Building a Human-Dog Interaction Inspired Emotional Engine Model

Csanád Szabó, András Róka, Tamás Faragó, Márta Gácsi, Ádám Miklósi, Péter Korondi

***Abstract*— We propose a state space based engineering solution for the emotional engine model of an artificial agent. Our model takes its inspirations from the evolution theory and the latest achievements of human-dog interaction research. We present our emotional model together with its background, show our simulation results and present the ongoing work concerning the applications that we chose to be extended by our engineering solution.**

I. INTRODUCTION

In the past few decades there have been lunched several projects to build autonomous robots that are able to interact and cooperate with people [1]. These robots follow social behaviors attached to their roles while interacting and communicating with humans. Such robots have been already applied for entertaining or care purposes. The social robots have in common that they possess emotional models to ease the human-robot interaction.

This paper introduces an abstract emotional model of an artificial agent. Our model is a combined behavior-emotional model that takes inspiration from two sources. On the one side, we approach the task of emotional modeling using an evolutionary point of view. Our approach is motivated by the explanation of emotions used in evolution theory [2]. On the other side, we make use of the knowledge gathered in the research of human-dog interaction. Dog has been selected by human to extend its capacities [3], henceforth, dog can be regarded as the living prototype of social robots. We present our engineering solution for the emotional model that includes the emotional space and the emotion arbitration. As our goal is to integrate our emotional model into numerous existing applications from social robots to personal data assistant equipment we make an effort to build the engineering model utilizing simple mathematical methods.

The paper is organized as follows. The following section gives a short overview of emotional models of two social robots. In Section III, we write about our modeling approach and present the neurobiological and ethological background of our model. The next two sections we use to describe our emotional engine from engineering point of view and the emotion arbitration together with the biological background of the arbitration rules. Section VI presents our simulation results and Section VII deals with the application that we are currently working on. Finally, Section VIII concludes the paper and sketches possible future work.

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II. SHORT OVERVIEW OF EMOTIONAL MODELS USED IN SOCIAL ROBOTICS

There is a common method how emotion handling components are structured within social robots. To recognize environmental events the robots are equipped with input devices (visual, audio, mechanical sensors). The emotional engine receives known and identified events carrying emotional information from the sensors of the robot. The emotional engine interprets the information and computes the impact of the event in the emotional model. Finally, the emotional engine interprets the emotions identified in the model and makes a transformation for the output peripheries of the robot in order to express the emotions.

Before designing our emotional model we investigated the existing models used in social robotics. In this paper, we present only those two robots – Kismet and Aibo – whose emotional models we considered to be the most elaborated.

The autonomous robot Kismet [4], [5] uses a vision system, microphones, a speech synthesizer, a two degree of freedom neck, and facial features that enables to display a wide variety of recognizable expressions. Kismet's designers integrate in their emotional modeling work theories from infant social development, psychology, ethology, and evolution enabling the robot to enter into natural social interaction with a human. The emotion system defines ”emotions” and ”drives” where drives operate on a slower time scale than emotions, drives contribute to the ”mood” (medium-term) of the robot [4].

The pet-like robot Aibo [6], [7] can move its four legs, its neck and its tail, has LEDs on its face and can play sound patterns while its input stimuli come from vision and sound processing. To maximize lifelike appearance designers intended to maximize the complexity of responses and behaviors of the robot. The emotional basis is split into drives and six basic emotions. Aibo's behavioral system was inspired by the study of canine behavior. The designers distinguish between *reflexive* (short-term) and *deliberate* (medium-term) behaviors. To increase the complexity of behaviors a stochastic state-machine is implemented to enable the addition of randomness in action generation and to realize nonrepeated behavior exhibition [6].

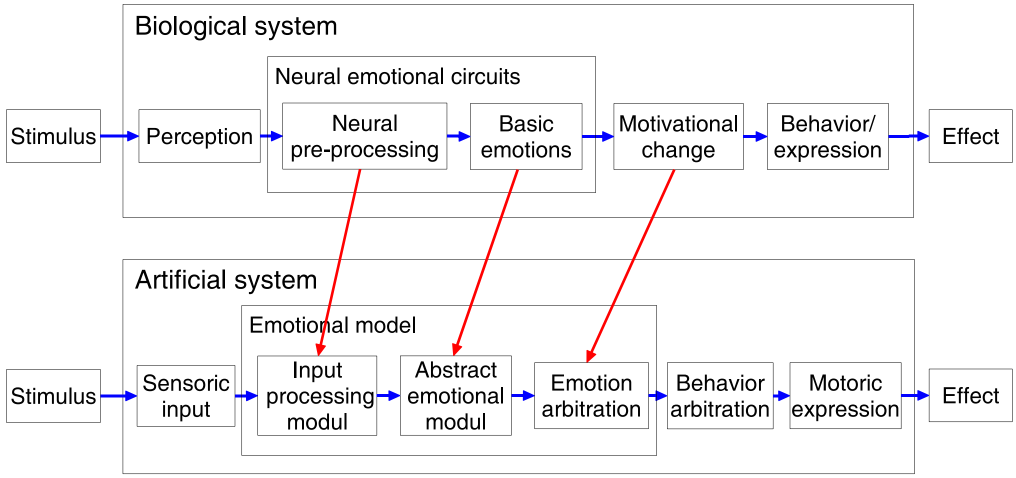

Fig. 1. Relationship between the the biological model and our model

III. Modeling Approach

We approach the task of emotional modeling from an evolutionary point of view. The emotions are specialized modes of operation shaped by natural selection to adjust the physiological, psychological, and behavioral parameters of the organism in ways that increase its capacity and tendency to respond adaptively to the threats and opportunities characteristic of specific kinds of situations [2]. The projections of these specialized operations of the central nervous system in behavior can be studied by the methods of ethology. This motivates us to put our emotional model on neurobiological and ethological basis.

A. Neurobiological background

Nowadays, emotional theories derived from neurobiological and evolutionary background propose that a small number of basic emotions are originate from relatively distinct neurological systems [8]. These theories are mostly based on results from patients with focal brain lesions or damage, behavioural and physiological examinations of different model animals like monkeys or laboratory rats, and lately noninvasive functional neuroimaging studies. It is well known for example that the amygdala plays a central role in the organisation of fear [9], and the insular regions can be associated with disgust [10].

In Panksepp's point of view core affects can be associated with distinct subcortical regions that are members of different brain circuits [11]. These circuits can be differentiated in pharmacological, neurological and also behavioural manner (SEEKING-expectation, FEAR-self-defence, RAGE-anger, LUST-sexuality, CARE-parental attachment, PANIC-grief, sadness, separation, PLAY-joy, happiness). These distinct systems are activated by sensory inputs, and also information stored in the autobiographical memory and higher cortical, cognitive functions can have impact on them, and also propulsive or inhibitory interactions are possible between them. We applied Panksepp's model to build our core emotional engine. Thus in our model we use several parallel and equal basic emotional states, that represent the different emotional circuitry of the brain. These emotional states can change independently in response on the external events.

B. Ethological background

Recent ethological research has brought dog into the foreground as the living prototype of social robots if we define robots as agents that are built to extend human capacities. The domestication of dogs began around 20.000 years ago, and since then dogs have been utilized by humans for different purposes that all needed some kind of mutual social understanding [3]. Ethologically inspired research shows that during the long-term human-dog relationship dogs have evolved behavioral skills which have increased the chances to survive in the anthropogenic environment [12]. Regarding communication, for example, dogs have evolved skills that enrich their capacities to communicate with humans in complex social situations [13].

Humans prefer to set up social relationships with agents that they cooperate with. Furthermore, humans are able and prefer to perceive certain human-like mental capacities, such as emotions, in other agents to ease the interaction with them. Dogs use a variety of visual (e.g. tail movement) and acoustic cues (e.g. frequency and tonality of barking) to express their emotional states, and humans seem to be able to recognize dogs' basic emotions without much specific experience [14], [15]. These behavioral cues may be partly redundant making the emotional behavior unambiguous and simplifying the recognition of the emotion.

It is important to emphasize that, on the engineering side, we do not want to provide an emotional model of the dog. We consider the analogy as important when modeling the emotional space of an artificial agent. We design human-robot interaction and are interested in emotions that humans assume and recognize interacting with an other species for which the dog may be a key example.

Our expert team hypothesized a preliminary model of emotional space in dogs based on extensive causal observations of human-dog interactions. As this preliminary model can be already interpreted by mathematical methods it will

TABLE I

IMPACT OF ENVIRONMENTAL EVENTS ON DOG'S BASIC EMOTIONAL STATES

	CONTEXT												
	greeting owner	leaving owner	petted by owner	owner initiates interaction	owner scolds / punishes	rejected interaction initiation	meeting familiar person	ambivalent social situation	facing threatening stranger	play with human	threatening stimulus in environment	strange environ-ment	unpleasant inner state
Happiness	4↑	3↓	2↑	1↑	4↓	2↓	2↑	2↓	4↓	3↑	4↓	2↓	3↓
Despair	5↓	3↑	3↓	2↓	4↑	2↑	2↓			3↓			1↑
Fear	3↓	1↑	2↓	1↓	3↑		1↓	1↑	3↑	3↓	3↑	2↑	1↓
Anger		1↑			1↓	1↑			3↑	2↓	1↑	1↓	2↑
Surprise			1↓		1↑	2↑	1↓	3↑	2↑		1↓	2↑	

be taken as a basis for modeling our emotional engine. Five basic emotional states are identified: *happiness, despair, fear, anger and surprise*. These basic emotional states of the dog can be identified by ethological tests in interactions with humans, and humans are able to recognize them and associate them with specific body movement patterns. It seems that the utilization of these basic emotions in the dog is enough to develop and maintain sophisticated social interactions with humans.

This behavioral-emotional model gives the link between the emotional engine and external events. How the environmental changes alter the observable behavior will report the likely inner state, and this will define how our emotional engine should react to events.

Our preliminary model presented in this paper can be seen as an extension and sophistication of our previous model introduced in [16]. The presentation of the knowledge gathered through the observations of human-dog interactions has been split up into two tables. Table I contains information about the impact of environmental actions on emotional states, that is, how environmental actions influence the internal states of the emotional space. Table II includes the dynamical characteristics of identified basic emotions. This knowledge about the dynamical characteristics makes a mathematical model that handles emotions on two time layers possible.

Environmental events may influence the emotional states of the dog across two attributes, which are

- arousal (5-steps classification ranging from very little up to very high),
- valence (positive, negative).

Concerning the dynamical characteristics of basic emotions following attributes were identified

- width of emotional peak (5-steps classification ranging from very short up to very broad),
- decline of short-term emotions (slow, medium, fast),
- impact of short term on medium-term emotions (little, medium, high),
- decline of medium-term emotions (slow, medium, fast).

We explain the content of Table I and II by taking a concrete example. The first column in the context field (Table I) stands for the *dog greets owner* action. In this context the owner of the dog comes home, after being separated from the dog for several hours. The impact of this

TABLE II

DYNAMICAL CHARACTERISTICS OF IDENTIFIED BASIC EMOTIONS IN DOG'S BASIC EMOTIONAL SPACE

	Width of emotional peak	Decline of short-term	Impact of short-term on medium-term emotion	Decline of medium-term
Happiness	3 (medium)	2 (medium)	2 (medium)	2 (medium)
Despair	4 (broad)	1 (slow)	2 (medium)	2 (medium)
Fear	5 (very broad)	1 (slow)	3 (high)	1 (slow)
Anger	4 (broad)	3 (fast)	1 (little)	1 (slow)
Surprise	1 (very short)	2 (medium)	1 (little)	3 (fast)

greeting interaction can be identified on happiness, despair and fear whereas anger and surprise are not affected. The event has a high arousal value (4 stands for high) and a positive valence (↑ stands for positive), that is, this impact dyad results in a high, positive influence on *happiness*. The same event has a very high, negative influence on *despair* and a medium, negative influence on *fear*. According to the first row of Table II the width of the emotional peak of *happiness* will be of medium value. Regarding *happiness* the same values will be valid for the impact of the short-term emotion on the medium-term emotion and the declination of short- and medium-term emotions, respectively.

In Figure 1 we summarized the relationship between the used simplified biological model and our model. The external events are perceived by the sensory system and recognized by the central nervous system. This preprocessing is modeled in our system, as the input processing modul (cf. Table I). In the brain the appropriate emotional circuits are activated and others blocked, thus the overall emotional state (emotional landscape) of the brain will finally affect the behavior via the motivational system. The emotional circuits appear in our engine as the emotional state space. The way the emotional space affects the behavior of the artificial system depends on the arbitration mechanism, which is based on how the central nervous system chooses the adaptive reaction in the given context.

IV. EMOTIONAL ENGINE

We use a discrete state space model to implement the emotional engine that is based on the expert knowledge about the basic emotional states of the dog described in Table I and the dynamical characteristics of identified basic emotions as presented in Table II. Concerning the design of the model we apply the methodological aspects introduced in [16].

The inputs to the system are the events which cause emotional changes in the dog. The inputs are collected at each time step in an input vector $\mathbf{u}[k]$. The inner states of the state space model represent the five basic emotional states identified for the dog. The emotional states are represented in the five dimensional state vector $\mathbf{x}[k]$. The state vector is stimulated by the inputs. We will use a two-time-layer based model to have short- and medium-term emotional levels. This approach is very similar to the one presented in [17]. We will have a five dimensional state vector at each time layer ($\mathbf{x}_R[k]$ and $\mathbf{x}_M[k]$), respectively.

We begin the modeling task with a linear model that we will extend by non-linear components to come up to the expectations set by the expert knowledge. We extend the linear core to achieve two goals. Firstly, we have to hold the emotion constant on a defined level (cf. emotional peak in Table II). This is a challenging task because our model operates with impulse responses. Secondly, we have to keep the emotions of our artificial agent within predefined limits of the emotional space.

The stability of the linear core is ensured by the adequate property of the system matrices ($\mathbf{A}$ and $\mathbf{M}$), values of the inner states have to decline in both time layers if no input occurs. We want the system to meet the requirements of asymptotic stability.

A. System implementing short-term emotional response

First, we develop a component of the emotional engine to implement short-time emotional responses. Figure 2 shows the used state space model where we marked the dynamically computed elements of the model.

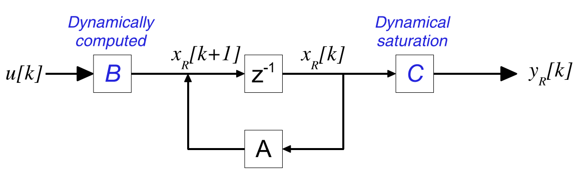

Fig. 2. Block diagram of the state space model of short-term emotion

$$\begin{aligned}\mathbf{x}_R[k+1] &= \mathbf{A}\mathbf{x}_R[k] + \mathbf{B}\mathbf{u}[k] \\ \mathbf{y}_R[k] &= \mathbf{C}\mathbf{x}_R[k]\end{aligned} \tag{1}$$

We interpreted the contents of Table I as steps that values of a single emotion have to rise or fall. The first column of Table II is interpreted as the time duration ("width") that a single emotion should stay on the defined level. We have decided to fulfill these expectation by computing the matrix $\mathbf{B}$ dynamically and by saturating the output through matrix $\mathbf{C}$ at a dynamically defined saturation level. If an environmental event occurs the saturation level is defined based on the impact of the environmental event and the current saturation level that is actually the output of the short-term layer ($\mathbf{y}_R$).

The matrix $\mathbf{B}$ will be computed based on the new saturation level, the desired width of the emotion, the matrix $\mathbf{A}$ and an anti-windup mechanism that is used due to stability reasons. The matrix $\mathbf{C}$ serves the saturation of the emotions on the current level. The extrema of the saturation levels are predefined. This method guarantees that the values of the output state vector are kept within the interval of $[-1, 1]$. The usage of the negative half-plane has no biological background it makes a faster decline of the states at medium-term layer possible.

B. Extending the emotional model with medium-term layer

Subsequently, we extend the system with a component that handles emotions on medium-term time layer. We assume that medium-term emotional responses can be calculated by summing up the output of short-term layer ($\mathbf{y}_R$) and the current value of the inner state at medium-term layer ($\mathbf{x}_M$). We argue that the operation is justified because the emotional response of the system should take into account the "mood" (medium-term) of the system as well. In contrast to the short-term layer we need a simple saturation function here to keep the output within the interval of $[0, 1]$.

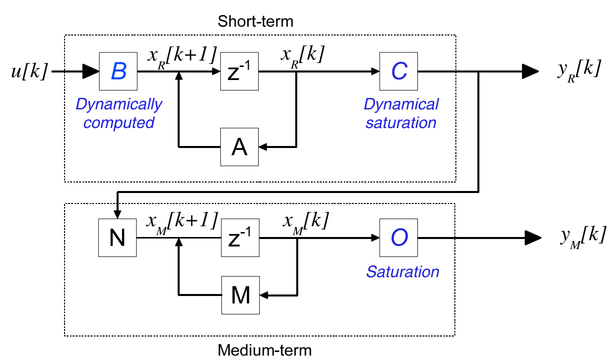

Fig. 3. Block diagram of the state space model handling short- and medium-term emotions

Figure 3 shows the used state space model where we indicated the two components that handle short-term and medium-term emotions, respectively. The properly conditioned matrix $\mathbf{M}$ has to meet the stability requirement against the medium-term emotion handling component. Through the matrix $\mathbf{N}$ the degree of the influence of the short-term emotional level can be taken into account. These two matrices will be set also taking into account that "mood" operates on a slower time-scale. The matrix $\mathbf{O}$ indicates the saturation at medium-term layer. The equations in the state space system are shown in (2).

$$\begin{aligned}\mathbf{x}_R[k+1] &= \mathbf{A}\mathbf{x}_R[k] + \mathbf{B}\mathbf{u}[k] \\ \mathbf{y}_R[k] &= \mathbf{C}\mathbf{x}_R[k] \\ \mathbf{x}_M[k+1] &= \mathbf{N}\mathbf{y}_R[k] + \mathbf{M}\mathbf{x}_M[k] \\ \mathbf{y}_M[k] &= \mathbf{O}\mathbf{x}_M[k]\end{aligned} \tag{2}$$

V. EMOTION ARBITRATION

After having dealt with the computation of the emotional space we have to address the task of emotion arbitration as we have to define which emotion or emotions will be selected to be expressed through the output peripheries of the artificial agent. At the current stage of our research we take into account only the output of short-term layer ($\mathbf{y}_R$), further investigation is needed for the integration of the medium-term layer ($\mathbf{y}_M$) into the emotion arbitration.

A. Rules of arbitration

Against Kismets "winner-take-all" approach for emotion arbitration [4], we set up a hierarchical rule tree for our biologically inspired model. These rules are the following:

1) If the output state vector of the emotional module has a positive value in only one dimension then this emotion is chosen for expression.
2) If more than one emotional dimensions have positive values then the decision is based on the following subrules:
    a) If *fear* has a value higher than 3 (medium), *fear* will be expressed, regardless of the other dimensions
    b) If one emotion dimension is higher than all the others then that emotion is chosen for expression
    c) If two or more dimensions have the same values then the following inner hierarchy will determine the expression:
        i) *fear* is the strongest,
        ii) *surprise* comes next,
        iii) *anger* follows,
        iv) finally, *happiness* and *despair* are equal.
    d) If two or more dimensions have the same value, that equals 3 (medium) or higher then the two strongest emotions chosen by the inner hierarchy above (cf. rule 2c) will appear in mixed or alternating behavior.

B. Biological background of the arbitration rules

In the following paragraphs the biological background of the arbitration rules will be explained. We consider that the rules 1 and 2b are self-explanatory therefore details about their background are omitted.

According to MacLean, emotions appear in an evolutionary hierarchy in the brain of the vertebrates, associating fear and anger with ancestral, while happiness and sadness with higher subcortical and cortical regions [18]. Although this triune brain hypothesis and the division of the nervous system to reptilian, old mammalian and neo-mammalian regions is obsolete in the light of newer neurobiological findings [8], this approach can be valid and helpful in setting up the hierarchy of emotions. The most basic and ancient adaptive behavior of the living is to protect and keep the integrity of the self, to avoid harm and danger. Key features that corresponds to predators, such as wide, lighting pair of eyes oriented horizontally, evoke high levels of fear automatically without higher processes, to provoke flee behavior [19]. In such situations all other input of emotional system is inhibited, to prioritize the safety of the individual.

Anger is also very basic and ancient state, such as fear anger is placed in the reptilian brain by MacLean [18]. Anger is an adequate reaction to gain or keep some important resource, to avert barriers, and to keep the integrity of the individual. But in contrast with fear, anger carries higher risk of being harmed, because if the physical abilities of the counterpart are assessed poorly, that can lead to the death of the individual.

The startle reaction is a complex automatic behavioral and neurological reaction at sudden stimuli [11]. It is an important feature of this reaction that the incoming stimulus is unidentified, it is not known that it is potentially harmful, it means a challenge or reward or can be neglected by the individual. The main function of surprise is to give extra information for the nervous system, to ease and fasten decision making about the adaptive response. Also surprise appears when the individual comes across with a phenomenon that is violating its expectations; however this reaction is usually caused by mild, low intensity stimuli.

In the hierarchy happiness and despair are placed on the lowest level, these emotions are assigned in the MacLeanian hierarchy to the newest, youngest parts of the brain, and higher cognitive processes are associated with them [18]. These emotions have main significance in social contexts, the feeling of happiness is close relationship with the brain's self-rewarding system, and appears in rapport with behaviors and social events that are important for the wellbeing of the individual, thus these are reinforced by this kind inner state. This can achieve and strengthen for example the social bonding between parent and offspring. Contrary to happiness, despair is caused by the loss or absence of the objects associated with the pleasant inner state, separation anxiety, wrench, detachment from the parents or a beloved other, loss of an important resource and failure to achieve something important can all evoke the emotion of sadness.

As for the rule 2d, we aimed to express clear basic emotions in our model, however, it is possible in some contexts that two or more emotion dimensions carry the same high values. In these situations the use of mixed emotions can be allowed. In this moment we mean by mixed emotions not the secondary or tertiary emotions that appears in Plutchik's circumplex model [20], but rather expression of mixed two emotions by ambivalent behavior. This means the expression of different emotions via different modalities, for example when the individual is threatened by an approaching stranger, it lowers itself and shows submissive behavior communicating fear, but parallel emits aggressive vocalizations to try to prevent further approach. It is also conceivable to express different emotions in the same modality in fast alternations, depending on the behavioral expressive capacity of the system.

VI. SIMULATION RESULTS

We have implemented our emotional model – engine and arbitration – in MATLAB framework. We have developed a GUI which allows, one the one side, to give inputs (environmental events) to the emotional model and, on the other side, to visualize the changes of the emotions in a diagram and to show the present decision of the emotion arbitration.

A fictive scenario was set up as shown in the first two columns of Table III. The owner separated from his dog previously enters the room where his dog is waiting, pets several times his dog and begins to play with it. After a while the owner interrupts the play, that is, he rejects the interaction and goes out of the room leaving the dog behind.

TABLE III
EVENTS AND RESULTS OF ARBITRATION IN THE SIMULATED SCENARIO

Time [sec]	Environmental event	Result of arbitration	Applied arbitration rule
10	Dog greets owner and is petted by him	Happiness	1
18	Dog petted by owner	Happiness	1
30	Dog plays with owner	Happiness	1
47	–	Neutral	–
50	Dog plays with owner	Happiness	1
67	–	Neutral	–
75	Dog plays with owner	Happiness	1
92	–	Neutral	–
105	Owner rejects interaction	Surprise	2c
109	–	Despair	2b
120	Owner leaves	Despair	2b
141	–	Neutral	–

Figure 4 presents changes of the emotions during the simulation and the last two columns of Table III shows the present decision of the emotion arbitration and the applied rule. At the beginning of the scenario *happiness* is dominating depending from the environmental event and how the distinct matrices of the emotional engine were tailored. At time the owner rejects the interaction *surprise* will be dominant for a short time and after *surprise* begins to decline *despair* will be the selected emotion.

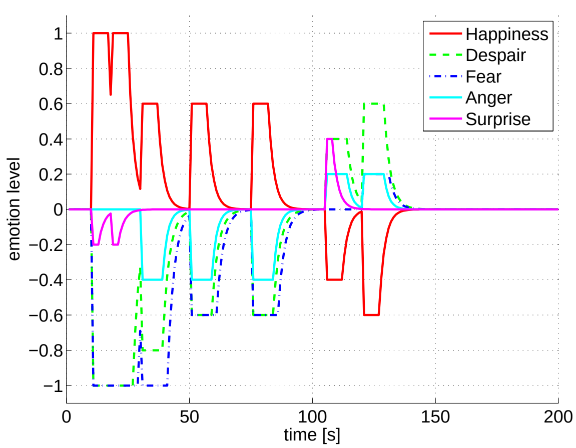

Fig. 4. Emotional response in the presented simuation

VII. APPLICATION

The computing devices that came as possible applications into our focus were chosen based on two distinct aspects. One aspect was to entertain the user (the owner of the artificial agent) assuming that entertainment guarantees the merchantability of the device. The other aspect is the scientific virtue of the artificial agent: is it possible to build a creature-like robot using simple engineering methods? Targeted applications should have in common that the artificial agents show attachment in their behavior to their owner.

Fig. 5. Selected robot to be extended by our emotional model

The robot shown in Figure 5 was chosen in accordance with the second aspect. We are currently working on the design of simple behaviors for the robot. The robot will express its emotions through its behaviors likewise the dog does. We intend to obtain a robot that seems more creature-like to humans, that can be easier accepted by humans and hence it can be employed as social robot in the human environment.

VIII. CONCLUSION AND FUTURE WORK

In this work we presented an emotional engine model designed for an artificial agent. We approached the task of emotional modeling from an evolutionary point of view, presented neurobiological background of emotions and as ethological research showed that human-dog interaction is a good model for inter-specific social interactions we chose human-dog interaction as basis for our modeling work.

We proposed a non-linear state space model to design an abstract emotional model. We extended the emotional engine by emotion arbitration. We set up a hierarchical rule tree for the arbitration and presented the biological background of the rules.

We have implemented the abstract emotional engine, showed simulation results and wrote about the applications we were currently working on.

Our future work will focus on the design, implementation and evaluation of the presented applications. Beyond this main effort we want to integrate the medium-term layer into the arbitration rules and put this integration on biological background. Considering the fine-tuning of our emotional engine we plan to carry out further special tests investigating the human-dog interaction.

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