Integrating Emotional Competence into Man-Machine Collaboration

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Abstract Emotional competence plays a crucial role in human communication and hence should also be considered for improving cooperation between humans and robots. In this paper we present an architecture and its realization in the robot head MEXI, which is able to recognize emotions of its human counterpart and to react adequately in an emotional way by representing its own emotions in its facial expression and speech output. Furthermore, mechanisms for emotion and drive regulation are presented. Therefor MEXI maintains an internal state made up of (artificial) emotions and drives. This internal state is used to evaluate its perceptions and action alternatives and controls its behavior on the basis of this evaluation. This is a major difference between MEXI and usual goal based agents that rely on a world model to control and plan their actions.

1 Introduction

Quality of human collaboration in accomplishing a specific task does not only depend on their objective competences regarding fulfillment of that task but also on their emotional competence which determines their behavior as a group. The same certainly also holds for tasks to be fulfilled by humans in cooperation with machines or robots. Accordingly, it seems reasonable to equip machines with emotional competence for improving the quality of task accomplishment, i.e. the task's result and the task accomplishing process itself. According to [1] and [2] emotional competence includes several aspects like the abilities to recognize and represent emotions, which are in the focus of many researchers nowadays. But emotional competence also includes mechanisms for emotional behavior, which means adequate reaction on emotions recognized at others, and emotion regulation, i.e. adequate handling of own emotions. In order to show emotional competence in man-machine coopera-

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tion all four aspects have to be considered as it is realized by the robot head MEXI presented in this paper. MEXI is able to recognize human emotions and to react adequately in its communication behavior (including emotion representation) with regard to emotions exhibited by its human counterpart. Furthermore, MEXI's internal architecture, which is based on emotions and drives for representing its actual state, integrates also the aspect of emotion regulation.

Numerous architectures have been proposed covering one or another aspect of emotional competence. Several expressive face robots have been implemented especially in Japan and USA, where the focus has been on mechanical engineering and design, visual perception, and control. Examples are Saya [3] or K-bot [4] that are constructed to resemble young females and are even equipped with synthetic skin, teeth and hair. They can only recognize and represent emotions. The humanoid robot WE4-RII [5], also determines how stimuli from the environment are evaluated in its current emotional state and how the robot reacts on them. Their model of emotion dynamics is inspired by the motion of a mass-spring system. Arkin et al. [6] discuss how ethological and componential emotion models influence the behavior of Sony's entertainment robots. The homeostasis regulation rules described in [7] is employed for action selection in Sony's AIBO and the humanoid robot SDR as well as in our approach. Canamero and Fredslund [8] realized the humanoid robot Feelix based on an affective activation model that regulates emotions through stimulation levels. Part of it relying on Tomkins' idea that overstimulation causes negative emotions [9] is also adopted in MEXI.

Most similar to our work is the robotic head Kismet built at the MIT [10]. However, KISMET does not recognize emotions like MEXI, but only extracts the intention of its human counterpart e.g. from speech prosody. Although Kismet's motivation system is strongly inspired by various theories of emotions and drives in humans and animals like MEXI, their target is completely different. While KISMET's target is to imitate the development and mechanisms of social interaction in humans, MEXI follows a constructive approach in order to realize the control of purely reactive behavior by its drives and artificial emotions and to show this internal state by corresponding facial expressions and speech utterances.

In this paper we present the robot head MEXI and how its internal architecture (Section 2), which is based on emotions and drives for representing its actual state, integrates the aspects of emotion recognition, representation and regulation (Section 3). Furthermore, we show how MEXI is able to react adequately in its communication behavior with regard to emotions exhibited by its human counterpart (Section 4).

2 Overview of MEXI's Architecture

The robot head MEXI has 15 degrees of freedom (DOF), that are controlled via model craft servo motors and pulse width modulated (PWM) signals. The neck has three DOF (pan, tilt, draw), eyes and ears each have 2 DOF and the mouth has 4

DOF. Furthermore, MEXI is equipped with two cameras, two microphones and a speaker in its mouth for audio output. These facilities allow MEXI to perceive its environment and react on it by representing a variety of emotions like happiness, sadness, or anger via its facial expressions, head movements and by its speech output.

MEXI's software architecture (see Figure 1) is designed according to Nilsson's Triple-Tower Architecture, that distinguishes between perception, model and action tower [11].

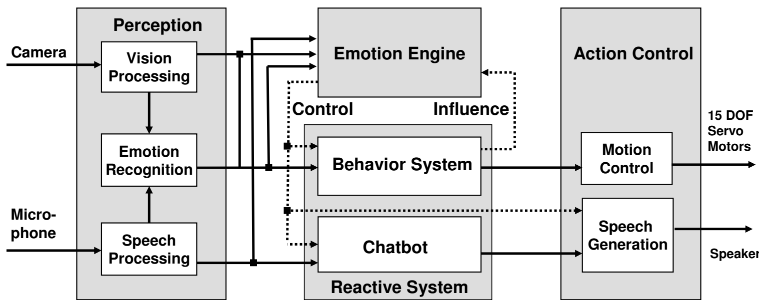

Fig. 1 Architecture of MEXI

The *Perception* component processes MEXI's visual inputs and natural language inputs. The *Vision Preprocessing* is responsible for detecting MEXI's toys or human faces for instance in order to track them with its eyes and head movements. The *Speech Preprocessing* is responsible for speech recognition, which is realized by the commercially available software ViaVoice [12]. One aspect of emotional competence is emotion recognition. In MEXI emotion recognition from human facial expressions [13] as well as from the prosody of human natural speech [14] is supported.

The *Reactive System* allows MEXI to directly respond to its visual and natural speech inputs received from its environment by corresponding head movements, facial expressions and natural speech output. The *Behavior System* is responsible for MEXI's movements. For generating the content of MEXI's answers the slightly extended commercially available *Chatbot* ALICE [15] is used. It receives the textual representation of input sentences from the speech recognition and generates textual output sentences. The content of the sentences generated by the Chatbot is influenced by MEXI's *Emotion Engine*. If MEXI is happy for instance, by chance corresponding output sentences like "I am happy." are generated.

MEXI uses its current perceptions and its internal state, representing the strength of its emotions and drives, to determine its actions following two principle objectives: One is to feel positive emotions and to avoid negative ones for itself and also for its human counterpart. The second objective is to keep its drives at a comfortable (homeostatic) level. In a feedback loop MEXI's internal state and its current perceptions are used by the *Emotion Engine* to configure the *Behavior System* in such a way that appropriate behaviors are selected in order to meet the two objectives stated above (see Section 3).

The *Action Control* component controls the servo motors for the above mentioned 15 DOF via the component *Motion Control* and is responsible for generating natural speech outputs with prosodic features corresponding to MEXI's current emotional state via the component *Speech Generation*. Together with the *Behavior System* the *Action Control* is responsible for the *emotion representation* aspect of emotional competence. The remainder of the paper will concentrate on the realization of emotion regulation mechanisms and emotional behavior by the *Emotion Engine*.

3 Emotion Engine

The *Emotion Engine* is the key component for realizing MEXI's emotional competence regarding emotion regulation and adequate behavior, which results in corresponding emotional expressions in MEXI's face and speech output. Since MEXI's main purpose of cooperation is communicating with its human counterpart the basic behaviors provided by the *Behavior System* were selected accordingly. However, in different contexts (and with according actors) additional behaviors realizing other tasks could be integrated as well. As already mentioned, MEXI's cooperation is determined by the two objectives, to keep its drives at a comfortable (homeostatic) level and to feel positive emotions and to avoid negative ones (for itself and its human counterpart). These objectives determine MEXI's actions resulting in a pro-active regulation of emotions and drives. Furthermore, an intrinsic self-regulation mechanism for automatic decay of emotions and cyclical increase/decrease of drives, as it can be observed also in humans, is realized. These regulation mechanisms and the representation of MEXI's emotions and drives are described next. Afterwards the feedback loop between *Behavior System* and *Emotion Engine* realizing MEXI's emotional behavior is explained.

3.1 Emotion, Drives and their Regulation

For MEXI we distinguish a small set of basic emotions that can be represented easily by MEXI's facial expression and audio output, i.e. anger, happiness, sadness and fear. Happiness is a positive emotion, which MEXI strives for, while the others are negative ones that MEXI tries to avoid. In order to realize a simple control mechanism for MEXI we consider mainly cyclical homeostatic drives. Homeostatic drives motivate behavior in order to reach a certain level of homeostasis. Examples in humans are hunger or thirst. MEXI has for instance a communication drive or a playing drive. Violation of the homeostasis is the more likely to cause according behavior the more the discrepancy between homeostasis and the actual ”value” increases.

Furthermore, an exploratory drive lets MEXI look around for new impressions, if none of the homeostatic drives causes any behavior.

In MEXI's *Emotion Engine* each emotion e_i is represented by a strength value between 0 and 1 and each drive d_i by a strength value ranging from -1 to 1. For each emotion a threshold **th** defines when MEXI's behavior will be configured to show this emotion, e. g. by corresponding facial expressions (see Figure 2, shaded areas). This is done by increasing the gain values of the respective desired behavior(s) (see next subsection). Drives have an upper and lower threshold $\mathbf{th_u}$ and $\mathbf{th_l}$ that define when a drive strives to dominate MEXI's behavior (shaded areas, see Figure 2) by increasing the respective gains. This also avoids that MEXI's behavior oscillates in order to satisfy competing drives. In order to realize pro-active behavior MEXI's drives increase and decrease in a cyclical manner. Between its thresholds a drive is in homeostasis.

The course of a drive $d_i(t)$ and an emotion $e_i(t)$ over time t is determined by the following equations, where $\Delta d_i(t)$ and $\Delta e_i(t)$ denote their change between time points $t-1$ and t:

$$d_i(t) = d_i(t-1) + \Delta d_i(t), \text{ with } \Delta d_i(t) = c_{d_i} \cdot \delta_{d_i}(t) \cdot k_{d_i}(t), \quad (1)$$

$$e_i(t) = e_i(t-1) + \Delta e_i(t), \text{ with } \Delta e_i(t) = c_{e_i} \cdot k_{e_i}(t). \quad (2)$$

c_{d_i} and c_{e_i} are positive values from the interval $]0, 0.5]$ that determine the gradient of a drive or emotion due to intrinsic regulation. They were determined experimentally. This intrinsic regulation happens even, if MEXI receives no perceptions or executes no behavior that could influence the respective drive d_i or emotion e_i. The acceleration factors $k_{d_i}(t)$ and $k_{e_i}(t)$ may accelerate or slow down the intrinsic regulation if their absolute value is > 1 (acceleration) or < 1 (slow down). They determine the influence of external stimuli or of MEXI's own behavior regarding a specific drive or emotion. How these factors are determined is described more closely below.

For drives an additional factor $\delta_{d_i}(t) \in \{-1, 1\}$ determines the direction of their course. It is dependent on the previous values $\Delta d_i(t-1)$ and $d_i(t-1)$. When a drive for example becomes 1 at the time t ($d_i(t) = 1$), it starts decreasing due to MEXI's internal regulation mechanisms and $\delta_{d_i}(t+1)$ becomes -1 meaning that the drive is going to be satisfied. When a drive becomes -1 ($d_i(t) = -1$), it automatically starts increasing and $\delta_{d_i}(t+1)$ becomes 1. This factor allows to realize a cyclical behavior of drives. For emotions this factor can be ommitted, since here only an automatic decrease is realized.

The principle development of emotions and drives over time is shown in Figure 2. Also the principle determination of acceleration factors due to external stimuli is explained below.

The solid curve in Figure 2 a) shows the development of a drive d_i. In order to realize pro-active behavior MEXI's drives increase and decrease in a cyclical manner. As a default excitation MEXI's drives would follow a sine wave (dashed curve) and incorporate only internal regulation mechanisms. This is realized by assigning

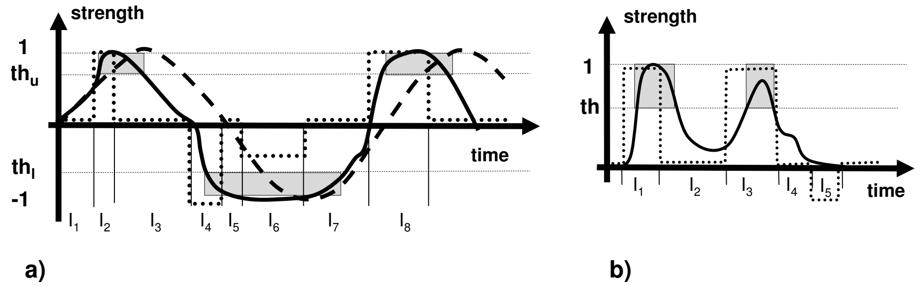

Fig. 2 Emotions and Drives

δ_{d_i} the values 1 and - 1 alternatingly. For drives the interval $]th_l, th_u[$ represents the level of homeostasis, 1 represents a very large drive striving for its satisfaction and -1 expresses that the drive was overly satisfied. Stimuli, i.e. perceptions and own behavior, influencing the drive are depicted as dotted line in Figure 2. Stimuli may accelerate a drive's increase (intervals I_2, I_8). The stimuli that satisfy the drive cause a steeper decrease (interval I_4). In these intervals ($t \in \{I_2, I_4, I_8\}$) the acceleration factor is greater than 1 ($k_{d_i}(t) > 1$) and accelerates a drive's increase (I_2, I_8) or its decrease (I_4). Other stimuli may cause a slower increase or decrease of the drive. In this case the factor $k_{d_i}(t)$ has a value between 0 and 1 ($0 < k_{d_i}(t) < 1$). The slower increase is shown in interval I_6, where a negative stimulus indicates its over-satisfaction. In some timing intervals MEXI's perceptions or their absence do not influence the depicted drive (indicated by a zero line of the stimuli, e.g. interval $I_1, I_3, I_7, \ldots$. In these cases the factor $k_{d_i}(t)$ is equal to 1 and the course of a drive runs in parallel with the excitation function.

Imagine for example that MEXI sees a human face in a state where its communication drive d_{com} is decreasing ($\delta_{com} = -1$). Since the current perception signals a potential communication partner for MEXI, its communication drive should be satisfied faster. This is reached by setting the acceleration factor $k_{com}(t)$ to a value $k > 1$. If no stimuli, that may influence the communication drive, are recognized $k_{com}(t)$ remains 1 and does not accelerate the normal internal regulation of the communication drive. If for instance the person disappears (the face becomes smaller) the communication drive might decrease slower, and hence the value of $k_{com}(t)$ should be in the interval $]0, 1[$.

Figure 2 b) shows the development of a positive emotion like happiness over time as the solid curve. The dotted curve shows the duration and evaluation of MEXI's current percepts. For positively evaluated percepts the curve is above the time axis, for negative ones it is below the time axis. In contrast to drives, for each emotion only one threshold **th** defines when MEXI's behavior will be configured to show this emotion, e. g. by corresponding facial expressions (shaded area) (see next subsection).

The acceleration factor $k_{e_i}(t)$ for an emotion e_i depends on the previous value of the emotion $e_i(t-1)$, the evaluation of the current perception and also on the current drive state. If a drive d_i concerning an emotion e_i increases, MEXI reacts in a neutral way, i. e. $k_{e_i}(t) = 0$ and hence also $e_i(t) = 0$. If that drive starts decreasing ($\delta_i(t)$ changes its value from 1 to -1 and hence Δd_i becomes < 0) then the emotion e_i increases very rapidly and $k_{e_i}(t) \geq 1$. The decrease of an emotion could also be accelerated by setting $k_{e_i}(t)$ to a value $k \leq -1$.

The increase of a positive emotion may be caused by positive perceptions of its environment (intervals I_1, I_3) and by the drives (their fulfillment). Hence, for $t \in \{I_1, I_3\}$ the acceleration factor $k_{e_i}(t)$ is larger than 1 ($k_{e_i}(t) > 1$). The decrease happens automatically with a certain adaptable amount per time unit, if the positive stimulus has disappeared (intervals I_2, I_4). In this case the acceleration factor $k_{e_i}(t)$ is equal to -1. By a negative stimulus the decrease of $e_i(t)$ is accelerated by setting $k_{e_i}(t) < -1$ (interval I_5).

Imagine for instance the communication drive d_{com} and its impact on the emotion happiness e_{happy}. Assume that it is not satisfied ($d_{com} > th_u$ and $\Delta d_{com} < 0$) initially. Then happiness may be increased by a positive perception perhaps a human face. This should result in an accelerated increase of e_{happy}, which is reached by setting the respective acceleration factor $k_{happy} > 1$. If the face suddenly disappears, happiness decreases ($k_{happy} = -1$). If according stimuli are recognized, happiness could decrease even faster resulting in $k_{happy}(t) < -1$.

3.2 Control of the Behavior System by the Emotion Engine

The feedback loop between *Behavior System* and *Emotion Engine* realizing MEXI's behavior as adequate reactions to its environment and the emotions of its human counterpart is depicted in Figure 3. For clarity reasons only some behaviors, drives and emotions are shown.

For realizing MEXI's *Behavior System* the paradigm of *Behavior Based Programming* developed by Arkin [6] is applied. So called basic behaviors b like *Smile*, *Look around*, *Follow face*, *Avert gaze* or *Sulk*, which may be either cooperative or competitive, are mixed by an accumulator Σ to compute the nominal vector $\mathbf{R}$ for the actor system from the fixed-sized vectors $\mathbf{C_b}$. A $\mathbf{C_b}$ generated by the basic behavior b contains 15 triplets $(c_{s,b}, v_{s,b}, m_{s,b})$ (one for each servo motor s) consisting of the nominal value $c_{s,b}$, a vote $v_{s,b}$ for each of the nominal values and a mode flag $m_{s,b}$ (cooperative vs. competitive).

Using the vote values a behavior can signal whether the output is of high importance ($v_{s,b} = 1$) or should have no influence at all ($v_{s,b} = 0$). Via this mechanism the influence of MEXI's external percepts, e.g. the emotions recognized at its human counterpart, on its behavior is realized. Apart from that also its internal emotional state may influence the actual behavior by setting appropriate *gain* values. The accumulator combines external votes and internal gains of a behavior b by calculating a weight $w_{s,b} = g_{s,b} \cdot v_{s,b}$ as their product. This weight is used to do the ranking of

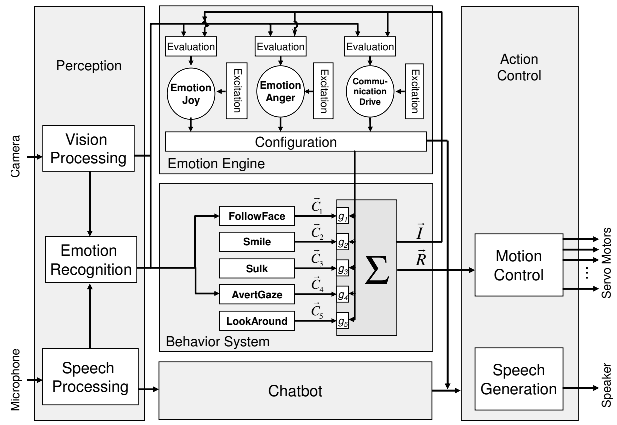

Fig. 3 Detailed Architecture

the behaviors. If the behavior b with highest weight is competitive, a winner-takes-all strategy is used and the resulting nominal value for servo s is $r_s = c_{s,b}$. Else a weighted median of all cooperative values is calculated. This calculation as well as the calculation of the Influence vector **I** is described e.g. in [16].

The *Excitation* components allow to realize MEXI's regulation mechanisms as described above. The *Configuration* component determines from the actual percepts (including the emotional state of MEXI's counterpart) and the internal state of emotions and drives which behaviors of the *Behavior System* should be preferred by setting the gain values for each behavior b. If a drive increases the gain for the behaviors, that will satisfy that drive, is increased by a certain (variable) amount per time. If a drive decreases the gains for the "satisfying" behaviors are decreased respectively. If a percept causes a certain emotion in MEXI the emotion strength is increased. If a certain threshold is reached the gains for according behaviors e. g. those that generate the corresponding facial expression are set to 1 and the Chatbot and Speech Generation are instructed to produce according speech output and prosody. Conflicts between drives may be solved for instance by a fixed priority. An example showing these interdependencies is described in Section 4. The gain calculations are presented elsewhere [16].

The *Evaluation* component evaluates the influence vector **I** calculated by the accumulator in the *Behavior System* in order to determine whether the preferred behavior really dominates the actual actions activated by the *Motion Control*. This decision is positive, if for competitive behaviors the influence equals 1 and for cooperative behaviors a specific threshold is exceeded. If the behavior was initiated by an emotion the negative excitation function is switched on for subsequent cycles in order to let the emotion strength decrease automatically (k_{e_i} becomes negative). In case of drives the strength of the drive is decreased by a specific amount (δ_{d_i} becomes -1). This is repeated, if the behaviors are preferred also for subsequent cycles until the lower threshold of the drive is reached.

4 Example Session

For an example, how MEXI reacts adequately to human emotions, have a look at the diagrams in Figure 4 that show how MEXI behaves when at time t_0 a person appears and MEXI sees a human face. At t_1 MEXI recognizes that the person has a sad facial expression and tries to distract her from that feeling by playing. - MEXI plays by getting shown its toy and tracking it. - At t_3 MEXI detects the toy and plays with it until it becomes boring and MEXI looks at the human face again at t_4.

The upper two diagrams show the votes $v_{s_h,b}$ and $v_{s_m,b}$ for two groups of servo motors involved in the execution of different sets of behaviors. Motors for head and eye movements $s_h \in \{1,\dots\ 7\}$ are for instance needed for the behaviors $FollowFace, FollowToy$ or *LookAround* which are competitive, but not for *Smile* or *Sulk* that are cooperative behaviors. Vice versa, motors for movements of the mouth corners $s_m \in \{8,\dots\ 11\}$ are needed for *Smile* or *Sulk* and not for the other behaviors. For behaviors not involving a group of servos the corresponding votes are constantly set to zero. The votes of the other behaviors depend on MEXI's current perceptions and somehow reflect its current action tendency due to these perceptions not taking into account its internal state.

The votes $v_{s_h,b}$ for the behavior $b = FollowFace$ and for $b = FollowToy$ are set to one when MEXI sees a human face (t_0 and afterwards) or its toy respectively (t_3 and afterwards). The behavior *LookAround* which lets MEXI look for interesting things (e. g. human faces) corresponds to MEXI's exploratory drive. It describes a kind of default behavior for the head movement motors. Therefore, the votes $v_{s_h,b}$ for $b = LookAround$ are constantly set to 0.5 and the gain is set to 1.0.

The behavior *Smile* only involves the motors for mouth movements. Since MEXI by default should be friendly the corresponding votes $v_{s_m,b}$ for $b = Smile$ are set to a high value of 0.8, when MEXI perceives a human face (starting at t_0). When MEXI classifies the human face as sad at t_1, it adapts its own facial expression to a neutral expression and no longer intends to smile. Hence, the votes $v_{s_m,b}$ for *Smile* are set to zero and remain there until MEXI sees its toy at t_3 and wants to smile again due to this perception ($v_{s_m,b} = 0.8$ at t_3).

The gain values reflect MEXI's action tendency due to its current internal state. The weight combines gains and votes, i.e. internal and external action tendencies and the influence shows which behavior is really executed (and to which extent in the case of cooperative behaviors). The influence of *LookAround* is one until t_0 and MEXI is looking around since nothing else is seen. When MEXI's communication drive d_{com} increases also the gain for *FollowFace* g_{FF} rises until d_{com} reaches its upper threshold ($th_u = 1$) and also g_{FF} is set to one at t_0. Since MEXI sees a face at t_0, also the weight of *FollowFace* becomes one and *FollowFace* is executed (its influence is one) because its weight is now higher than that of *LookAround*. At t_1 MEXI detects the sad face of its human counterpart and stops smiling (vote of *Smile* is set to zero, hence weight and influence become zero too). Since MEXI now wants to distract the human from her sadness by playing with its toy, its own *PlayToy* drive increases to one causing the gain for *FollowToy* to increase as well. Since MEXI now wants to play, the communication drive starts decreasing faster

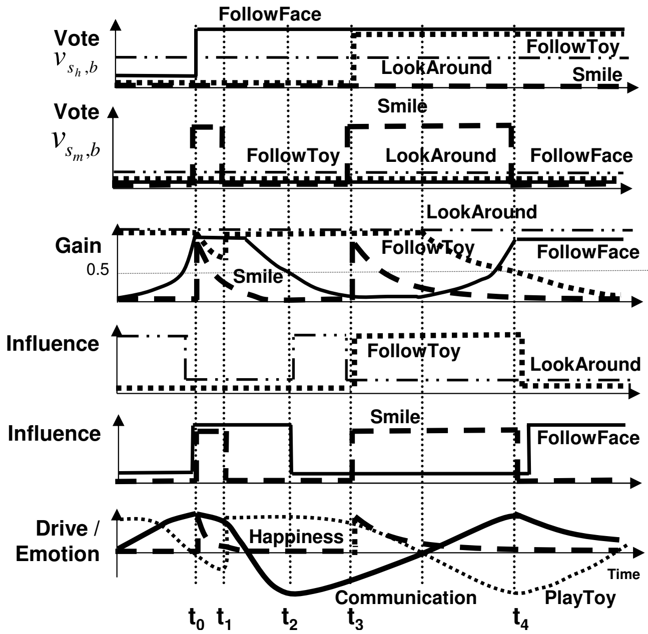

Fig. 4 Example Session

until it becomes zero at t_2. Now the weight of *LookAround* is larger than that of *FollowFace* and MEXI looks around (influence of *LookAround* = 1 from t_2 to t_3) until at t_3 the weigth of *FollowToy* is larger than that of *LookAround*, since MEXI detects its toy at t_3 and the corresponding vote $v_{s_h,FollowToy}$ becomes one. Then also the *PlayToy* drive and due to this also the gain of *FollowToy* start decreasing until the drive is minus one ($th_l = -1$) at t_4. Since at t_4 the communication drive has reached its upper threshold ($th_u = 1$), the gain of *FollowFace* is set to one and its weight is the highest again resulting in execution of *FollowFace* after t_4 (influence = 1).

The emotion *Happiness* is set to one each time the influence of *FollowFace* or *FollowToy* starts rising (t_0,t_3), i.e. the communication drive or the playing drive starts being satisfied (δ_{com} is set to -1). As result of the rising of the emotion *Happiness* (threshold = 1) the gain value of the behavior *Smile* also is set to one and MEXI starts smiling, because also the vote is one (t_0 and t_3). *Happiness* automatically decreases caused by the respective excitation function (e.g. from t_3 until t_4). This decrease becomes faster by setting $k_{happy} < -1$, when MEXI receives corresponding percepts like a sad human face (t_1). MEXI smiles until the weight of *Smile* becomes zero because of MEXI's percept ($v_{s_m,Smile} = 0$ at t_1 and t_4). Another reason to stop smiling may be that the gain of *Smile* has decreased to zero because of a corresponding decrease of *Happiness* due to its excitation function e_{happy}.

5 Conclusion

In this paper we presented the architecture of the robot head MEXI and how it supports emotional competence in human-robot cooperation. The paper concentrates on two important aspects of emotional competence: how internal regulation mechanisms for emotions and drives can be realized and how adequate behaviors for external emotion regulation as well as for reaction on human emotions can be incorporated. We presented MEXI's software architecture and how it is used to realize its actions without any explicit world model and goal representation. Instead MEXI's artificial emotions and drives maintained by the Emotion Engine are used to evaluate its percepts and control its future actions in a feedback loop. The underlying Behavior System and the Emotion Engine are based on the behavior based programming paradigm extending Arkin's motor schemes to a multidimensional model of reactive control. This architecture supports a constructive approach for synthesizing and representing MEXI's artificial emotions and drives rather than emulating human ways of "feeling". MEXI integrates also components for emotion recognition components from facial expression and natural speech. Based on these building blocks MEXI can cooperate with humans in real-time by communication behavior, which could be extended to other tasks by integrating appropriate actor facilities and basic behaviors into the Behavior System and the Emotion Engine. Our experiences with MEXI on different public exhibitions and fairs show that MEXI, although realizing only a restricted set of emotions and drives, attracts human spectators and maintains their communication interest. However, it remains a question for psychological studies, how different humans react when they cooperate with emotionally extended machines. We plan to investigate how the constructive approach of emotions and drives for behavior control can be transferred to other application domains than human-robot communication.

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