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Emotion-based Architecture for Social Interactive Robots

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1. Introduction

Applications of robots as assistance systems in household, health- or elderly care lead to new challenges for roboticists. These robots need to fulfill complex tasks and navigate in complex human "real world" environments. One of the most difficult challenges in developing assistance robots for everyday life is the realization of an adequate human-robot interface. Traditional interfaces like mouse, keyboard, or joystick appear inappropriate because even untrained non-robot or computer specialists should be able to control the robot.
From our point of view, the best way to achieve this goal is, to enable the robot to "natural" human interaction. Since approx. 65% of the information in human-human interaction is conducted non-verbally (Birdwhistell, 1970), the robots need the abilities to recognize and express these non-verbal signals.
The now upcoming question, whether humans would accept and use these interaction abilities of a robot at all, can be answered by investigating two studies.
Firstly, in (Reeves & Nass, 1996) it is proved that humans tend to use their experiences and customs from human-human interaction in human-machine interaction. They treat their computer as if it has a mind, they talk to it, they have some special emotional connection to it, and they even give non-verbal signals that are used in human-human interaction to it although they know that it has no possibility to recognize or even understand them. These results suggest that humans would use the humanoid interaction abilities of a robot. In (Breazeal, 2002) it is shown that the usage of emotional expressions of a robot enhance the human-robot interaction. So if a robot would have the abilities for humanoid interaction humans would use these features.
Secondly, in (Watzlawick, 2000) it is pointed out, that social interaction takes place in every situation in which two or more persons are facing each other. So it is clear, that if a robot should act as partner of a human, it needs the abilities for social interaction.
In the following, psychological fundamentals that are necessary for the realization of social interactive robots are explained. Afterwards, the related work on social interactive robots is summarized and discussed. Then the emotion-based control architecture of the robot ROMAN of the University of Kaiserslautern is introduced and the results of some tests to evaluate this architecture are presented. Finally at the end, a summary of this chapter as

well as an evaluation of the developed architecture and an outlook for future work are given.

2. Psychological Insights

To enable a robot to interact socially, it is suggestive to investigate how social interaction between humans is realized. Psychological theories make statements about the involved components and their meaning to humans. In first place these components are motives and emotions. To have a social interactive robot it seems appropriate to transfer these components to the technical system.
In the following the definition of "social interaction" is discussed. Afterwards the involved psychological components, emotion and motives, are investigated. The function of emotions for the social human-human interaction as well as the importance of a motivation component is illustrated. Finally the relation between these psychological approaches for the social human-human interaction and the emotion-based architecture of ROMAN are pointed out.

2.1 Social Interaction

Psychologists differ between the two terms: "social interaction" and "social communication". Both terms are central for the human life in social groups.
Social interaction describes the alternating sequence of actions between humans that react on each others actions (Ulich, 2000).
Social communication describes the percipience and the exchange of information between two or more humans (Hobmair et al., 2003).
These definitions forebode that social interaction and social communication are closely connected to each other. It is not possible to have social interaction without social communication and vice versa. If people are influencing each other by their actions they are also transmitting information. If someone gives information to a person, this person is automatically influenced in some way. Because of this, in the following, the term "social interaction" will be used for both, interaction and communication.
As mentioned in (Canamero, 1997; Canamero & van de Velde, 1997) emotions play a major role in guiding and motivating actions in social interaction situations. The emotional state reflects the level of success of the interaction; it is conducted to the interaction partner by the emotional expressions. This information enables one interaction partner to react more precisely to the other one. That way misunderstanding can be prevented.

2.2 Emotion

In psychology there exist several theories about the generation of emotions (Hobmair et al., 2003). With the help of these theories the meaning of emotions to social interaction can be worked out. An overview of emotion theories can be found in (Ulich & Mayring, 1992). Two of the theories mentioned there are discussed in the following. Darwin postulated the evolutionary biological theory stating that the correlation between feeling and the expression are the same all over the world and they are inborn. That means that these expressions can be used all over the world for communication what means an enormous benefit unlike to speech. Functionalist oriented component-stress-models like postulated by

Lazarus or Leventhal, mention that emotions are the results of the evaluation of specific goals. This already happened in the beginning of mankind. That means that emotions are the result of the adaption of humans to a highly complex environment. In summary, emotions are correlated to specific expressions and they are necessary for the interaction with a complex environment.
Emotions include changes in physical and psychical state. These changes are perceived by humans and are rated as comfortable or uncomfortable. Therefore emotion mainly influences the behavior of humans.

In (Hobmair et al., 2003) several functions of emotions are pointed out:

- **Selective function**: Emotions influence the perception of the environment as well as the perception of internal stimuli.
- **Expressive function**: This is the most important function for social interaction. Facial expressions, gesture, body posture, and the tone of the voice are changed by emotions. These changes are used to conduct non-verbal information.
- **Motivational function**: Emotions activate and control the behavior of humans. Humans try to experience comfortable rated emotions again and try to avoid uncomfortable emotions.

This motivational function of emotions is the main reason for humans to interact. They want to reach a certain goal and as long this goal is not reached negative emotions are experienced. To explain this motivating and goal generating processes the theoretical construct of motives and motivation was invented (Hobmair et al., 2003). Therefore it is also necessary to investigate motives in order to explain the human interaction.

2.3 Motives and Motivation

Motivation is, unrecognizable from outside, a reason that activates and controls human acting in order to achieve a specific target. These reasons are named motives (Mietzel, 2000). When motives activates, goal directed behaviors are stimulated. This process is called motivation. So motivation is a state of activity that is controlled by motives. This state of activity lasts until the specific goal is reached or a motive of a higher priority gets active (Hobmaier, 2003).

According to (Hobmair et al., 2003) a motive is defined by five criterions:

- **Activation**: Specific behaviors are activated
- **Direction**: The activity is directed to a specific goal and lasts until this goal is reached or a motive of a higher priority level gets active
- **Intensity**: The intensity of the activity of a motive can vary
- **Duration**: In most cases the activity is maintained until the specific goal is reached.
- **Motivation**: A theoretical construct to explain the reasons for the observed behavior

The intensity of a motive does not only depend on the strength of the releasing stimulus. As mentioned in (Toman, 1973), motives have a time depending **cyclical character**. That means the more time passed since the last stimulation, much higher the intensity of the motive will

be. On the other hand, if a motive was active, just a few seconds ago, the same stimulus will only cause a little or even no intensity.
The activation of motives is explained using the control-loop-theory (Hobmair et al., 2003). The difference between the actual-state and the target-state leads to activity of the motives.

In summary, to realize social interaction an emotional state is necessary, because it is responsible for the human adaption to complex situations – like an interaction. This emotional state influences the perception system. It is also responsible for the expressions during the interaction. These expressions are of enormous importance for the interaction since they can be understood all over the world. Finally emotions are necessary to generate goals. The satisfaction of these goals is the reason why humans interact at all. So, the model to describe the human interactive system consists of an **emotional state**, a **perception system**, an **expressive system**, and a **motivational system**.

3. Social Interactive Robots and Agents

A number of research projects focus on human-robot interaction. In general the generated systems can be divided in embodied (robot or avatar) and disembodied systems. Since disembodied systems have the disadvantage that they can not use non-verbal signals for their interaction they are not taken into account in this chapter, as non-verbal signals are essential for social human interaction. In the following some representative projects for the generation of embodied systems for social human-robot interaction are presented.
There are a lot of systems that have the abilities to express emotions but they are lacking an architecture consisting of an internal emotion or motivation system, but as mentioned in section 2 this is essential for realizing adapted behavior in interaction situations. The different expressions are triggered by some specific events, e.g. the recognition of a special word. One of these systems is the humanoid robot Barthoc (Hackel et al., 2006). This robot has a huge number of degrees of freedom; therefore it is able to use gestures, facial expressions, body posture, and speech to interact with humans. It also has the abilities to recognize speech and to detect humans by its camera system. Another project in this area is Fritz (Bennewitz et al., 2007). Fritz is a communication robot that is able to walk – a biped robot – to interact by speech, facial expressions and gestures. A very interesting aspect in this project is the emotion expression by the tone of the voice. Therefore, the emotional state is mapped to speed, frequency, and volume of the voice.
A very complex and advance emotion architecture for social interaction is realized in the virtual agent Max (Becker-Asano et al., 2008). The architecture consists of a cognition module and an emotion module. The cognition module generates goals, depending on the achievement of these goals the emotion module is changes. The emotion module influences the cognition module by directly triggering behaviors or by defining goals, like experiencing positive emotions. That way, Max is able to generate dynamic sequences of emotional expressions in interaction situations. Although, as mentioned in (Bartneck et al., 2004), virtual agents have the disadvantage that they are not physically present and can not manipulate the real world, move, react on or use touching, this approach provides a lot of interesting aspects. Especially the experience in the combination of cognition and emotion in one control architecture is useful for future work on social interacting robots.

Certainly one of the best known projects in the area of social interactive robots is Kismet (Breazeal C. & Brooks R., 2005). Kismet was the first robot that is able to generate sequences of behavior and emotional expressions in an interaction situation. Besides the facial expressions Kismet is also able to generate sounds. These sounds are also adapted to the actual emotional state. The control architecture of Kismet consists of an emotional state, a perception system, a drive system for intrinsic motivation, and an expression system for generating emotional expressions and behavior. The emotional state also selects the group of possible behaviors. For behavior activation a drive system is used. The drives calculate their satisfaction depending on sensor data and activate different behaviors of the predefined group in order to reach a satisfied state again. Although the emotion representation and – depending on this – the adaption to changing situations are limited to the predefined set of emotions and the corresponding behaviors, Kismet proved that social human-robot interaction is possible. The psychologically grounded architecture of Kismet can be used as starting point for further development of social interactive robots.
A project that is closely geared to Kismet is Mexi (Esau et al., 2007). Mexi is able to generate facial expression depending on its internal state. According to (Breazeal C. & Brooks R., 2005) this state depends on emotions and drives, however the underlying architecture is less complex than the architecture of Kismet. Because of this it is more limited in its interaction abilities. Furthermore Mexi uses a chatbot to communicate verbally. But the chatbot has no direct influence on the emotional state of the robot. So the emotional state can not be changed directly depending on the verbal interaction.
One of the most advanced projects in the area of social human-robot interaction is Qrio (Aoyama & Shimomura, 2005). Qrio is a complex biped humanoid robot that is able to navigate in human environment. Qrio was developed as entertainment robot. It has the abilities to interact with humans using speech, body posture, and gestures. In context of social interaction Qrio is missing the most important medium, the facial expressions. As already mentioned before, most information in an interaction is conducted non-verbally and the facial expressions are the most important non-verbal signals. For realizing the emotional influence on Qrio's behavior the emotion grounded architecture was developed. This control architecture of Qrio consists of a perception part, an emotion representation, predefined behaviors, and a memory part. A very interesting aspect of this architecture is the memorization of the experienced emotion in correlation to the perceived object. They call this method emotionally grounded symbol acquisition, which seems to be very useful for the development of social interactive robots. That way the emotions experienced in the interaction with a special person can be remembered if this person is met again.

4. The Emotion-based Architecture of the University of Kaiserslautern

The emotion-based control architecture supporting human-robot interaction is tested on the humanoid robot ROMAN (figure 1). For social interaction, ROMAN is equipped with 24 degrees of freedom (11 in the face, 3 in each eye, 4 in the neck and 3 in the upper body) to realize non-verbal signals. To detect its interaction partner as well as its operational environment, two Point Grey Dragonfly cameras are installed in the eyes, six microphones and four infra red distance sensors mounted in the upper body. More information on the mechatronics system can be found in (Hirth & Berns, 2007). Besides this, the dialog system –

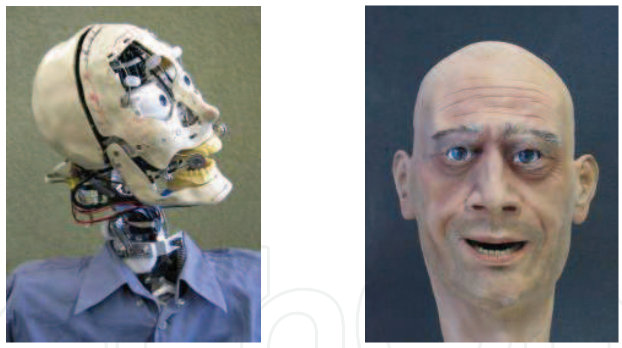

Fig. 1. The social interactive humanoid robot ROMAN, left: bare head, right: silicon skin clued on the head

based on speech synthesis and recognition – explained in (Koch et al., 2007) – is integrated to communicate using verbal speech.

For the realization of the emotion-based architecture, the integrated Behavior-based Control (iB2C) (Proetzsch et al., 2007) is used. According to section 2 the architecture consists of an emotional state, a perception system called percepts of interaction, the habits of interaction as an expressive system, and motives as motivational part (see figure 2). To achieve "natural" social interaction the goal of the implementation is to realize the functions of emotions: selective function (here: percepts of interaction), expressive function (here: habits of interaction), and motivational function (here: motives) besides this the characteristics of motives should be considered: activation, direction, intensity, duration, motivation, cyclical. The percepts of interaction perceive information of the environment. Depending on this information, direct responses – reflexes – performed by the habits of interaction are activated and the motives calculate their satisfaction. This satisfaction changes the actual emotional state of the robot. Besides this the motives activate several habits of interaction to change the robots behavior in order to reach a satisfied state. The actual emotional state influences the percepts of interaction, the motives, and the habits of interaction. In different

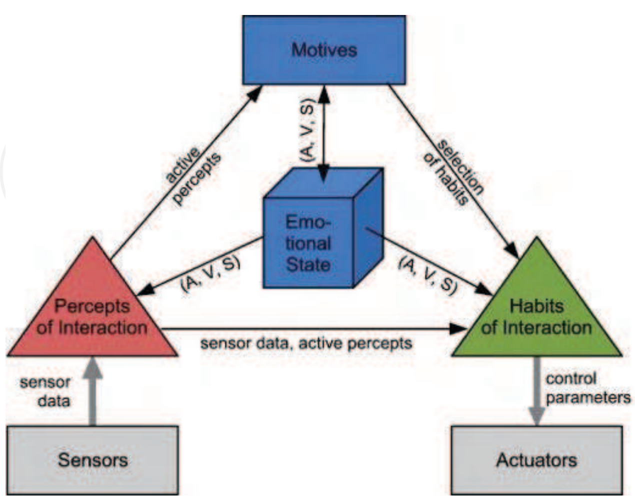

Fig. 2. The emotion-based control architecture, consisting of the four main groups, motives, emotional state, habits of interaction, and percepts of interaction; the emotional state of the system is represented by the 3 dimensions arousal (A), valence (V), and stance (S)

emotional states, the robot will interpret its environmental information in different ways and it will also act in a different way. For example if it is very nervous, its movements will be executed much faster and also its speech will be conducted much faster, than otherwise. Besides this, the actual emotion is displayed by facial expressions and body postures.

4.1 Emotional State

When creating emotion-based control architecture, the first question is how to describe an emotional state for using it in a humanoid. Looking to psychology leads to the so-called affective or emotion spaces. Several psychologists and cognitive scientists have designed different emotion representations: Like discrete affective vector representations (Ekman, 1992; Ortony et al., 1988), two dimensional representation (Plutchik, 1980; Russell 1980), and three dimensional representations (Broekens & de Groot, 2004; Mehrabian, 1996). A disadvantage of the discrete affective vector representation is that it lacks precision, because no continuous changes of the strength of a certain emotion are possible. In the two dimensional and especially in the three dimensional representations, the strength emotions can be described more precise and smooth continuous transitions between the several states can be realized. In two dimensional emotion representations the state is described by some kind of intensity value and a positive/negative rating. This does not suffice for the description of the complex state of an interaction. Therefor a third dimension representing the willing to interact is used. Because of this a three dimensional representation provides much more possibilities to specify the actual state. According to the studies of (Breazeal & Brooks, 2005; Lee et al., 2006), the emotional space shown in figure 3 was selected. The three axes of the emotional space are arousal (A), valence (V), and stance (S). Arousal specifies how thrilling a stimulus is to the robot. Valence describes how favorable or unfavorable a stimulus is to the system. High valence means the robot is very content with the situation and low valence means the robot is discontent. Stance specifies the attitude of the robot to the environment in a certain situation. High stance means the robot is willing to get new stimuli; low stance means the robot is not willing. In most emotional representations for every emotion a subarea in the emotional space is reserved. If the actual emotional state is

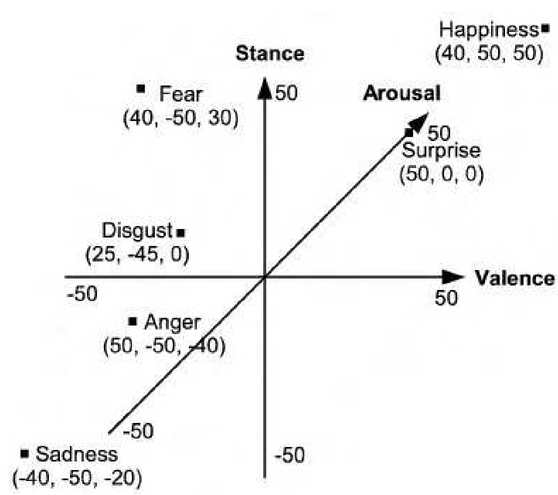

Fig. 3. The emotion space of ROMAN, this representation is used to define the actual emotional state of the system; every emotion can be described by the three parameters arousal, valence, and stance

within this area, the corresponding emotion is activated. That means every emotion that should be used has to be predefined. In psychology six basic emotions are distinguished: anger, disgust, fear, happiness, sadness, and surprise (Ekman & Friesen 1978) and all other emotions are mixtures of them. Because of this, the architecture does not work with a predefined number of emotions, but with the 3D-coordinates of an emotional state. This brings the advantage that every basic emotion, as well as mixtures of them, can be represented in the emotion space. An advantage in comparison to discrete emotion representations depends on the fact, that two emotional states that are located in the same subarea of the emotion space can be differentiated easily by using the coordinates.

According to the expressive and selective function of emotions, the whole robot behavior is influenced by the emotional state. If the robot is in a depressive state, for example, its movements and its speech will be slower and its voice will be deeper. By contrast, if the robot is very nervous, its movements will be very fast, the eyes and the eyelids will move with high frequency, and also its speech will be faster and the voice will be much higher.

The perception of the environment is also influenced. A certain situation will be interpreted in different ways depending on whether the emotional state of the robot is in a positive range or in a negative range.

4.2 Percepts and Habits of Interaction

The percepts of interaction are responsible for the detection of the environment. The sensor data is interpreted and combined to more complex information. That way a detailed description, e.g. of the interaction partner could be generated. Every environmental stimulus is represented by one percept. If the stimulus is detected, the corresponding percept is activated. Depending on the active percepts the motives determine their satisfaction with regard to the active percepts and the emotional state. Depending on the satisfaction of the motives, the emotional state is changed and the habits of interaction are stimulated (Strupp et al., 2008).

The habits of interaction describe the expression mechanism of the robot. As basic modules for the habits of interaction (Hirth & Berns, 2007) the behavior modules of iB2C, figure 4, are used.

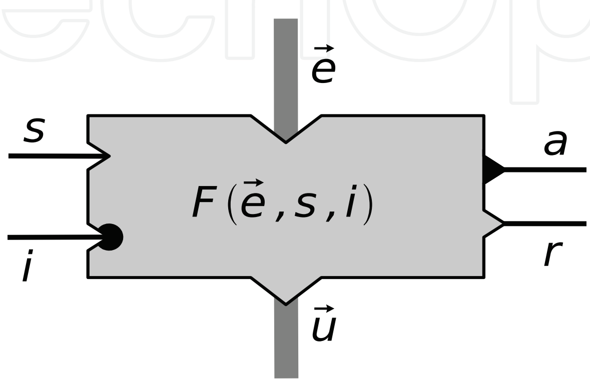

Fig. 4. The iB2C module: all habits of interaction are built out of these modules

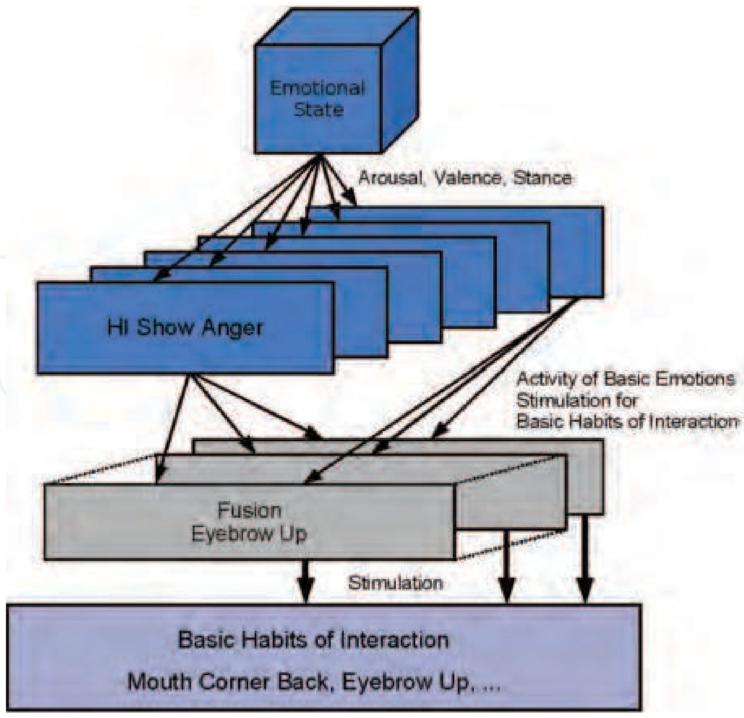

Fig. 5. The generation of emotional expressions using the concept of habits of interaction

These modules have three inputs: stimulation s, inhibition i and data input $\vec{e}$, and three outputs: activity a, target rating r and data output $\vec{u}$. In addition these modules have a function for
the calculation of the output data depending on the input: $F(\vec{e},s,i)=\vec{u}$ this function is called transfer function. The activation ι of a behavior is calculated depending on the stimulation and the inhibition: $\iota = s\cdot(1-i)$. More complex habits of interaction, e.g. emotional expressions, can be generated as a combination of basic habits of interaction. Habits of interaction concerning the same or similar body parts can be grouped. Based on the hierarchical ordering of the habits of interaction, different complexity levels can be generated. That way a complex behavior network for the generation of social behavior in an interaction situation is generated.

The most important function of the habits of interaction is the expression of ROMAN's emotional state. Therefore six habits of interaction representing the six basic emotional expressions (anger, disgust, fear, happiness, sadness, and surprise) are generated (figure 5). The (A,V,S)-vector representing the actual emotional state is the input of these modules. Depending on this vector every module calculates its activity. The activity of emotion$_i$, a_i where $i \in \{\text{anger}, \text{disgust}, \text{fear}, \text{happiness}, \text{sadness}, \text{surpise}\}$, is calculated in equation 1, where d denotes the diagonal of the emotion space (figure 3), P_i represents emotion$_i$ and $\vec{e}$ the input vector (A,V,S).

$$a_i = \frac{d - |P_i - \vec{e}|}{d} \tag{1}$$

For every basic emotion the specific expression, including facial and body movements, is defined depending on (Ekman & Friesen, 2002). To achieve more than just the basic emotional expressions the output is merged by a weighted fusion depending on their activity. That way it is possible to display a huge number of emotions instead of just the six basic ones.

4.3 Motives

To have a robot that uses an emotional state and that has the ability to express these emotions, leads to the question: how to activate these components. As explained in the model of (Mietzel, 2000) in section 2, a key factor for the social human-human interaction is to reach a certain goal. Without these goals humans would not interact with each other. As already mentioned, motives are generating goal directed behavior sequences. A certain motive is defined by its activation, direction, intensity, and duration. They represent the combination of emotions, needs, and their satisfaction.
The motives in the emotion-based architecture of ROMAN (Hirth & Berns, 2008) have an internal goal function that needs to be satisfied. They calculate their satisfaction depending on the activated percepts of interaction. This satisfaction influences the actual emotional state. The motives also try to change the robot's behavior in a way to reach a maximum of satisfaction. The output of different motives, that means the change of the emotional state and the activation of habits of interaction, is merged depending on the satisfaction of the motives. The lower the satisfaction of a motive, the higher is its influence on the robot behavior. In a robot system motives can be used to define some basic goals of the robot. For the use in a system for the interaction with humans some kind of communication motive seems to be appropriate. Also some kinds of safety motives are useful.

The motives are built using behavior modules of the iB2C-Architecture of the Robotics Research Lab (Proetzsch et al., 2007), see section 4.1. A motive (see figure 6) consists of three inputs (stimulation s sensor data $\vec{e}$ and inhibition i) as well as three outputs (control data $\vec{u}$, activity a, and target rating (satisfaction) r). In addition, it has four internal functions.
The first function $r(\vec{p},\vec{w},d,t)$ (see equation 2), calculates the target rating (satisfaction) of the motive by comparing the goal of the motive and the active percepts.

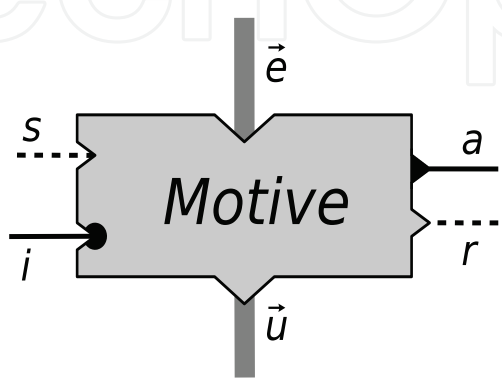

Fig. 6. A single motive module, of the emotion-based architecture of the humanoid ROMAN

$$r(\vec{p},\vec{w},d,t) = sigmoid\left(\left(\sum_{i=0}^{N} \frac{w_i}{\sum_{j=0,j\neq i}^{N} w_j} \cdot p_i\right) + t \cdot d\right) \tag{2}$$

Where N denotes the number of percepts, every percept $\vec{p}$ ($\vec{p}$ is part of the sensor data $\vec{e}$) represents one complex environmental information, e.g. the position of the interaction partner. The strength of the corresponding stimulus, e.g. the probability for the detection of a face, is represented by the activity of the percept. The weight vector $\vec{w}$ contains one weight for every percept; the weight represents the importance of the specific percept to the current motive. If the information, represented by the percept, is of maximum importance the weight value is 1 if it is completely unimportant the weight value is 0. As mentioned in section 2 every motive has a time depending characteristics, this is represented by $d \in [0,\infty]$. The time since the last stimulation of the motive is denoted by t, the strength of the influence of this time is specified by d. The sigmoid function is shown in equation 3.

$$sigmoid(x) = \frac{1}{2} + \frac{1}{2} \cdot \sin\left(\left(\frac{x - t_0}{t_1 - t_0} \cdot \pi - \frac{1}{2}\right) \cdot \pi\right) \tag{3}$$

The second function calculates the activation $\iota(s,i) = s \cdot (1 - i)$, where $i \in [0,1]$ denotes the inhibition input.
Depending on the activation and the target rating, the third function of a motive calculates the activity $a(r(\vec{e},\vec{w},d,t),\iota)$ (see equation 4). The activity-function of a motive is a piecewise defined function in which the interval $[0,t_0]$ denotes the inactive area of the motive, $[t_0,t_1]$ the area in which the activity is calculated based on $r(\vec{e},\vec{w},d,t)$ and $[t_1,1]$ means the satisfaction area. The codomain for the satisfaction function as well as for the activity function is $[0,1]$, corresponding to the control-loop-theory explained in section 2.

$$a(r(\vec{e},\vec{w},d,t),\iota) = \tilde{a}(r(\vec{e},\vec{w},d,t)) \cdot \iota \tag{4}$$

$$\tilde{a}(r(\vec{e},\vec{w},d,t)) = \begin{cases} 0, \text{ if } r(\vec{e},\vec{w},d,t) < t_0 \\ 1, \text{ if } r(\vec{e},\vec{w},d,t) > t_1 \\ r(\vec{e},\vec{w},d,t), \text{ else} \end{cases}$$

Finally the fourth function of a motive determines the control data $\vec{u} = F(\vec{e})$ that change the emotional state and contain stimulation and control values for the Habits of Interaction.
That way the characteristics of a motive mentioned in section 2 are realized:

- Activation, by $\iota(s,i)$
- Direction, by the internal goal function
- Intensity, by $a(r(\vec{e},\vec{w},d,t),\iota)$
- Duration and Cyclical character, by $r(\vec{e},\vec{w},d,t)$

- Motivation, by $\vec{u}$

As described above a motive gets active if the discontent value exceeds t_0 . The motive than calculates $\vec{u}$ for changing the robot's behavior in order to reach a saturated state. If the saturation of the motive is getting higher, the activity of the motive is getting lower. In addition every motive consists of different states. In every state the weight vector $\vec{w}$ as well as the dependence of time d may change. That way the generated motives realize the above mentioned request that they act in a completely different manner depending on their progress and on the environmental situation.

Motives that realize similar behaviors are grouped together. Within these groups the different motives can be realized on different priority levels or also on the same priority level. Motives on higher priority levels inhibit motives on lower levels, depending on their activity. For generating the output of a motive group, the output of a single motive is merged by a weighted fusion. The different motive groups are also realized on different priority levels. Groups on higher priority levels inhibit groups on lower levels. The activity of a motive group is represented by the activity of the corresponding fusion module and the inhibition of a motive group is realized by inhibiting this fusion module. Because of this modular set up the motive system remains maintainable and it can easily be exchanged or extended. The motives that are implemented at the moment and their functions are listed in table 1.

Motive	**Function**
Obey humans	If a human gives the robot the order to do something it will stop its actual work and obey this order.
Self-protection	Generate an evasive movement, if a close object is detected.
Energy consumption	If the robots energy is low it will try to get new energy, by telling humans in its surrounding.
Avoid fatigue	If the load is to high this motive avoids the starting of new processes.
Communication	If a person is detected this motive tries to start a conversation and takes care that the person is focused.
Exploration	If the robot is getting bored because of the absence of stimuli, this motive starts the exploration of the robots surrounding.
Entertainment	If ROMAN is exploring its environment but does not get any interesting stimulus, this motive gets active. ROMAN starts to sing a song especially to attract the interest of humans in its surrounding.

Table 1. All motives of interaction implemented at the moment in the control architecture of ROMAN

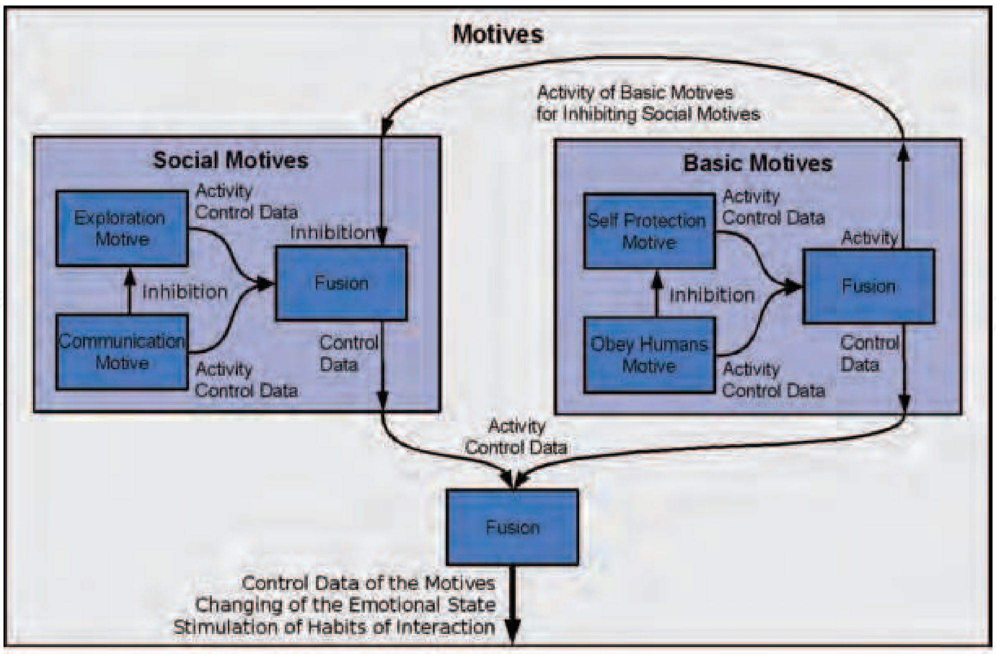

Fig. 7. An extract of the realized motive system; basic motives have a higher priority level than social motives

As an example an extract of the realized motive network is explained (see figure 7). In this example two motive groups are illustrated. The first group is the "social motives" that contains the "exploration motive" and the "communication motive" and the second group are the "basic motives" that contains the "self protection motive" and the "obey humans motive". Within the "social motives" the "communication motive" is on a higher priority level than the "exploration motive", therefore the "exploration motive" is inhibited by the "communication motive". The control data output of both motives is merged by a weighted fusion depending on the activity of the different motives. In the "basic motives" group, the "obey humans motive" has a higher priority than the "self protection motive". That way multiple groups of motives can be generated. These groups are also considered as motives. They are included in a larger group called "motives". In this example the "basic motives" are on a higher priority level than the "social motives", so the "social motives" are inhibited by the "basic motives". The output of the single motive groups is also merged by a weighted fusion depending on the activity of the different groups. This activity represents the activity of the single motives within a group.

5. Evaluation and Results

To test and verify the emotion-based architecture different experiments have been developed and conducted. In these experiments the single parts of the emotion-based architecture – percepts of interaction, habits of interaction, emotional state, and motives – were tested.

5.1 Percepts of Interaction

The percepts of interaction were used to realize a camera based emotion detection system. First experiments of this system show correct detection rates of about 60% for the emotions happiness, sadness, and surprise. Since the percepts of interaction are not in the main focus of this chapter no detailed description of these experiments will take place here. For more information see (Strupp et al., 2008).

5.2 Habits of Interaction and Emotional State

In this experiment the subsystem of the habits of interaction for generating emotional expressions in combination with the representation of the emotional state were tested.

Experimental Setup: Nine images (figure 8) and nine videos showing the facial expressions of ROMAN were presented to 32 persons (13 women and 19 men) of the age ranging from 21 to 61 years. Every person has to rate the correlation between presented expression and the six basic facial expressions with grades from 1 to 5 (1 means a weak and 5 a strong correlation). The videos were chosen instead of the robot to achieve the same presentation of the expression for every subject. This is important because the position of the robot and the subject may influence the rating of the expression strength. To avoid these problems and in order to get comparable results the video presentation was preferred. The program used for the analysis of the evaluation was the SPSS[1] (Statistical Package for the Social Scientist). The results of the evaluation are shown in table 2 and in table 3. The left column contains the shown facial expression. The right column contains the average values of the detected correlation between the six basic facial expressions and the current picture or video.

Fig. 8. Basic facial expression from left to right: anger, disgust, fear, happiness, sadness, and surprise

[1] http://www.spss.com/de/

Presented emotion	Detected strength
Anger	Anger: 4.5, Disgust: 1.8, Fear: 1.5, Happiness: 1.0, Sadness: 1.4, Surprise: 1.2
Disgust	Anger: 1.7, Disgust: 2.6, Fear: 1.0, Happiness: 2.6, Sadness: 1.2, Surprise: 3.7
Fear	Anger: 1.4, Disgust: 1.8, Fear: 3.6, Happiness: 1.5, Sadness: 1.8, Surprise: 3.8
Happiness	Anger: 1.1, Disgust: 1.0, Fear: 1.2, Happiness: 4.3, Sadness: 1.0, Surprise: 2.3
Sadness	Anger: 2.2, Disgust: 1.3, Fear: 2.8, Happiness: 1.0, Sadness: 3.9, Surprise: 1.3
Surprise	Anger: 1.3, Disgust: 1.3, Fear: 2.7, Happiness: 1.4, Sadness: 1.6, Surprise: 4.2
50% Fear	Anger: 1.5, Disgust: 1.5, Fear: 3.0, Happiness: 1.6, Sadness: 1.8, Surprise: 2.8
Anger, Fear, and Disgust	Anger: 3.0, Disgust: 2.4, Fear: 2.0, Happiness: 1.0, Sadness: 2.5, Surprise: 1.4
50% Sadness	Anger: 2.2, Disgust: 2.4, Fear: 2.8, Happiness: 1.0, Sadness: 3.7, Surprise: 1.3

Table 2. The results of the experimental evaluation of the images

Experiment Results: The results of the evaluation show that the correct recognition of the facial expressions anger, happiness, sadness and surprise is significant (significance $\alpha < 5\%$). But the facial expressions fear and disgust are not identified that good. Furthermore the results show that in most cases there are no significant differences between the evaluation of the pictures and the videos (significance $\alpha < 5\%$). Due to continuous human machine interaction the result of the video experiment is more important. The analysis of the understated emotions (fear 50% activation and sadness 50% activation) show, the subjects recognize that the facial expression is not that strong than in the case of 100% activation. The evaluation of the anger, fear and disgust mixture shows that in this case no facial expression is identified. But the selected facial expressions are named in the most cases (similar to the interpretation of comparable human faces expressions). Compared to psychological experiments for the recognition of human facial expressions there was no significant difference in the evaluation of the basic emotions anger, happiness, sadness and surprise.

5.3 Motives

To check the functionality of the motive system another experiment was conducted. In this experiment, the activation, activity and target rating of the involved motives and some other, interesting for the actual scenario, are monitored. These values are displayed in diagrams where the y-axis represents the monitored value and the x-axis represents the time in seconds. In the following we present the results of two representative runs.

Presented emotion	Detected strength
Anger	Anger: 3.7, Disgust: 2.1, Fear: 2.7, Happiness: 1.4, Sadness: 1.7, Surprise: 1.7
Disgust	Anger: 3.0, Disgust: 2.6, Fear: 1.9, Happiness: 1.0, Sadness: 2.3, Surprise: 1.5
Fear	Anger: 1.9, Disgust: 1.5, Fear: 3.3, Happiness: 2.5, Sadness: 1.5, Surprise: 3.3
Happiness	Anger: 1.1, Disgust: 1.0, Fear: 1.1, Happiness: 4.3, Sadness: 1.1, Surprise: 2.5
Sadness	Anger: 1.6, Disgust: 1.5, Fear: 1.9, Happiness: 1.1, Sadness: 3.6, Surprise: 1.5
Surprise	Anger: 1.6, Disgust: 1.6, Fear: 3.5, Happiness: 1.3, Sadness: 1.3, Surprise: 4.6
50% Fear	Anger: 2.0, Disgust: 1.8, Fear: 3.2, Happiness: 1.4, Sadness: 1.8, Surprise: 3.5
Anger, Fear, and Disgust	Anger: 1.9, Disgust: 1.4, Fear: 2.4, Happiness: 1.2, Sadness: 3.4, Surprise: 1.5
50% Sadness	Anger: 1.6, Disgust: 1.4, Fear: 2.0, Happiness: 1.1, Sadness: 3.5, Surprise: 1.5

Table 3. The results of the experimental evaluation of the videos

Experimental Setup: For the first experiment, the exploration-motive, communication motive and the self-protection motive are activated. A person stands at one side of ROMAN. That means the robot needs to turn its head to see this person. The activation, the activity, and the target rating of the different motives are recorded.

Expected Behavior: It is expected that the exploration motive gets discontent, which will be displayed by a rising target rating value. This will initiate a turning of the head. If the robot recognizes the person; the communication motive should get discontent because it wants to start a dialog with the person. If the target rating-value of the communication motive reaches the maximum, this motive will get active. It should inhibit the exploration motive and start a dialog. During the dialog the person should step closer towards the robot. This should cause an activation of the self-protection motive. The robot should move backwards and asks the person to step back. Afterwards, when the person has stepped back, the dialog should be resumed to completion.

Experiment Results: The results of this experiment are shown in figure 9. The exploration motive gets discontent and active, turns the robot's head and detects the person. After approx. $5s$ the communication motive gets active and the exploration motive is inhibited. After approx. $45s$ the target rating of the communication motive increases as the probability rate of the human detection decreases. Approx. at $50s$ the target rating of the communication reaches 1 (maximum) and the exploration gets active again. But a few

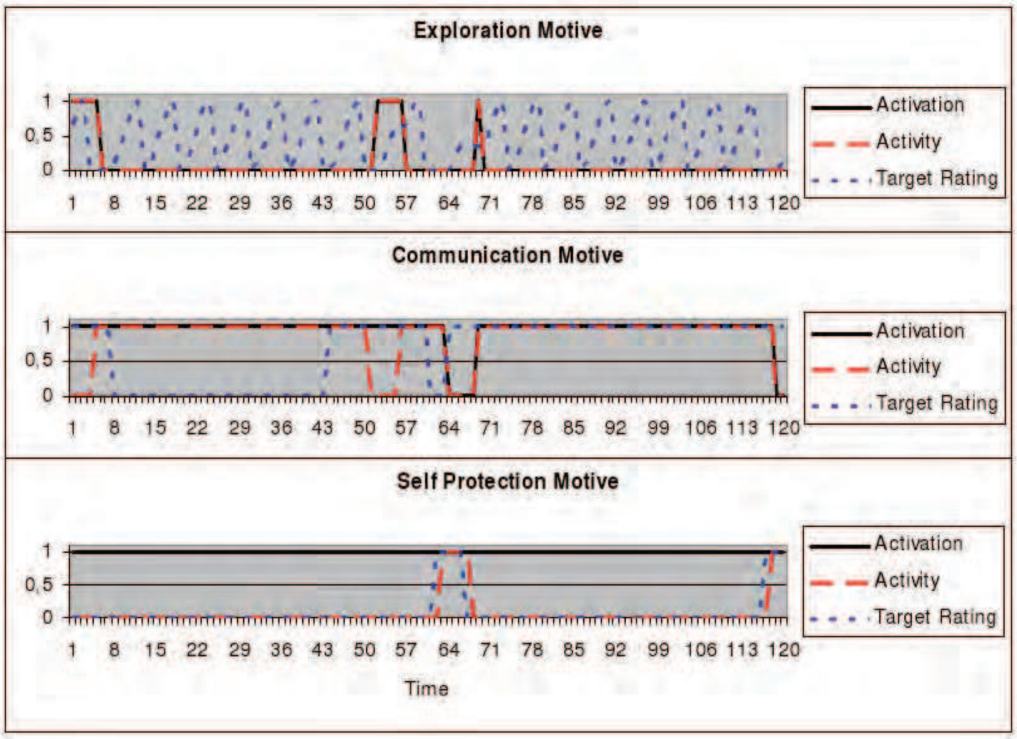

Fig. 9. The results of the experiment: the activities and discontents of the exploration motive, communication motive, and follow object behavior during a communication are measured

seconds later the subject is detected again and the communication continues. After approx. $58s$ the target rating of the self protection motive increases as the subject is too close to ROMAN. The activated motive inhibits all other motives, activates an evasion behavior and tells the human to step back. After approx. $68s$ the target rating and the activity of the self protection motive reaches 0 again and the communication is restarted.

6. Conclusion

This chapter explained the benefit of social interaction for humanoid robots by presenting psychological background of social interaction and ways to realize social interaction on a robot. The state-of-the-art in developing social robots was discussed in detail. Afterwards the humanoid robot ROMAN was introduced and the developed emotion-based control architecture that enables ROMAN to interact socially was explained in detail. Finally the results of some tests to evaluate this architecture were presented.

Although the structure of the emotion-based architecture will not be changed, the several subsystems need to be extended and the communication between these systems needs to be improved. For future, the amount of observable behaviors by the percepts of interaction will be increased. The habits of interaction will be extended by the integration of arms and hands in order to use gestures for the communication. That will increase the expressiveness of ROMAN enormously. In order to realize situation adapted behavior in interaction situations it is necessary to investigate, which motives are necessary. Therefore an interaction situation needs to be developed and studied in cooperation with psychologists. Furthermore

psychological experiments need to be conducted where the impressions of ROMAN to humans are evaluated and also the quality of the interaction has to be evaluated.
As final test-scenario, an interaction situation could be mentioned where the robot should assist a human in solving a problem. This problem might be a tangram-game which the robot knows how to solve. By investigating its human partner, the robot should then adapt its expression and helps to the situation.

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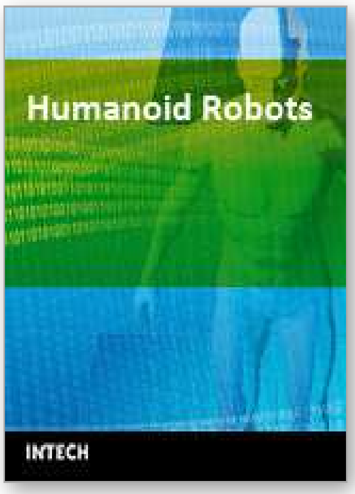

Humanoid Robots

Edited by Ben Choi

ISBN 978-953-7619-44-2

Hard cover, 388 pages

Publisher InTech

Published online 01, January, 2009

Published in print edition January, 2009

Humanoid robots are developed to use the infrastructures designed for humans, to ease the interactions with humans, and to help the integrations into human societies. The developments of humanoid robots proceed from building individual robots to establishing societies of robots working alongside with humans. This book addresses the problems of constructing a humanoid body and mind from generating walk patterns and balance maintenance to encoding and specifying humanoid motions and the control of eye and head movements for focusing attention on moving objects. It provides methods for learning motor skills and for language acquisition and describes how to generate facial movements for expressing various emotions and provides methods for decision making and planning. This book discusses the leading researches and challenges in building humanoid robots in order to prepare for the near future when human societies will be advanced by using humanoid robots.

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