

# **The Impact of Animal-like Features on Emotion Expression of Robot Head EDDIE**

Kolja Kühnlenz<sup>1,2</sup>, Stefan Sosnowski<sup>2</sup> and Martin Buss<sup>2</sup>

<sup>1</sup>*Institute for Advanced Study (IAS)*

<sup>2</sup>*Institute of Automatic Control Engineering (LSR)*

*Technische Universität München*

*D-80290 Munich, Germany*

*kolja.kuehnlenz@ieee.org*

## **Abstract**

This article investigates the influence of animal-like features (ears of a dragon lizard and crown of a cockatoo) and their pose variations on the quality of emotion expression of the robot head EDDIE. User studies are conducted presenting emotional expressions composed of the six basic emotions (based on FACS Action Units) in combination with the animal-like features under various inclination angles to human participants in randomized order. The results show, that a) the animal-like features have a significant influence on emotion expression, b) the expressed emotions are shifted in affective space dependent on the inclination angles of the animal-like features, c) these shifts are not uniform and different in orientation for each of the expressed emotions, and d) for some emotions ground truth is matched better with the animal-like features in addition to FACS Action Units. The animal-like features, thus, help to improve the emotion expression of EDDIE, which is particularly beneficial because some Action Units have not been realized well or not realized at all. This study is a successful demonstration how expressive robot heads with rather technical design can benefit from additional expressive features, e.g. animal-like or fictionally designed, which are not based on FACS, in order to improve emotion expression.

*Keywords: Emotions, Robotics, Emotion Expression, Facial Expressions, Human-Robot Interaction*

## **1. INTRODUCTION**

It is well known that emotional signals strongly influence human-human communication and interaction. In order to facilitate emotionally enriched communication also in a human-robot context, means of expressing “emotional states”

of a robot are necessary, i.e. expressive features, which provide additional cues on the progression of the communication or interaction process. A common approach is the integration of facial expression elements in the robot artefact as very elaborated frameworks on human facial expressions exist, which can be utilized, e.g. (Blow et al., 2006; Breazeal, 2002a; Hara & Kobayashi, 1996; Sosnowski et al., 2006a; Zecca et al., 2004).

The design and control of such expressive elements have a significant impact on how the represented emotional state of the robot is perceived by the human counterpart. Particularly, the controlled posture is an important aspect and a well investigated issue in human nonverbal communication considering facial expressions. Common frameworks are works using the Facial Action Coding System (FACS) (Ekman & Friesen, 1977) and variants establishing the link between muscular activations and facial expressions, i.e. the quantitative contribution of muscular group poses to perceived emotions, e.g. (Grammer & Oberzaucher, 2006). This way, a continuous representation of the emotional (affective) space composed of the dimensions valence/pleasure, arousal, and dominance/stance is used and the contribution of muscular group poses to these components is provided.

However, a comprehensive post-evaluation is essential as the actuating elements of the robot (motors, joints, transmission elements, etc.) differ significantly from those of the human. Thus, although elaborated frameworks as e.g. FACS are used in the design process a significant deviation of the intended and perceived expression can be expected. In particular, for expressive features, which are not covered by FACS (e.g. animal-like or fictionally designed), no framework exists in order to use such features in a control architecture for emotion expression. Pose variations of such non-FACS features constitute an additional challenge. Therefore, user studies would be necessary, which systematically investigate the impact on such features on emotion expression.

Works are known, which are concerned with evaluation of various robot designs and appearances in user studies. Mostly, questionnaires are used, which test participants have to answer after specific interaction scenarios (Nakata, Sato & Mori, 1998; Nakata, Mori & Sato, 1999; DiSalvo

et al., 2002; Kanda et al., 2005; Littleworth et al., 2004; Salem, Nakatsu & Rauterberg, 2009). These questionnaires are formulated in terms of categories to be matched or semantic differential scales, i.e. several categories consisting of bipolar adjective pairs, where users have to match their impression either on one of those adjectives or on a scale between them, e.g. pleasant-unpleasant, calm-agitated. The latter approach is also basis of Kansei-engineering, e.g. (Shaari et al., 2002; Salem, Nakatsu & Rauterberg, 2009). However, investigations of the impact of pose variations of non-FACS features on emotion expression has not been conducted to the best of the authors' knowledge.

This article investigates the influence of such controllable animal-like features on the progression of expressed emotions of the robot head EDDIE.

Design of EDDIE encountered various scientific questions, which led to the investigation presented. A technical design was chosen in order not to elicit wrong expectations regarding the capabilities of the robot. In consequence, only a subset and approximation of the action units of FACS necessary for emotion expression was covered by actuated robotic features. This led to deviations of the displayed emotion states from ground truth, which is shown in a preliminary evaluation study in Section 3. The idea in order to overcome these drawbacks is to systematically integrate additional features not covered by FACS, e.g. animal-like or fictional, which may influence the displayed emotion state and eventually even compensate those deviations and, thus, improve the quality of emotion expression. In earlier works, we have successfully shown that such additional features have a significant impact on the displayed emotion state. The objective to be investigated in this article is how the displayed emotion state continually changes with the adjustment of the actuated feature poses and whether or not a systematic pose-control of these features can improve emotion expression. Main contribution is a report on the results and experiences from this investigation, which may help as a guideline for future design of emotional robots.

The remainder of this article is organized as follows: Section 2 briefly describes mechanics, mechatronics, and control architecture of EDDIE; Section 3 presents results from a user study evaluating the emotion expression of EDDIE only considering

features related to FACS action units; in Section 4 the impact of additional animal-like features on emotion expression is investigated evaluating users' perceptions in dependency of the inclination angles of these features; Conclusions are given in Section 5.

## 2. System Description of Robot Head EDDIE

EDDIE is a robot head designed for displaying facial expressions, particularly, emotional expressions realizing 13 of the 21 action units of FACS relevant to emotional expressions. The distribution of the individual degrees of freedom among the expressive elements is shown in Table 2. In addition to the facial elements, animal-like features - the comb of a cockatoo and the ears of a dragon lizard with special folding mechanisms, are integrated. The design and control architecture (Sosnowski, Kühnlenz & Buss, 2006a) are briefly described in the following.

CAD modeled freeform parts are manufactured by rapid-prototyping, the remainder is crafted in aluminum. The rapid-prototyping parts consist of PA3200GF, a glass reinforced plastic, which is coated in a metallic aluminum finish to conform it to the aluminum parts.

For actuation commercial miniature servo motors are chosen: Atom Mini (3Ncm, Jamara), C1081 (12Ncm, Graupner), C5191 (56Ncm, Graupner), which provide high torques while being compact, low cost and easy to obtain. With their internal logic and a PWM-signal, they can easily be position-controlled.

The eyes are based on two gimbal-mounted concentric rings. Both rings consist of PA3200GF. A miniature servo, mounted in a bracket at the outer ring, moves the inner ring in the horizontal of the outer ring. Both eyes are tilted vertical by a shared servo. The rotation axis of the outer rings is held in place by three aluminum holders. The camera is attached to the inner ring. The eyes are each covered with a pair of eyelids, made of PA3200GF, each eyelid is separately moved by a servo. Similar to the human eye, the lower eyelid is smaller than the upper (70° aperture angle of the spherical segment instead of 90°). Camera covers are halves of ping pong balls, painted by

airbrush with an iris including structure and the iris muscle. The pupil is a hole of 10mm diameter. Combination with the dark camera lens results in a natural looking eye.

The brows have two degrees of freedom each. A servo rotates a mounting in which a second servo is integrated. The first servo actuates up-down motions, the second rotates a rod at the end of which the virtual brow is mounted.

The ears are composed of a folding and a rotating unit. In the folding unit four rods, which are supported in a swivel joint and connected by a membrane, are moved by two servos. With it the ears can be tilted up or down or be stretched completely. The rotating unit is moved by a single servo and can position the ears righted or parallel to the side of the head. The membrane is made of red paper segments.

Similarly to a human's jaw, the jaw consists of a rigid upper jaw and a separate lower jaw, which can be moved by a servo. Both jaw parts have semicircles as frontal areas, to appear more organic. In each jaw part two servos are integrated, which can draw the lips at the corners of the mouth up or down. The lips are made of red colored foam. The red color increases the signal effect and the similarity to human lips. A test with blue lips showed a significantly lower effect on the whole appearance (subjective impression).

The crown is composed of a L-shaped holder, giving the necessary height above the rest of the head, a servo and four feathers. The feathers are pivoted and are moved simultaneously by a lever mechanism (see Figure 3). The feathers copy the feathers of a lesser sulphur-crested cockatoo (*acatua sulphurea sulphurea*). Their length is arranged in a level that all ends are located above another when closed. The feathers can support facial expressions in their effect by being positioned either up or down. The red color brings out their signal effect.

The control hierarchy for EDDIE can be separated into three levels. Figure 4 shows how the client/server architecture and the low level motor control are connected. The desired emotional state to display can be set either with a graphical user interface or an interface to a high-level decision control. This client enables the user or a high level controller to set one of the basic emotions, the coordinates in the affective state space, the text for text

to speech output, the gaze direction of EDDIE or change parameters on the server side. The clients are connected to the EDDIE server via a TCP/IP link.

The server handles incoming requests and processes them with the appropriate submodule. These submodules manage the transformation between affective space, action units and joint space for commands in the three-dimensional affective space representation (basic emotions are represented by their respective coordinates in the state space), calculate the viseme for a given text string and the sound, generate randomized movements if the robot is in idle state and merge all movements.

Embedded controllers finally receive the position commands over RS232 or USB and set the servo motors accordingly.

In this paper, only the graphical user interface in combination with the server module controlling basic emotions (for those motors relevant to FACS Action Units, i.e. facial expressions) is used. The animal-like features ears and comb are just positioned in three different inclination angles plus being dismantled.

The most important submodule is the affective space to action units to joint space mapping, where the motor commands for the display of specific facial expressions are calculated. The mappings are derived as follows: Basic emotions are set according to the activation of Action Units for the respective emotion specified in FACS. The activation levels of the animal like features are determined heuristically, with respect to observations of dog/cat ear movements and aggressive postures of dragon lizards, since these features are not covered in FACS. This results in six given activation sets for facial expressions in the extrema of the state space. For displaying facial expressions in the rest of the state space, interpolation is used to determine the activation levels for the action units. Since a linear mapping of an activation level to one of the affective dimensions does not give a satisfactory result, the pleasure-arousal-state-space is divided into four quadrants. For each quadrant and each action unit an interpolation function is derived in such a way, that the functions are continuous at the transition between quadrants.

Quadrant I:	Quadrant II: $SI = arousal + (pleasure - 128)$
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$S1 = 128 + 128 \cdot \sqrt{\frac{pleasure^2 + arousal^2}{255}}$ $S2 = (pleasure - 128) + (255 - arousal)$ $S3 = arousal$	$S2 = arousal + (pleasure - 128)$ $S3 = arousal$
<p>Quadrant IV:</p> $S1 = arousal$ $S2 = 128 - 128 \cdot \sqrt{\frac{pleasure^2 + arousal^2}{255}}$ $S3 = arousal$	<p>Quadrant III:</p> $S1 = arousal$ $S2 = 128 - 128 \cdot \sqrt{\frac{pleasure^2 + arousal^2}{255}}$ $S3 = arousal$

Table 1. Exemplary calculations for the activation levels of the folding mechanism of the ear: Pleasure range: 0 (miserable) to 255 (happy), arousal range: 0 (sleepy) to 255 (surprised), with (pleasure/arousal)=(128/128) being neutral

Motor commands are then computed as position commands with the respective activation level:

$$Position = Position_{LowActiv} + \left( Position_{HighActiv} - Position_{LowActiv} \right) \cdot \frac{ActivationLevel}{255}$$

Thus the module transforms an emotional state in the affective state space into joint space and gives the user feedback in the affective and joint space representation. More details on the design and control of EDDIE can be found in (Sosnowski, Kühnlenz & Buss, 2006a).

Parts	ears	eyes	eyelids	brows	jaw	lips	crown	total
DOF	6	3	4	4	1	4	1	23

Table 2. Actuated degrees of freedom (DOF) and controllable expressive features.

### 3. Evaluation Study

First evaluation studies of EDDIE, which motivated this investigation, had shown rather mediocre results of the recognition rates of individual basic emotions. Besides the emotion 'surprise', which had been recognized comparatively well, the recognition rates

of the other five basic emotions were just over 50%. These studies had been conducted using a categorical test, where test participants had to match the currently displayed state to one of several possible emotion categories. From these categorical results, however, there was no possibility to draw any conclusions on the underlying deficiencies or on how to adjust the individual motor commands such that emotion expression is improved. So, another study was conducted based on a semantic differential approach, which is described in the following. In this Section only actuated features of EDDIE related to action units of FACS are considered, i.e. EDDIE is evaluated without ears and crown.

A study with 30 participants has been conducted. A number of 6 different facial expressions corresponding to certain emotion states has been presented to each subject separately in random order only using those expressive features corresponding to action units of FACS, i.e. with the additional animal-like features dismantled. The subjects' impressions of the shown emotions have been acquired by using a German translation of the semantic differential of Mehrabian.

The results of the study are presented in Figure 8 showing the expected emotion values (ground truth) and the values obtained from the study (measurements) in affective space (dimension dominance is not displayed). The results of the study show how each expressed emotion is located in affective space as perceived by the participants.

### 3.1 Discussion

The results in Figure 8 show that a slight tendency of the displayed emotional expressions towards ground truth is noticeable, e.g. happiness, however, in general a significant deviation exists. As discussed initially in Section 1 this shortcoming is mainly due to a divergence of the realized “muscle groups” from the required ones of individual FACS Action Units.

As discussed in earlier works, from the results and the knowledge of the action units needed for each specific emotion (Grammer & Oberzaucher, 2006) the quality of the

realization of each action unit in the mechatronical robot face can be concluded. Additionally, steps for improvement can be derived from the results. For example, the results in Figure 8 show that the displayed emotion 'anger' has been perceived as a nearly neutral emotion only slightly off the origin towards its ground truth position. Anger activates the Action Units 4 (brow lowerer), 5 (upper lid raiser), and 23 (lip tightener). Action Unit 4 has been implemented, but in comparison to the other expressive elements (e.g. red color of the lips) is much less noticeable. Yet, Action Unit 4 has a strong impact on valence and arousal. Further, Action Unit 23 has not been implemented, which has also an impact on valence.

Moreover, in Figure 8 a global positive valence shift can be noted. A possible reason for this shift can be noted in Figure 2. The lips of EDDIE are designed in such a way that it seems to smile slightly in most displayed emotion states. Thus, a possible guideline for improvement is a mechanical adjustment of the lips' inclination angles.

Summarized, a significant shortcoming of the emotion expression of EDDIE with FACS-related features can be noted.

In the following section, the impact of actuated features not covered by FACS on emotion expression is investigated in order to assess, whether these could be used and controlled to improve emotion expression.

#### 4 Dependency of Emotion Expression on Actuator Commands of Animal-like Features

In this section additional animal-like features (ears and crown) are introduced, which are pose-controllable and the dependency of the expressed emotions on the inclination angles of these features is investigated. Of particular interest in this context is whether and how these features would significantly vary the expressed emotion, i.e. shifting it along the individual dimensions of affective space, and whether they could be used to intensify or improve it. Therefore, we incrementally adjusted the inclination angles of ears and crown and evaluated the resulting perceived emotions from the user study.

These results are discussed in the following.

An evaluation study with 30 participants has been conducted evaluating the influence of the two animal-like features (crown of a cockatoo and ears of a dragon lizard) of EDDIE. In a 2x2 ANOVA design with repeated measures (1. Factor: crown, 2. Factor: ears) the impact of these two factors on emotion expression in affective space has been investigated. Each factor has been realized in four conditions (from fully stilted to dismantled). All six basic emotions have been displayed with each combination of the two factors. Afterwards, the participants have had to rate each displayed emotion on the verbal semantic differential scale. Every subject has participated in one third of the 96 possible combinations.

In earlier works, we had successfully shown that the additional animal-like features of EDDIE have a significant impact on several dimensions of most emotion states (Bittermann, Kühnlenz & Buss, 2007). These results of the ANOVA are shown in Table 3. The table shows the resulting p-value for all emotions and all dimensions (V: valence, A: arousal, D: dominance) for the varied factors (ears, comb, ears & comb), where  $p < 0.05$  as well as the F-value (effect). The results show that the ears and the comb basically have a significant influence ( $p < 0.05$ ), in particular, for the emotions happiness, surprise, anger and disgust. For example the interaction effects of ears & comb on the valence component of anxiety and sadness are significant at a level of  $p = 0.001 < 0.05$  (Table 3, row 5). From this analysis, however, it is not clear how these features influence the expressed emotion and how this influence depends on the current feature pose.

In order to investigate this influence quantitatively, the dependency between expressed emotion states and feature inclination angles is examined. These results from the study are shown in Figures 9 to 11, which are discussed in the following.

## 4.1 Discussion

The results of the study generally show that the individual perceived emotional expressions are shifted along the dimensions of affective space dependent on expressed emotion and inclination angles. An interesting aspect to be noted is that obviously the

impact of the animal-like features is different depending on the current state in affective space. While for some emotions a shift towards positive valence and higher arousal side can be noted (e.g. for 'disgust', Figure 9), the impact of ears and comb is rather reverse for other emotions (e.g. for 'surprise', Figure 9).

Particularly for 'surprise' a beneficial contribution of these expressive features is apparent. Without animal-like features, a significant divergence between measured 'surprise' and ground truth was present as discussed in Section 3. With these features attached, however, the measured state approaches neutral valence as the inclination angles increase, which is characteristic for ground truth 'surprise'.

In case of the state 'disgust' the arousal component is negative without the animal-like features. As the inclination angles of ears and comb rise, the state approaches neutral arousal, which is characteristic for ground truth 'disgust'. Thus, also a beneficial impact is notable for 'disgust'. However, its valence component is still too large.

Evaluating the propagation of the perceived emotions in Figure 9 straightforward control commands can now be derived in order to improve the expressions of 'surprise' and 'disgust' using the ears and comb in addition to the facial elements covered by FACS. In case of 'surprise' a full extension of these features and in case of 'disgust' a slight extension contribute to approach ground truth of both emotions to be expressed. Considering again the global positive shift due to the lip design deficiency it can be expected that ground truth 'surprise' and 'disgust' are nearly perfectly achievable after a modification of the lips using the animal-like features ears and comb. This is a nice result considering that EDDIE's and human facial Action Units differ substantially. It is, thus, obvious, that introducing additional features may strongly contribute to an improvement of the expression of artificial emotions even if some Action Units of FACS are not realized well.

Similar results can be noted for the expressions 'happiness' and 'sadness' shown in Figure 10. An increase of the inclination angles of ears and comb shifts the state 'happiness' slightly towards ground truth. In case of 'sadness' a shift towards ground truth is notable only for the arousal dimension, while valence stays nearly constant.

However, for both of these emotions the beneficial impact of the animal-like features is weaker than for 'surprise' and 'disgust'.

A different behavior is notable for expressions 'anger' and 'anxiety' shown in Figure 11a. There, no clear tendency of the progression of the perceived facial expression with increasing inclination angles is visible as the emotion state rather jumps forth and backwards. Thus, no arrows are shown in Figure 11a. Obviously, in this case no beneficial impact of the additional animal-like features is present.

However, looking at Figure 11b additionally showing the dominance dimension, it can be noted that both expressions are strongly shifted apart along the dominance axis with 'anger' having a significantly higher dominance than 'anxiety' with ears and comb fully extended. This result is consistent with the ground truth values for both states. In consequence, it can be concluded that the additional animal-like features beneficially contribute to distinguish both states from each other.

Summarized, it has been shown that the expressive non-FACS features of EDDIE have a significant impact on emotion expression. The variation of the individual expressions with the amount of extension of these features is different for the individual expressions. Moreover, the expressive features contribute to improve the expression of particular emotions. In a more general context, the described way the semantic differential approach can be utilized as a generic means to evaluate the influence of actuated expressive elements of an arbitrary kind on the perceived emotion. The knowledge gained from such evaluation procedures can then be used for the derivation of control commands for those expressive elements as discussed. Thereby, actuated expressive features of arbitrary design can be systematically controlled in order to intensify or attenuate the displayed emotion in a particular selected dimension, e.g. valence, arousal, dominance in case of the affective space as explained for the expressions 'surprise' and 'disgust'.

emotion	dimension	factor	F-value	p-value
1, 2	V	comb	F(3,12)=4.013	0.034
1, 2	V	ears * comb	F(9.36)=3.631	0.003

1, 2	A	ears * comb	F(9,54)=3.258	0.003
3, 4	V	ears * comb	F(9,18)=5.843	0.001
5, 6	V	ears	F(3,6)=4.835	0.048
5, 6	V	ears * comb	F(9,18)=4.132	0.005
5, 6	A	ears	F(3,6)=67.582	0.000
5, 6	A	comb	F(3,6)=11.987	0.006
5, 6	D	ears	F(3,62)=46.724	0.000
5, 6	D	ears * comb	F(9,18)=9.463	0.000

Table 3. Results of 2x2 ANOVA, repeated measures. (1: happiness, 2: surprise, 3: anxiety, 4: sadness, 5: anger, 6: disgust; V: valence, A: arousal, D: dominance) (Bittermann, Kühnlenz & Buss, 2007).

## 5. Conclusions

In this article the influence of animal-like features in addition to standard features covered by the Facial Action Coding System (FACS) on emotion expression of a robot head is investigated in user studies. It is found that those features have a significant impact on emotion expression. Moreover, depending on the expressed emotion state different progressions of the expression in affective space with increasing inclination angles of the animal-like features are found. It is shown, that with such animal-like features and for certain inclination angles ground truth emotion states are matched better than with only FACS-related features. By evaluation of these results it is discussed that control commands for such animal-like features can be derived in order to improve the emotion expression of the robot. The results show that emotion expression can be improved by considering also features, which are not FACS-related. So, particularly for robots, where robotic expressive features do not match the muscle groups of individual FACS Action Units well or if certain Action Units are missing, e.g. if a rather technical design of the robot is chosen, the use of animal-like or fictionally designed features can be particularly beneficial in order to compensate such mismatches and the resulting degradation of emotion expression. Of course the presented work has limitations as

currently only quasi-static analyses are conducted. Dynamic properties, however, may also have a significant impact, e.g. the time-dependent trajectory of the expressive features. These aspects, however, would have to be considered in tight connection with interaction situations, which would go beyond the scope of this article and are, thus, subject to future work.

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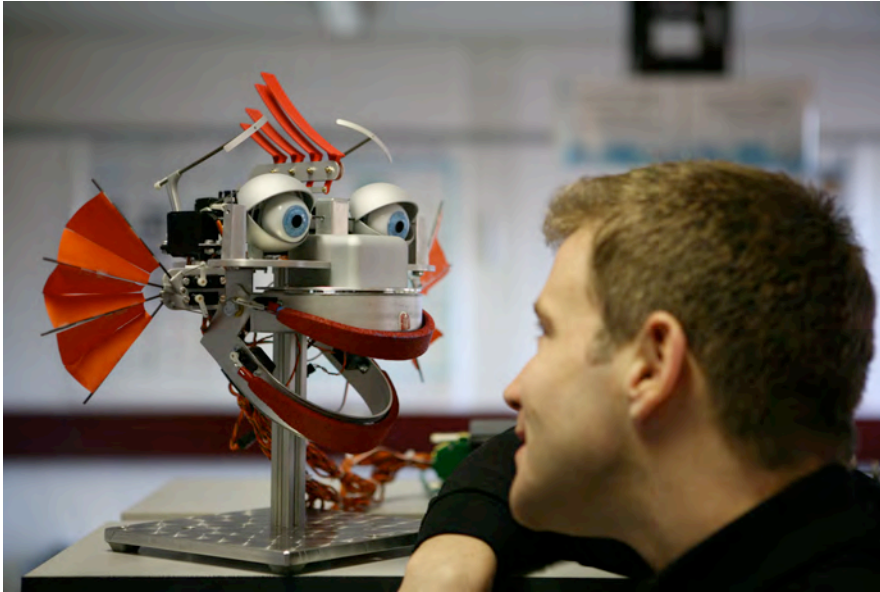


Figure 1. Robot head EDDIE with actuated features for displaying facial and non-facial expressions (Kühnlenz, 2006).

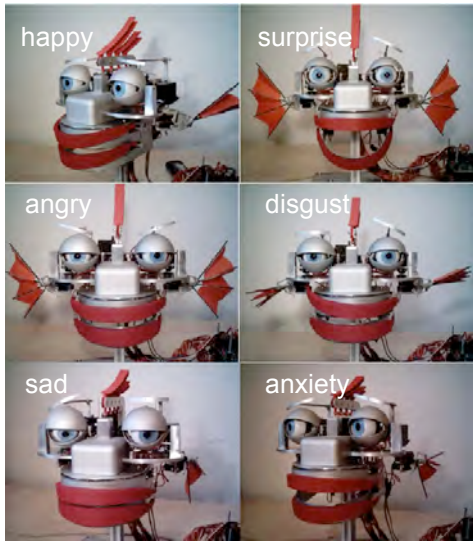


Figure 2. Expressions of EDDIE.  
(Sosnowski, Kühnlenz & Buss, 2006a).



Figure 3. Mechanical details.  
(Sosnowski, Kühnlenz & Buss, 2006a).

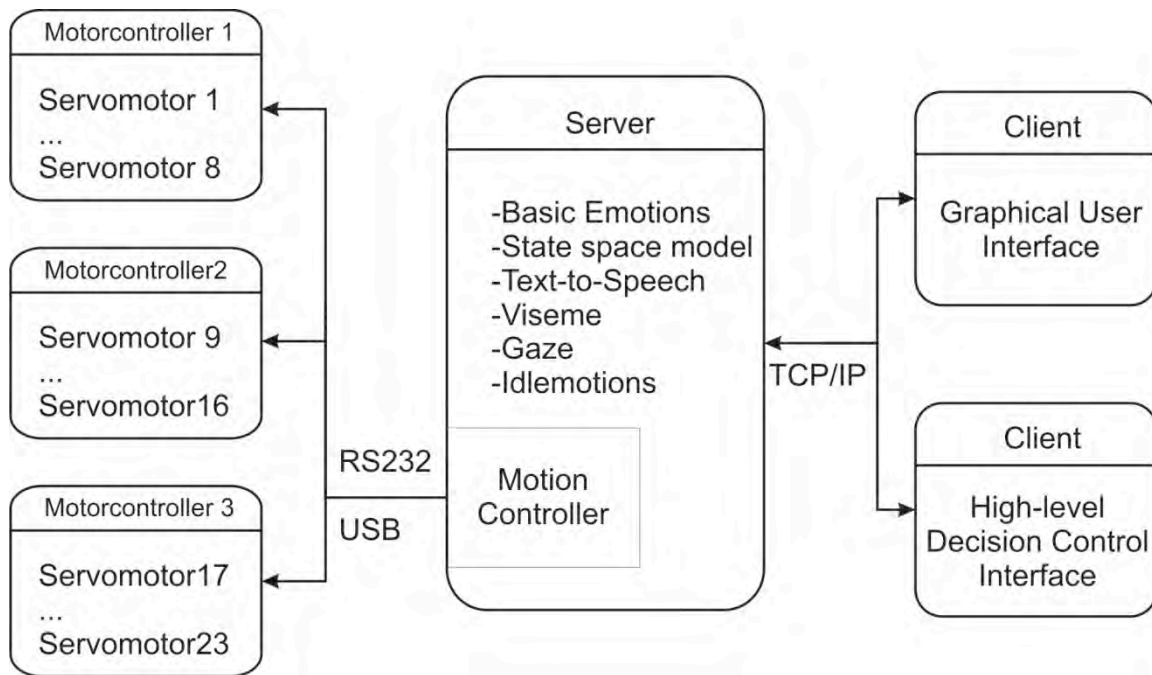


Figure 4. Overview of the control architecture

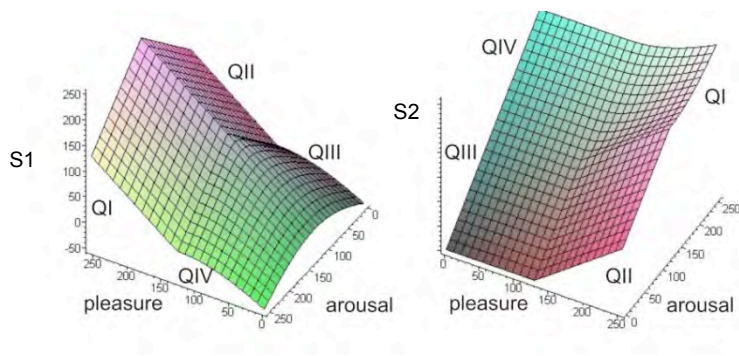


Figure 5. S1 plotted in the Pleasure-Arousal domain

Figure 6. S2 plotted in the Pleasure-Arousal domain

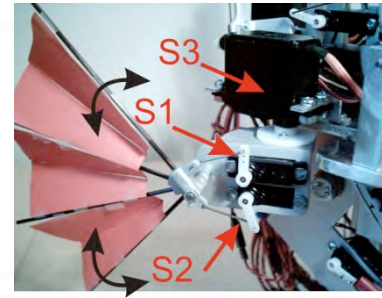


Figure 7. Positioning S1 to S3

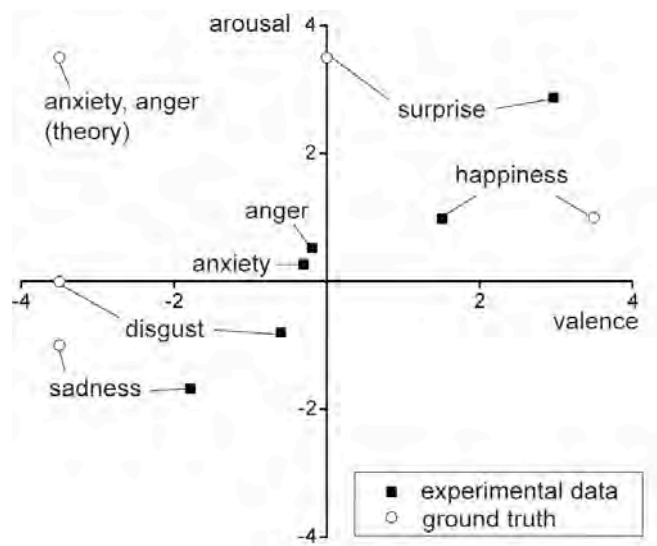


Figure 8. Results of dimensional evaluation study on EDDIE based on the semantic differential approach (without ears and comb).

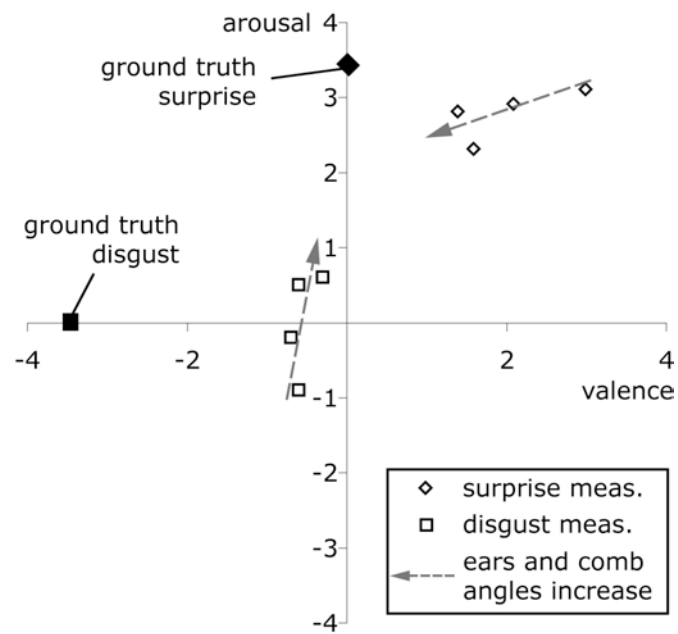


Figure 9. Results for displayed 'surprise' and 'disgust' of a dimensional evaluation study of EDDIE with varied angles of the ears and the comb.

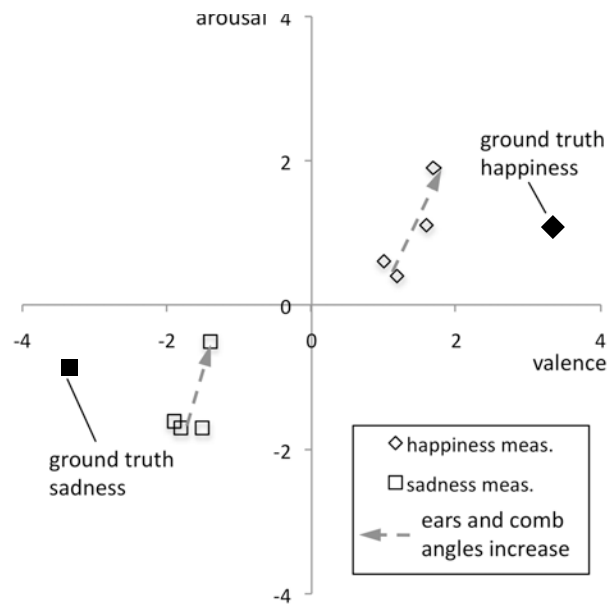


Figure 10. Results for displayed 'happiness' and 'sadness' of a dimensional evaluation study of EDDIE with varied angles of the ears and the comb.

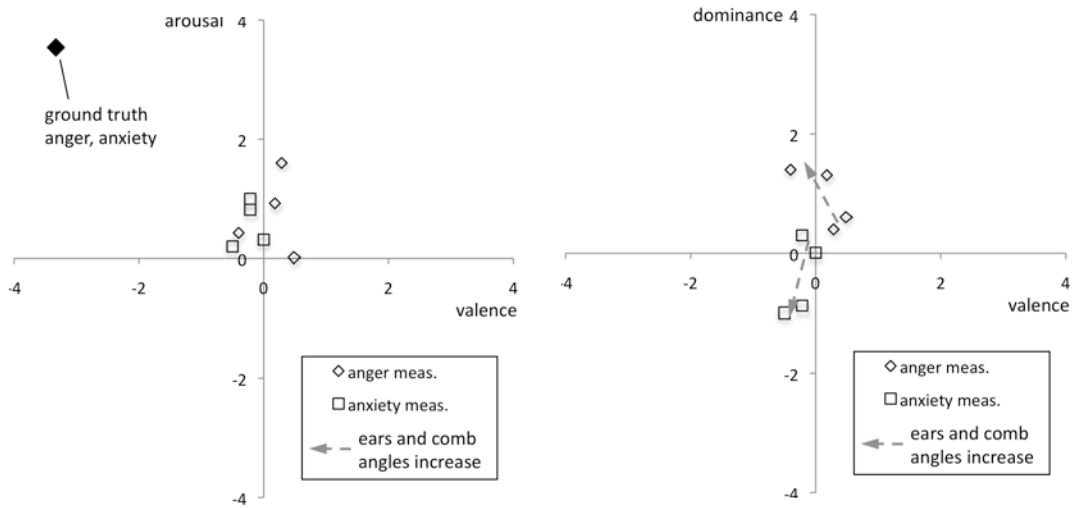


Figure 11. Results for displayed 'anger' and 'anxiety' of a dimensional evaluation study of EDDIE with varied angles of the ears and the comb; a) valence and arousal, b) valence and dominance.