness were 97.0 %, 93.2%, and 96.2 %, respectively. The average confidence levels of anger, happiness, and sadness expressing motions were 4.51 (SD = 0.70), 4.44 (SD = 0.66), and 4.49 (SD = 0.73), respectively. Table 1 shows the confusion matrices of the recognition rates for the three emotions.

For the *ibuki*'s gait-induced upper body motions, Table 2 and Table 3 show the confusion matrices of the average recognition rates for the three emotions (anger, happiness and sadness) for both with and without vertical oscillation conditions. In the with vertical oscillation condition (Table 2), recognition rates are: 56.0 % for anger, 77.7 % for happiness, and 97.0 % for sadness. On the other hand, in the without vertical oscillation condition (Table 3), recognition rates are: 57.6 % for anger, 63.7 % for happiness, and 95.9 % for sadness. Chi-square tests were performed to check whether participants could distinguish the three different emotions during their assessment. As a result, both conditions were statistically significant: $\chi^2(6) = 343.4, p < 0.001$ in the with vertical oscillation condition and $\chi^2(6) = 314.8, p < 0.001$ in the without vertical oscillation condition. Mann-Whitney U-tests were performed to check the difference in recognition rates between with and without vertical oscillation for each emotion. To reduce the possibility of false positives due to multiple tests (for three emotions), we adjusted the significance level from 5.000 % to 1.667 % according to the Bonferroni adjustment. As a result, there was significant difference for happiness ($U = 1.62 \times 10^5, p < 0.001$, effect size Cohen's $d = 0.313$). There was no significant difference for anger ($U = 1.39 \times 10^5, p = 0.591, d = 0.033$) and sadness ($U = 1.43 \times 10^5, p = 0.313, d = 0.062$).

TABLE 2. Confusion matrix of recognition rates under the with vertical oscillation condition in Experiment 1. Expressed emotions are shown in columns and selected emotions are shown in rows. Each value indicates the average recognition rate [%].

	Anger	Happiness	Sadness	Other
Anger	**56.0**	9.0	18.7	16.3
Happiness	6.9	**77.7**	4.9	10.5
Sadness	0.7	0.7	**97.0**	1.5

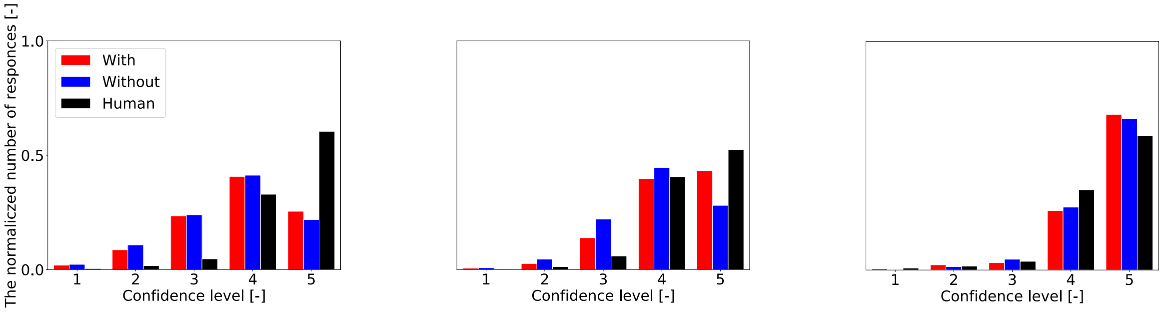
TABLE 3. Confusion matrix of recognition rates under the without vertical oscillation condition in Experiment 1. Expressed emotions are shown in columns and selected emotions are shown in rows. Each value indicates the average recognition rate [%].

	Anger	Happiness	Sadness	Other
Anger	**57.6**	10.0	16.8	15.6
Happiness	4.5	**63.7**	9.6	22.2
Sadness	0.9	2.8	**95.9**	0.4

Fig. 9 shows the distributions of the confidence level in the with and without conditions (red and blue) and the original human gait (black). The vertical oscillation condition is indicated by the red color. The averages of participants' confidence level of assessed emotions are: 3.79 (SD = 0.98) for anger, 4.22 (SD = 0.82) for happiness, and 4.59 (SD = 0.71) for sadness. Without vertical oscillation condition is indicated by the blue color. The averages of participants' confidence level of assessed emotions are: 3.70 (SD = 1.00) for anger, 3.95 (SD = 0.86) for happiness, and 4.58 (SD = 0.67) for sadness. Mann-Whitney U-tests were performed to check the difference in confidence levels between with and without vertical oscillation for each emotion. As a result, there was a significant difference for happiness ($U = 1.68 \times 10^5, p < 0.001, d = 0.329$). There was no significant difference for anger ($U = 1.49 \times 10^5$, $p = 0.125, d = 0.096$) and sadness ($U = 1.44 \times 10^5$, $p = 0.535, d = 0.012$).

IV. EXPERIMENT 2

In Experiment 1, we compared two conditions - the presence or absence of vertical oscillation. The result of happiness emotional expression supported the hypothesis that gait-induced upper body motion with vertical oscillation enhances human perception for robot emotional expressions. In Experiment 2, we investigated whether the congruence of the vertical oscillation enhances the human perception



(A) Anger (B) Happiness (C) Sadness

FIGURE 9. Histograms of confidence level of (A) Anger, (B) Happiness, and (C) Sadness emotions in Experiment 1. The vertical axis represents the normalized number of responses and the horizontal axis represents each confidence level. Red, blue, and black color indicate confidence levels of the with vertical oscillation condition, the without vertical oscillation condition, and the original human gaits, respectively.

of *ibuki*'s emotional expressions through the gait-induced upper body motions. Therefore, an additional group of participants evaluated the gait-induced upper body motions with exchanged vertical oscillations (incongruent motions). After this, we analyzed the perception difference between the incongruent motions (newly obtained with this assessment) and the previous congruent motions (the with vertical oscillation condition in Experiment 1).

A. PROCEDURE

First, we describe how we created an incongruent motion with an exchanged vertical oscillation. We selected similar gait phase pairs from three types of anger and happiness emotions in Fig. 7. One pair was Anger 1 and Happiness 1, which motions began at the right leg pre-swing phase (50 % in a gait cycle) and also ended at the right leg pre-swing phase (50 % in a gait cycle). Thus, the phase transitions of those two vertical oscillation were almost matched. Another pair was Anger 2 and Happiness 2. Anger 2 began at the right leg pre-swing phase (50 % in a gait cycle) and also ended at the right leg pre-swing phase (50 % in a gait cycle). On the other hand, Happiness 2 began at the right leg stance phase (0 % in a gait cycle) and also ended at the right leg stance phase (10 % in a gait cycle). As mentioned before, the human CoM oscillates twice on the sagittal plane in one gait cycle, the phase transitions of those two vertical oscillations were also matched. However, the remaining pair of Anger 3 and Happiness 3 motions could not be exchanged due to an inconsistency in gait phases. Anger 3 began at 50% and ended at 30% in a gait cycle. In contrast, Happiness 3 began at 10% and ended at 20% in a gait cycle. As a result, we created two incongruent anger motions with happiness vertical oscillations and two incongruent happiness motions with anger vertical oscillations as shown in Fig. 10. Also, sadness motions were not exchanged as the recognition rate of the robot's emotional expression of sadness was as high as that of the rate in the human data - with or without vertical oscillation.

Therefore, we prepared two pairs of incongruent anger and happiness motions with exchanged vertical oscillations, one pair of original anger and happiness motions, and three original sadness motions. Like in Experiment 1, we also prepared nine videos from the front view as dummy trials. In total, we prepared 18 videos for Experiment 2. Similar to the way we conducted Experiment 1, at the beginning of each condition, the gait-induced upper body motion of neutral emotion without vertical oscillation was shown as a reference. After that, a video was displayed on each page in random order one at a time. Each video was looped three times. After each viewing, participants were asked to: 1) Assess which emotion was expressed from four choices: anger, happiness, sadness, and other, 2) Indicate the confidence level of their choice from a range of totally not confident (1) to highly confident (5).

A total of 151 people (70 females and 81 males, average age = 35.1, SD = 9.27) participated in Experiment 2. As in Experiment 1, the significance level was 5.000 % (the marginally significance level was 10.000 %), the detection power was 90 %, and we conducted the survey with a sample size of 150 participants.

B. RESULT

Table 4 show the confusion matrices of the recognition rates for the incongruent motions. Fig. 11 show the histograms of confidence level of (A) anger motions and (B) happiness motions. Red and black color indicate confidence levels of congruent and incongruent motions. For the anger gait-induced upper body motion with the happiness vertical oscillation, the recognition rate was 48.3 % and the average confidence level was 4.03 (SD = 0.84). For the happiness gait-induced upper body motion with anger vertical oscillation, the recognition rate was 58.6 % and the average confidence level was 4.01 (SD = 0.85). On the other hand, for congruent motions in Experiment 1, the recognition rate and the average confidence level were 48.3 % and 3.79 for anger, and 58.6 % and 4.22 for happiness.

Mann-Whitney U-tests were performed to check the difference in recognition rates and confidence levels between congruent and incongruent motions. To reduce the possibility of false positives due to multiple tests, we adjusted the

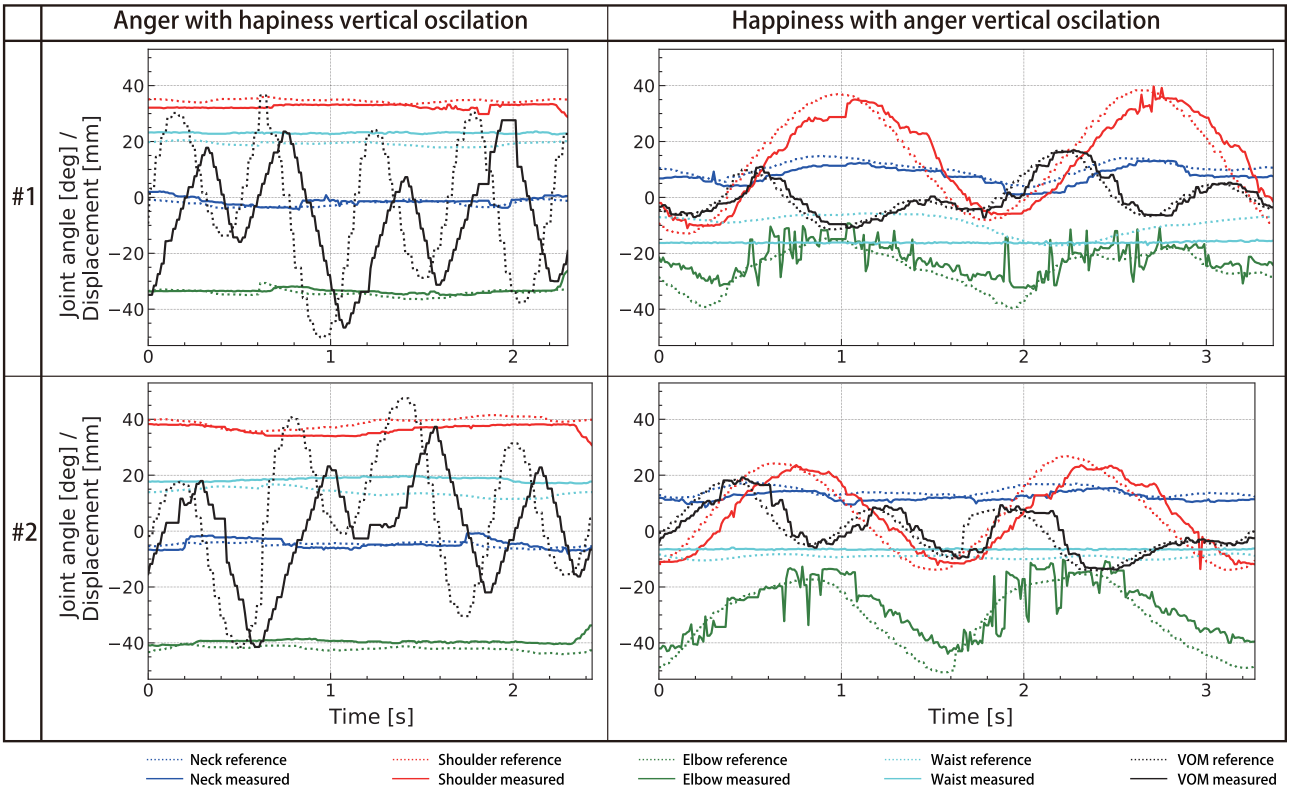
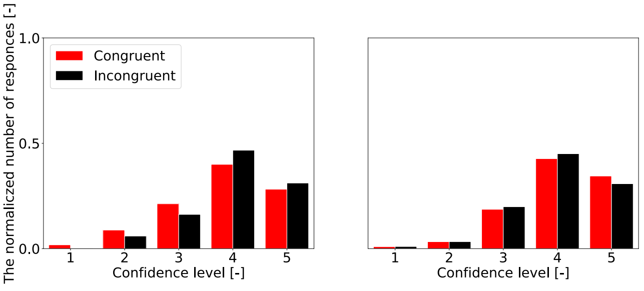


FIGURE 10. Gait-induced upper body motion under the exchanged vertical oscillation condition. The graph shows two anger motions with happiness vertical oscillation and two happiness motions with anger vertical oscillation. The vertical axis represents joint angles [deg] about two cycle gaits of the neck, right shoulder, right elbow, waist, and displacement [mm] of vertical oscillation. The horizontal axis represents time [s]. The dotted lines show the reference joint angles, and the solid lines show the measured angles (The fluctuation of the measured sensor value was due to the electrical noise.).

TABLE 4. Confusion matrix of recognition rates for the incongruent motions in Experiment 2. Expressed emotions are shown in columns and selected emotions are shown in rows. Each value indicates the average recognition rate [%].

	Anger	Happiness	Sadness	Other
Anger	**48.3**	27.5	13.6	10.6
Happiness	6.0	**58.6**	12.9	22.5



(A) Anger (B) Happiness

FIGURE 11. Histograms of confidence level of (A) anger motions and (B) happiness motions. Red color indicates confidence levels of congruent motions which were assessed in the with vertical oscillation condition of Experiment 1 (Red histogram in Figure 9). Black color indicates confidence levels of incongruent motions with exchanged vertical oscillation which were assessed in Experiment 2. The vertical axis represents the normalized number of responses and the horizontal axis represents each confidence level.

significance level from 5.000 % to 2.500 % according to the Bonferroni adjustment. Between the incongruent and congruent motions of anger and happiness, there was a marginally significant difference in recognition rates for anger ($U = 7.45 \times 10^4, p = 0.033, d = 0.154$) and significant difference for happiness ($U = 6.52 \times 10^4$, $p < 0.001$, $d = 0.429$). There were also significant differences in confidence levels for both anger ($U = 9.10 \times 10^4, p = 0.001, d = 0.255$) and happiness ($U = 6.91 \times 10^4$, $p < 0.001$, $d = 0.254$).

From these results, we concluded that the recognition rates decreased when the vertical oscillation did not match the emotional human movement. Interestingly, participants' confidence level in anger with happiness vertical oscillation gait-induced upper body motion was significantly higher than that of anger gait-induced upper body motion with anger vertical oscillation in Experiment 1. Thus, the results show that easily recognizable motion patterns and high confidence motions patterns may not always match - as seen in the higher confidence level of anger with happiness vertical oscillation condition compared to anger with the original vertical oscillation condition.

V. DISCUSSION

In this paper, we implemented gait-induced upper body motions that express three emotions using the VOM of the

TABLE 5. Summary of emotional expression recognition by walking motions of robots in previous researches: this study (Human and *ibuki*), the previous *ibuki*'20 study by [28], Wabian-2R [12]) and the original CG by [29], and Nao by [13] and the original CG by [7]. Height indicates a robot or a CG avatar height as a representative size scale. Participants indicate people who participated the survey. Choices indicate emotion options in the survey. Each value indicates the average recognition rate [%]. * indicates a value which is not shown the exact value in a paper (The author read the value from a graph.).

	Height [cm]	Participants	Choices	Anger	Happiness	Sadness	Fear	Neutral
Human	170	79	4	97.0	93.2	96.2	N/A	N/A
ibuki	120	178	4	56.0	77.7	97.0	N/A	N/A
ibuki '20	120	17	3	43	62	88	N/A	N/A
Wabian-2R	148	26	6	N/A	55.8	92.3	N/A	80*
Nao	57	59	5	51.8	34.7	66.1	15*	63.9
CG (Destephe)	N/A	16	6	61.9	65.5	76.2	85.7	N/A
CG (Venture)	N/A	26	6	90*	65*	90*	90*	90*

mobile android *ibuki*. We also confirmed that the recognition rate and confidence level of the emotional expression of happiness were higher with vertical oscillation. From the incongruent motion of anger and happiness, we can see that the incongruence of the vertical oscillations of anger and happiness decreased recognition rates. However, the confidence level of anger was increased by using happiness vertical oscillation.

For reference, we summarize our results and previous research of emotional expression of robot walking motion here. Table 5 shows the robot height, the survey scale, the number of question answer options, and recognition rates of emotional expression of robot walking in previous research: *ibuki*'20 [28], Wabian-2R [12], CG of Wabian-2R [29], Nao [13], and CG of human animation [7].

In previous research [28], we investigated *ibuki* gait-induced upper body motions based on Destephe's data [30], adding simple cosine wave VOM movements. Recognition rates at *ibuki*'20 in Table 5 are under the condition of 0.8x speed and simple cosine wave vertical oscillation (there were four conditions by combining [0.6x, 0.8x speed] x [with, without vertical oscillation]). Note that, in the previous study, only recognition rates with a confidence level of more than 2 degrees were counted in the results. Because the gait-induced upper body motions were consisted of the same joints, it is suggested that vertical oscillation of the human emotional gait, and not a simple cosine wave, enhances the human perception for the gait-induced upper body motions. In addition, the average confidence level for all emotions was 3.43 in the previous study. In contrast, in this study, it was 4.07 for the with vertical oscillation condition. Again, it is considered that the application of the human emotional gait for the vertical oscillation contributed to the increase in confidence level.

For the perception of anger, the gap in recognition rates between humans and robots is pronounced. In the case of humans, emotional expression of anger was recognized with the same accuracy as other emotions. However, in robots they were about 50%. We consider that velocity and acceleration of walking motions are important for the correct recognition of angry emotion. Montepare *et al.* reported that the anger gait is recognized by a heavy-footed gait characteristic [31]. In our experiments, as we used time series joint angle data for emotional gait-induced upper body motions, the lack of consideration of velocity and acceleration might have caused the lack of recognition. We can see this also happening if we review [7] and [13]. In [7], where she considered joint angles and velocities of human walking while creating walking animations, the recognition rate of anger was 78%. Even though [13] used that as a basis to move their robot, the recognition rate decreased to 51.8 %. Furthermore, Ikeda and Watanabe reported that humans are better able to perceive anger than happiness [32]. In the natural world, angry creatures, either animals or humans, are objects of fear, and observers must be sensitive in taking action (e.g. fight or flight). Therefore, it is natural to have an advantage in perceiving anger. Nevertheless, it is difficult to perceive anger expressed by robots. To achieve a high level of perception for a robot's expression of anger, we must sufficiently reproduce a wider range of components, from the joint movement features to the appearance humans use to convey their anger. On the other hand, the results show that confidence level for the anger emotion was not correlated to the original motion. For that reason, the vertical oscillation of happiness could increase the confidence level of anger expression in Experiment 2.

For the perception for happiness, our results suggested that vertical oscillation is important for both recognition and confidence aspects. This is consistent with [10] which identified faster gait speed and large vertical movement as characteristics of happiness. We calculated the approximate ratio of vertical movement compared to the heights of humans, *ibuki*, *ibuki*'20, Wabian-2R, and Nao in Table 5. The ratio of the original human walking motion and *ibuki* were both 0.06. In other words, the 120 cm high *ibuki* was swinging the upper body about 7 cm while moving. In the previous research, *ibuki*'20 ration was about 0.04 (5 cm vertical movement / 120 cm height). Wabian-2R was about 0.007 (1 cm / 148 cm, referred from [33]) and Nao was 0 (0 cm / 57 cm, as inferred from [34]). From these results, it is suggested that there is a positive correlation between the ratio of vertical movement per height and the recognition rate of happiness.

For the perception of sadness, our results show that the effects of the vertical oscillation were small for both recognition and confidence. This is consistent with [12] that the locomotor unit are important for the expression of happiness in the walk but does not have much influence on the expression of Sadness. As can be seen in the study by [7], sadness has different gait characteristics compared to anger and happiness, such as the neck and torso bending forward. As a result, recognition rates for humanoid robots (*ibuki*, Wabian-2R) were as high as for human gaits. Since those robots have a human-like appearance, participants were easily able to perceive sadness with a high level of confidence.

The limitations of this paper are mainly that this study used online video surveys with a questionnaire that had a pre-designed response range. Therefore, this method may miss some details, like participants' further perceptions when they watched the emotional gait-induced upper body motions. Further real-time robot evaluation by participants is needed for further understanding. From the author's experience, we expect that emotional perception is made stronger by watching real robot motions. In addition, humans also express gait characteristics on the roll or yaw axis joints. However, the gait-induced upper body motions in this paper were limited only to the sagittal plane.

VI. CONCLUSION

In this paper, we investigated the perception of emotions expressed by three different gait-induced upper body motions by a mobile android. We focused on the CoM trajectory on the sagittal plane during human walking and implemented the motion by the VOM.

For simplicity, time series pitch axis joint angle data was used in this study. In the future, we will consider adding roll and yaw axis joint movements, which are necessary for the perception from the front or diagonal view. In addition, a motion control until acceleration level is also important for mobile robots to express dynamic gait-induced upper body motions, such as heavy footsteps in anger, while moving.

Our current research is essential for applying emotional gait-induced upper body motions to mobile humanoid robots for real-world human-robot interaction. We hope to validate the effectiveness of emotional gait-induced upper body motions at different distances from viewers in future studies. Particularly interesting is investigating the relationship between distance from the viewer and the fluctuation in perception (recognition rates and confidence levels). Furthermore, if robots can physically express themselves in a human-like manner, humans can respond and readily adapt to the robot's behavior. For example, by approaching humans closer while expressing emotions, an android can naturally provide an opportunity to start a conversation. This robots' function opens up avenues to a more natural way of communication.

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