Control and Expression of Life-like Body Movement

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Abstract — An automatic choreography method to generate life-like body movements is proposed. This method is based on somatics theories that are conventionally used to evaluate human's psychological and developmental states by analyzing the body movement. The idea of this paper is to use the theories in the inverse way: to facilitate generation of artificial body movements that are plausible regarding evolutionary, developmental and emotional states of robots or other non-living movers. This paper reviews somatic theories and describes a strategy for implementations of automatic body movement generation. In addition, a psychological experiment is reported to verify expression ability on body movement rhythm.

I. Introduction: From Dance Therapy to Robot Assisted Therapy

Recently, some trial experiments on psychological therapies have been carried out with using animal-like robots [1]. These trials are called Robot Assisted Therapies (RAT) or Robot Assisted Activities (RAA). The idea of RAT/RAA is derived from therapeutic activities with animals that are called Animal Assisted Therapies (AAT) or Animal Assisted Activities (AAA).

The therapeutic abilities of animals, however, are not explained enough, so that AAT/AAA is carried out without having explicit theories or methodologies on producing desirable psychological effect on patients thorough interactions between the patients and the therapeutic animals. Likewise, theories on RAA/RAT are not enough constructed yet. As a result, there are no explicit and structural strategy on designing hardware and software of the robots for therapy.

The interaction with patients and therapeutic animals are constructed mainly with non-verbal communication, especially bodily communications. Dance therapy is the most representative method that facilitates bodily communications to effect patients' psychological state. Therefore it is plausible that the theories and the methodologies of dance therapy provide the strategy on designing hardware and software of therapeutic robots to generate therapeutic bodily interaction toward patients.

As shown as Fig. 1, dance therapy is activity with the loop constructed with understanding and affecting the patient's psychological state. In the loop, body movements of both of the patient and therapist play 2 roles; representations of psychological states and effecter on psychological states. A well-designed body motion that expresses psychological state will have power to produce sympathy on patients' mind. Thus, sympathy thorough expressive bodily interaction is the key strategy of dance therapy.

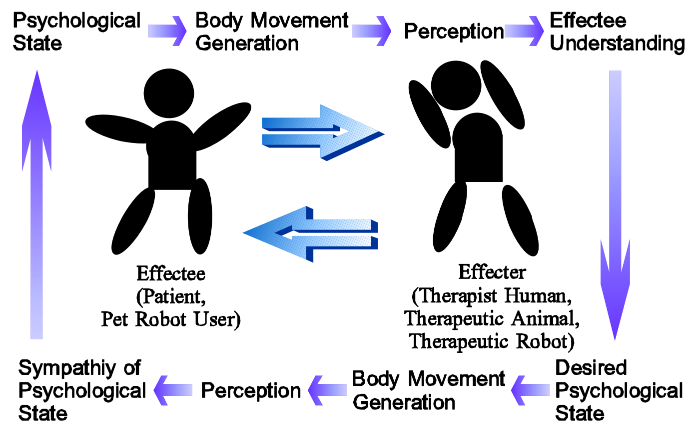

Figure 1: Strategy of Dance Therapy

Needless to say, RAT/RAA requires the strategy. This is the reason that the body expression ability of therapeutic robots will required.

There are several schools of dance therapy. Among them, the author chose concrete and quantitative theories, because they are easy to use for implementation for therapeutic robots. In this paper, the dance therapy theories are explained and facilitated for software that generates expressive body movement of CG artifacts.

II. *Somatics:* Theories of Relationship between Psychological State and Body Movement

Researchers of dance therapy have been developing their theories on the relationship between psychological states and body movements. Body movement has 2 aspects, namely temporal aspect and geometrical aspect. In this section, Kestenberg and Hunt theories are introduced as theories that rule the temporal aspect of body movement generation. Also Cohen's theory is explained as theory on geometrical theory.

Table 1: Cohen's Evolutional Patterning of Body Movement

Pattern Name	Classification on animals	Order on body movement
Disorder	No nerve connection	No synchronism
Breath	Multicellulars	Synchronism
Core-Distal	Symmetric Bodied Animals	Radial symmetric movement
Head-tail	Coelomata (fishes, insects, etc.)	Tension propagation from head to tail
Upper-lower	Amphibians	Tension separation into upper/lower half bodies
Homo-lateral	Reptiles	Tension separation into leftr/right half bodies
Contra-lateral	Mammals	Left-right crossed tension separation

Table 2: Hunt's stereptype of muscular tension rhythm

Rhythm Name	Periodicity	Acceleration
Undulate	Strong	Low
Sustained	Weak	Low
Restrained	Weak	High
Burst	Strong	High

A. Cohen's constraint system on degree of freedom of body

Comparing body movement pattern of animals, Cohen[2, 5] found the relationship between evolutionary state and mechanical constraints on body movement shown in Table 1.

Frogs, for instance, control their body by dividing muscular tension control into *upper and lower* half bodies. Horses are more evolutionaryly developed, so that they can control their body in the frog's way when they run very fast, namely gallop.

Moreover horses can select more complicated control ways. In 'homo-lateral' (or 'ipsilateral' in terms of biology) control mode, tension control is separated into right and left half bodies. As a result, left forelimb and left hind leg moves together. Likewise, right forelimb and right hind leg moves together. The running of horses in homo-lateral control mode is named *walk*.

When a horse walks little faster (i.e. *trot*), it moves right forelimb and left hind leg together, and moves left forelimb and right hind leg together. This right-left crossed tension control is named *contra-lateral* mode.

As shown in Table 1, there are 7 stages of body constraint patterns in evolutionary and developmental process. Animals can use more complex control modes when they are evolutionaryly complex species and they developed enough.

B. Muscular tension rhythm stereotypes

From many observations on movement of animals and humans, somatics researchers got an idea that the number of tension patterns made by nerve system (called 'central pattern generator', CPG) is limited, and stereotypes of CPG patterns exist.

The hypothesis made by Valerie Hunt has 4 stereotypes of CPG rhythm patterns shown in Figure 2. The patterns can be interpreted mathematically as Table 2. The keys of Hunt's categorization are periodicity and acceleration (or differentiability) of patterns.

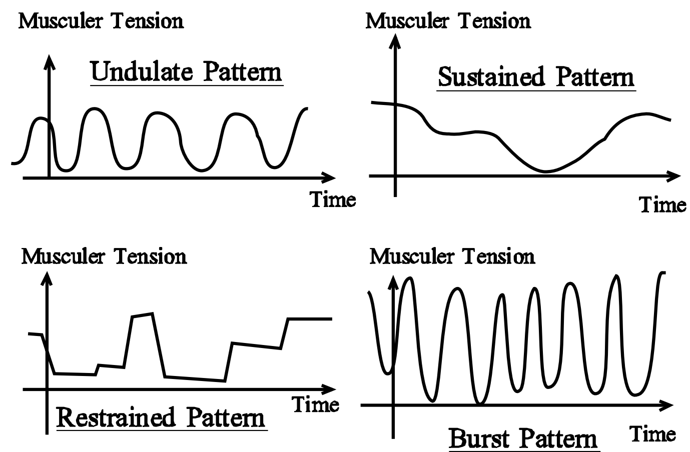

Figure 2: Temporal patterns of Hunt tension stereotypes

There is another hypothesis with more detailed categories. Observing body movement of babies, Judith Kestenberg[7] found that the oscillation patterns of CPG signals can be classified into 10 stereotypes shown on Figure 3. Each pattern has relationship to psychological state and developmental state shown in Table 3. While growing up, a baby gradually acquires more varieties of muscular tension pattern that reflects more complicated psychological state.

III. An Implementation Example of Algorithmic Choreography

A. Purpose

In order to show how to interpret the theories from engineering viewpoint and how to realize a choreography algorithm based on the theories, an example of practice is reported in this section.

B. Equipmental setting

Because of the facility for realization of movement display, the implementation is done in 3-dimensional computer graphics world. The computer graphics software is developed with OpenGL libraries.

Table 3: Kestenberg's interpretations of body movement rhythms

Rhythm Name	Darwinian classification	Temporal pattern of muscular tension	Psychological state	When appears on human infant
Sucking	Indulging	Small sine wave	Absorbing affection	Birth –
Snapping/ Biting	Fighting	Small triangle/ trapezoidal wave	Attention to something	0.5 year old –
Twisting	Indulging	Small sine + drift	Intention on locomotion	9 months old –
Strain & Release	Fighting	Large long bang-bang wave	Concentration and relinquish	1 year old –
Runnging & Drifting	Indulging	Drift	Controlling continuity of movement	2 years old –
Starting & Stopping	Fighting	Bouts and intervals	Decision on starting and stopping	2.5 years old –
Swaying	Indulging	Small long sine wave	Enjoying pleasure	3 years old –
Surging & Birthing	Fighting	Large long sine wave	Enduring pain, trying to escape from pain	3.5 years old –
Jumping	Indulging	Large short sine wave	Excited	4 years old –
Spurting & Ramming	Fighting	Large short triangular wave	Intentional violence, hostility	5 years old –

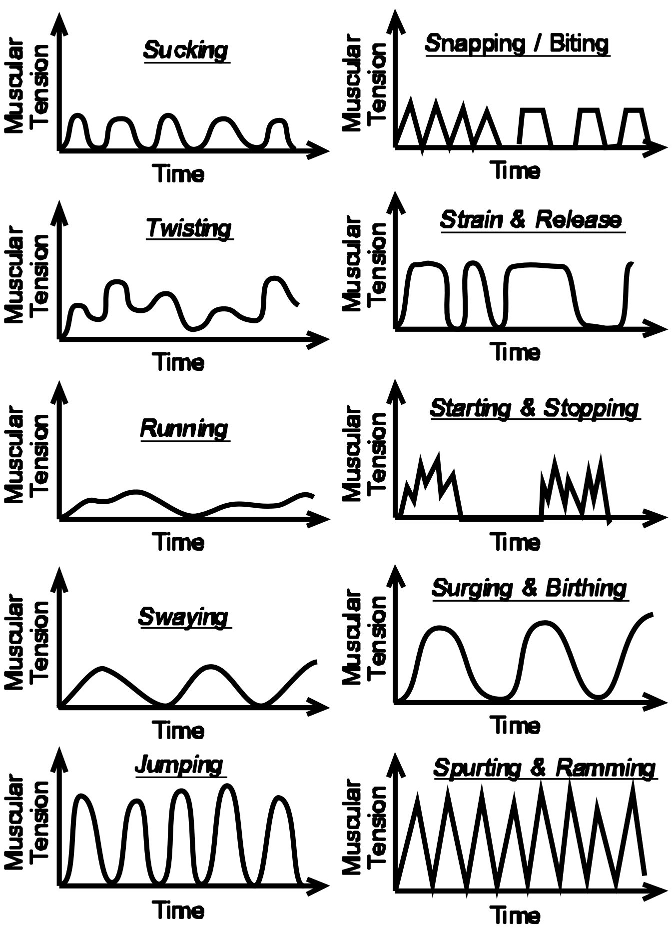

Figure 3: Temporal patterns of Kestenberg tension stereotypes

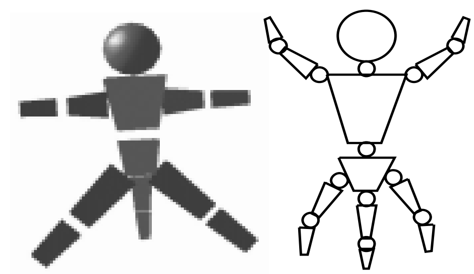

Figure 4: Kinematic structure of a CG model with bendable limbs with 12 joints and 24 DoF

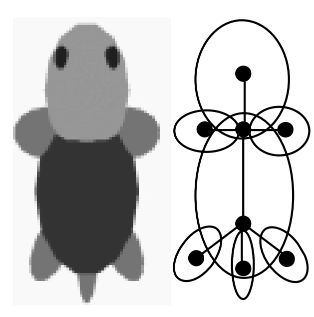

Figure 5: Kinematic structure of a simplified CG model with a fixed pelvis and 7 free joints. Total DoF is 14.

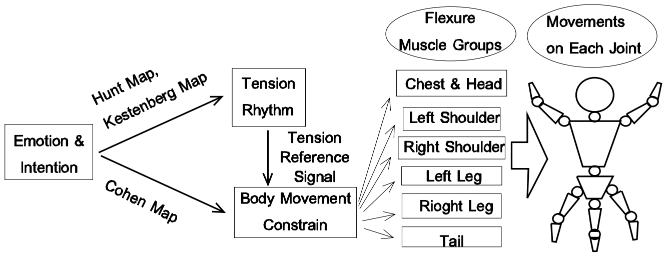

Figure 6: Mapping from emotional and intensional state to body movements

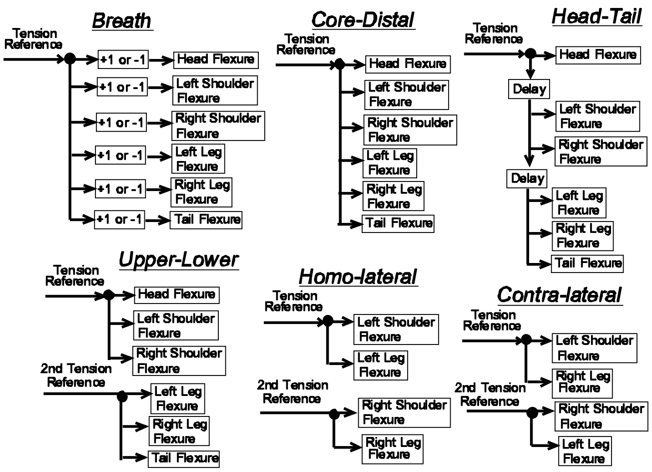

Figure 7: A realization of control diagrams of Cohen patterns

A body shown in Figure 4 is modeled after an ordinary life-like body. The body has 12 joints. Each joint has 2 DoFs on bend directions, so the body has 24 DoFs.

In addition to this, another body with simplified limbs is also created as shown in Figure 5. This body has 14 DoFs.

The movement generation algorithm is demonstrated on both body structures.

C. Interpretation and implementation

As shown Figure 6, when the evolutionary/ developmental state and psychological state of the agent are given, proper muscular tension rhythm and body movement constraint are determined according the hypothesis of Cohen and Hunt (or Kestenberg). Then, the algorithm distributes the tension signal on each muscle.

This methodology of movement generation is ruled by evolutionary, developmental and psychological relationships described in the previous section. Therefore, the movement generated will reflect the character's evolutionary, developmental and psychological states to some extent.

i) Implementation of Cohen's movement constraints

Cohen's movement constraint is simply a matter of distribution of tension signal. Figure 7 shows the implementation on control block diagrams.

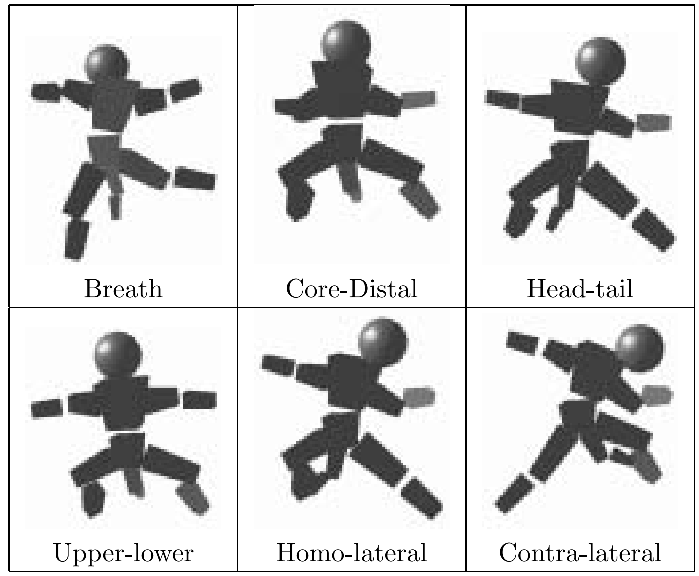

Figure 8: Cohen evolutional phases of body movement pattern

ii) Implementation of Hunt and Kestenberg tension rhythm stereotypes

Hunt and Kestenberg tension rhythm stereotypes shown in Figure 2 and Figure 3 should be interpreted into mathematical terminologies. Hunt's stereotype can be interpreted as wave with periodical terms (like sinusoidal wave) and stochastic drift terms. Table 3 contains examples of mathematical interpretations of Kestenberg's stereotypes.

The rhythm generation is implemented by basic mathematical functions of C language.

D. Results

Figure 8 shows still images of automatically generated body movement in Cohen's 6 body constraint mode. The experimenter selected evolutionary/developmental state and emotional state of the character, and inputs them to the system. Then the system processed and generated body movements as shown Figure 6.

IV. Experiment on Measuring the Relationship between Hunt's rhythm Stereotypes and their Impressions

A. Purpose

This section reports a result of expressions of typical body movements that work in Hunt's tension rhythm stereotypes. Besides the somatic theoretical thoughts described above, the effectiveness of the body movement generation methods should be tested in an experiment.

The experimental hypothesis is the following: movement expressions in animated characters can convey emotional

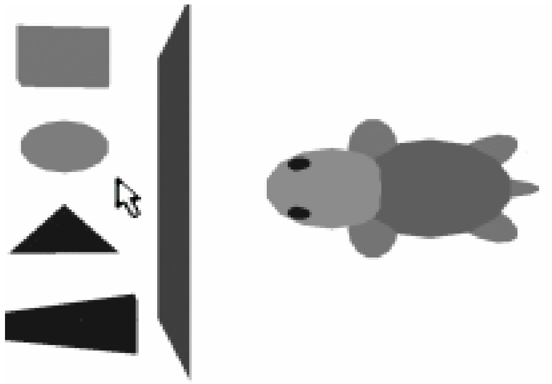

Figure 9: Initial image of the experiment

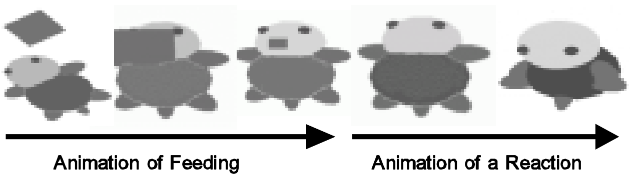

Figure 10: Animation of feeding scene and one of the 4 reactions

impressions by selecting proper tension rhythms and patterning according to theoris of somatic modelling.

The effectiveness of automatic movement generation method can be considered as effectiveness on expression. It has temporal aspect and geometrical aspect. The temporal aspect means plausibility and expressiveness of rhythms and timings of the movement. Likewise, the geometrical aspect means plausibility and expressiveness of postures and paths of the movement.

Because of the size limitation on this paper, the author reports only an experiment on the expressiveness of movement rhythms.

B. Procedure

Overview of the experimental procedure is as the following:

1) The number of subjects is 11. Each subject is shown the computer graphics character and objects as Figure 9. In the screen, there are 4 objects in the left that are explained to each subject as foods for the character. The character has no movement.

2) Each subject is told to select one of the foods by clicking it. After clicking a food, animation begins as shown as Figure 10. The wall disappears, and the selected food moves and fade away into the character 's mouth, so that it seems eating the food.

3) After eating, the character starts body movement as reaction. Unique reactive movement is prepared for each food.

In order to reduce the number of comparisons in the experiment, 4 stereotypes of Hunt's classification are employed.

1) When you feed the food at upper-most position,
Question-A: Does it seem as if the character calmed down?
Calmed Down -- Relatively Calmed Down -- Relatively Excited -- Excited
Question-B: Dose it seem as if the character is feeling pleasure?
Feeling Pleasure -- Relative Pleasure -- Relative Displeasure -- Feeling Displeasure

2) When you feed the food at 2nd position,
<the same questions as 1) >

3) When you feed the food at 3rd position,
<the same questions as 1) >

4) When you feed the food at 4th position,
<the same questions as 1) >

Figure 11: Experimental Questionnaire Sheet

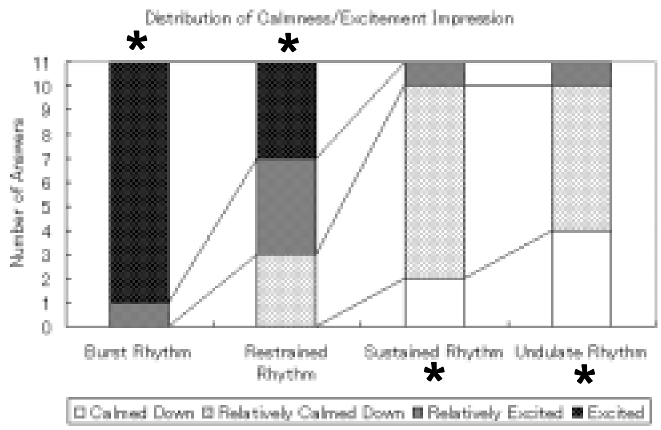

Figure 12: Answer distributions on 'calmed down' vs. 'excited' impression

The reactive movements are driven in *Core-distal* type body constrain and Hunt's tension stereotypes. The food in the upper-most position causes reaction with *Undulate* rhythm. The 2nd food causes *Burst* rhythm. The 3rd food causes *Restrained* rhythm. The food in the lower-most position causes *Sustained* rhythm.

The order of selection is free, and redoing of selection is allowed.

4) Each subject is told to watch the reactive movement for 5 seconds, and answer the impressions of the movement by filling the questionnaire sheet shown in Figure 11. The questionnaire has 2 scales of impressions. One is the scale with 4 degrees to answer about calmness vs. excitation of the movement. The other scale is also with 4 degrees to answer the impression about whether the movement seems with pleasure or displeasure.

5) After collecting answers, Mann-Whitney's U-test is applied on distributions of the answers. Significance level is set to 5 %.

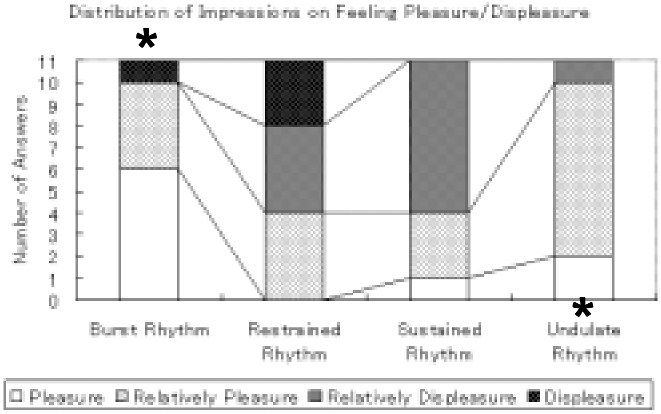

Figure 13: Answer distributions on 'feeling pleasure' vs 'displeasure' impression

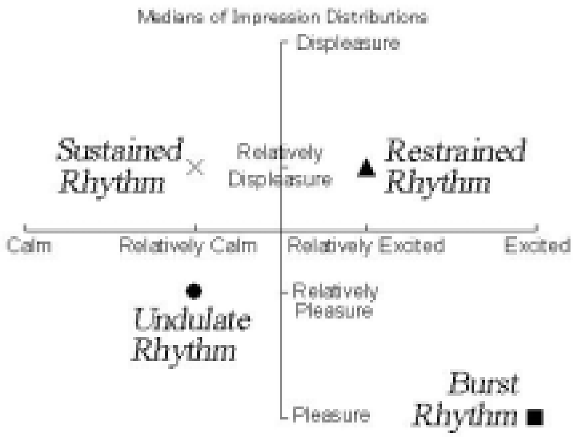

Figure 14: Medians of impression answer distributions of 4 Rhythms

C. Results and discussion

Figure 12 and Figure 13 show the distributions of all answers. Significant tendencies are marked with *.

According to Figure 12, Burst rhythm and Restrained rhythm produced impression of excitation. This means that movements with large acceleration produce impression of hastiness. In contrast, Sustained rhythm and Undulate rhythm produced calm impression.

Figure 13 shows Burst rhythm and Undulate rhythm produced strong impression that the character moves with pleasure. This means that smooth and periodical body movements are signs of pleasure.

Figure 14 summarizes the results. Each of Hunt's 4 stereotypes of tension rhythms fortunately has unique pair of calmness and pleasure impressions. That implies the possibility of emotional expression by showing body movement with proper tension rhythm.

V. Summary and Conclusion

The methodology on algorithmic generation of proper and plausible body movements is described with an implementation example and an experiment on performance of rhythmic body expression.

This methodology is based on Cohen's and Kestenberg's theories that describe the relationship between evolutionary, developmental and psychological states and body movement. Therefore this method can be regarded as a theoretical way to generate typical body motion that produces life-like impressions and emotional impressions.

An implementation is organized to show the utility of this methodology. The key concepts of the theories are interpreted into engineering terminologies. Also a scheme of choreography algorithm is described with block diagrams.

In the experiment, movement expressions succeeded in conveying emotional impressions by selecting proper tension rhythm from Hunt's stereotypes.

In future work, evaluation of expression accuracy, harmonization with other modalities (voice, facial expression, and so on) and harmonization with context, should be studied.

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