An Emotional Engine Model Inspired by Human-Dog Interaction

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***Abstract*— We use an engineering approach based on state space modeling to develop the emotional engine of an artificial agent. The model is inspired by the latest achievements of human-dog interaction research. Our goal is to build a model that can be easily integrated into existing applications in the field of robotics, computing and communication systems. The proposed model ensures this integration by using simple arithmetics, while being scalable and stable.**

I. INTRODUCTION

In the past decades robotic research interest has broadened to include domestic applications, and huge efforts have been invested in building robots that support people in their daily life. Robots that are used in close collaboration with people face very different challenges and have to confront and solve new problems in comparison to industrial robots. Industrial robots work in well-known environments (factories), safety is guaranteed through special instructions and the robots receive their tasks via computers. In contrast domestic robots are required to work in environments that are often unfamiliar and very dynamic. Furthermore, these robots are expected to interact and cooperate with people directly. This requirement for human-robot interaction forces robot designers to deal with cognitive, emotive aspects in addition to the technical and technological issues in robotics. We refer to robots that interact and communicate with humans by following social behaviors attached to their roles as social robots. These social robots possess emotional models to ease their interaction with humans.

The research of social robots integrates impacts from arts, engineering, medicine and other scientific fields. Social robots have been already applied in the fields of entertainment, healthcare, education, child- and eldercare.

In our work we use an engineering approach inspired by a general model of basic emotions based on human-dog interactions to develop an abstract model of the emotional engine of an artificial agent. The emphasis of our work is on the theoretical side of the modeling. The challenge of the present project is to build a non-human emotional agent which is able to interact with humans in a natural way and is based on a simple engineering model utilizing simple mathematical methods. Our goal is to develop a model that can be integrated in numerous existing applications from social robots to personal data assistant equipment as well as ”simpler” domestic applications. The only requirement towards the robotic application is that it has to have ”instruments” to express its inner states which will be recognized as emotions on the human side.

This paper is organized as follows. Section II gives an overview of emotional models applied in different social robots. Section III presents the methodology we used to set up our model. Section IV deals with the ethological background of our approach. Section V describes first the parts of the emotional system then the complete system which implements our emotional engine. Finally, Section VI concludes the paper and sketches possible future work.

II. OVERVIEW OF USED EMOTIONAL MODELS

Social robots using emotional models have a general structure of emotion handling components (cf. Fig. 1). The robots are equipped with input devices (visual, audio, mechanical sensors) to recognize events in the environment. Identified events carrying emotional information are passed to the emotional engine. 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.

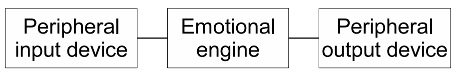

Fig. 1. General structure of emotion handling components in the robots

In order to identify the relationship between our emotional model and existing emotional models used in social robotics, we review six robots with regard to their abilities, with special focus on the used emotional models. Figure 2 shows an image of each of the investigated robots.

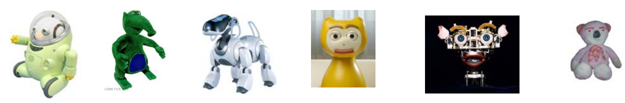

Fig. 2. Investigated robots: Ifbot, Probo, Aibo, iCat, Kismet, Emotirob (from left to right)

We set up several evaluation criteria to investigate emotion handling of the robots from our point of view. Firstly, we investigated whether the emotional model distinguishes between the duration of emotional states (short-, medium-, long-term). Secondly, we searched for probabilistic methods used in the context of the emotional model. Finally, we

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inquired whether the emotional model has ethological background. Table I compares the emotional models reviewed in light of our evaluation criteria. The emotional model we propose in this paper is intended to satisfy all of our evaluation criteria.

TABLE I
COMPARISON OF THE EMOTIONAL MODELS USED IN EXISTING SOCIAL ROBOTS

Study	ster	mter	lter	prob	ethb
Ifbot [1]	X				
Probo [2]	X	?			
iCat [3]	X	X		X	
EmotiRob [4]	X				
Aibo [5]	X	X		X	X
Kismet [6]	X	X			X
Our proposal	X	X	X	X	X

ster: Short-term emotional response. *mter:* Medium-term emotional response.
lter: Long-term emotional response. *prob:* Probabilistic nature.
ethb: Ethological background.

The ”sensitivity communication” robot Ifbot [1], [7] was developed to investigate human-robot interaction. Ifbot is able to recognize people's emotion based on the tone of their voice, to represent emotional states and to express six basic emotions on its face. The facial expressions are mapped to an emotional space which is represented by a neural network. The third layer of the special five-layer perceptron was used to extract characteristics of facial expressions in order to identify emotions. This solution results in a 3D emotional model where the trajectory in the emotional space of a facial expression can be mapped to a defined emotion. The facial expressions are learned by the neural network and a smoothing method is used to achieve seamless facial control.

The huggable robot Probo [2], [8], [9] was created for therapeutic purposes, it functions as a robotic user interface between an operator and a child. Probo's interaction is carried out by use of cameras, touch sensors, microphones on the input side and speakers and facial expressions on the output side. In [2] the authors write about the influence of the input stimuli on the attention- and emotion system. A three level behavior-based framework [10] (reactive, routine and reflective level) is presented in [9], of which Probo implements the first two levels (the third level is regarded as future work). Using the three levels Probo will be able to have short- and medium-term emotional responses. The emotional space is set up by two parameters: arousal and valence. The emotion interpretation method results in a specific emotion and a corresponding intensity.

The ”iCat” user-interface robot [3], [11], [12] uses the approach of applying animation principles to robotics to create believable behavior in order to increase its life-likeness. iCat is a desktop user-interface robot with mechanically rendered facial expressions. The animated behavior of iCat robot is divided into two parts: *mode animation* (medium-term) and *action animation* (short-term). To define the behavior of mode animation a probabilistic automaton was used. In [3] authors argue that using probabilities for the mode behavior results in more authentic behavior. The main strength of iCat is the highly elaborated emotion interpretation by means of facial expression based on animation techniques.

In the frame of the EmotiRob project [4], [13] the companion robot called EmI was designed for therapeutic purposes. Inputs are video and audio signals which allow EmI to detect the emotional state of the human partner. Each experienced action or word is associated with a vector of primary emotions. This causes the emotions of the robot to change dynamically. The emotional experience is generated based on the emotional state of the robot and its human partner.

Kismet [6], [14], [15], [16] was developed to explore issues in building social intelligent autonomous robots. The robot has a vision system, microphones, a speech synthesizer, a two degree of freedom neck, and facial features which enable it 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. A detailed description about Kismet's elaborated emotion system (stimulation, emotional space and emotion arbitration) can be found in [6].

The autonomous robot Aibo [5], [17] was designed for entertainment purposes. The pet-like robot 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. The detailed description of the behavioral and emotional model of Aibo can be found in [5].

III. METHODOLOGY

We aim to design and implement an abstract emotional model that can be integrated not only in the aforementioned social robots but also in embedded systems, in simpler and general equipments (mobile phone, car, wash machine, intelligent home, etc). The use of an abstract emotional model makes two more components necessary for the emotion handling process compared to the structure depicted in Figure 1. In Figure 3 these components are identified as input and output middleware, respectively. The input middleware matches the actual physical inputs of the input devices to the abstract model inputs, while the output middleware implements a similar matching on the output side.

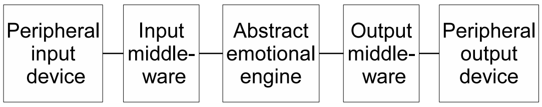


Fig. 3. General structure of emotion handling components in the robots in case of an abstract emotional model

All these systems are equipped with peripheral devices that can be used for human-robot interactions beyond their original functions to express the inner states of the system. As each appliance is equipped with different peripheral devices the middlewares require particular design decisions for each appliance which is beyond the scope of this paper.

The most important requirement towards our architecture is that its operation should not put a high load on the resources of the system. The system has to be able to carry out its initial tasks, functions beside the computational load of the proposed model. For this purpose an event-triggered application which runs in the background seems to be the most suitable.

We selected a linear open loop discrete time state space model to build the core part of our emotional engine. The linear core part may be extended with non-linear elements in the future wherever our modeling work justifies this. The core part has to meet the following aspects:

- Simple arithmetic: The computational model should not use unnecessarily complex functions and arithmetic operations.
- Time and amplitude scalability: People use their devices for different amounts of time each day. Taking the usage time into account the time constants of the changes of the inner states should be set up adequately. Thus pleasant interaction should be attainable with equipment that are used rarely (only a few minutes a day), as well as with an equipment that is carried during the whole day, without getting on the user's nerves.
- Stability: The stability of a linear open loop system can be ensured by the selection of the eigenvalues of the system matrix. The trajectory of inner states should be predictable for all possible environmental actions.

In the case of the discrete state space model the events that ensure the operation of the system are the events initiated by users on the one hand and the interrupts that occur in regular intervals (sampling time) on the other hand. The calculation of the inner states at sampling time can be performed by simple operations. Time scalability can be achieved by choosing the appropriate sample time.

IV. 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 [18]. 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 [19]. Regarding communication, for example, dogs have evolved skills that enrich their capacities to communicate with humans in complex social situations [20].

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 [21], [22]. 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.

Extensive causal observations of human-dog interactions led our expert team to hypothesize a preliminary model of emotional space in dogs (Table II). This preliminary model can be already interpreted by mathematical methods and taken as a basis for modeling our emotional engine. Four basic emotional states are identified: *happiness, despair, fear, anger*. 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 four emotions in the dog is enough to develop and maintain sophisticated social interactions with humans.

Further, environmental events may influence the emotional states of the dog across three attributes, which are

- arousal (high, medium, low),
- valence (positive, negative),
- variance (high, medium, low).

We explain the content of Table II by taking a concrete example. The first column in the context field 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 greeting interaction can be identified on happiness, despair and fear whereas anger is not affected. The event has a high arousal value (3 stands for high), a positive valence ($\uparrow$ stands for positive) and a low variance (1 stands for low), that is, this impact triad results in a high, positive influence with high probability on the emotional state *happiness*. Low variance means that the factor is near the expected arousal value with high probability. The same event has a high, negative influence with high probability on *despair* and a medium, negative influence with medium probability on *fear*.

TABLE II

IMPACT OF ENVIRONMENTAL ACTIONS ON DOG'S BASIC EMOTIONAL STATES

	CONTEXT										
	greets O	leaving O	touched by O	O init. int.	O rej. int.	O not as exp.	ambi. sit.	play w. h.	nov. stim.	unfam. env.	facing stranger
Happiness	3↑1	3↓1	2↑1	2↑2	2↓1	1↓2	2↓1	2↑1		1↓3	2↓2
Despair	3↓1	3↑1	2↓2	2↓1	2↑1	1↑2	1↑2	2↓1			
Fear	2↓2		2↓2				1↑2	2↓1	1↑2	2↑2	2↑2
Anger		1↑3	1↓2		1↑2	1↑3	1↑2	2↓1	1↑2		1↑2

Abbreviations:
O: owner
init. int.: initiates interaction
rej. int.: rejects interaction
not as exp.: does not react as expected
ambi. sit.: ambivalent social situation
play w. h.: play with human
nov. stim.: novel stimulus in environment
unfam. env.: unfamiliar environment

V. EMOTIONAL ENGINE

This section describes in detail our emotional engine model. 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 II. At the design of the model we apply the methodological aspects detailed in Section III.

Though we know that in fact the dog's emotional model is complex and non-linear, for lack of details we at first model the emotional engine with a linear model. The use of the linear model is a simplification in order to implement the expert knowledge and to meet the previously listed methodological requirements. We will have to extend the linear core with two non-linear components. The first component will serve to saturate the emotions to keep emotional responses in a defined interval. The second element will implement the probabilistic behavior of the emotional responses identified in the emotional space in dogs.

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 four basic emotional states identified for the dog. The emotional states are represented in the four dimensional state vector $\mathbf{x}[k]$. The state vector is stimulated by the inputs. We will distinguish between three types of emotional handling: short-term, medium-term and long-term.

The stability of the linear core is ensured by the adequate property of the $\mathbf{A}$ system matrix. We want the system to meet the requirements of asymptotic stability.

The model can handle time constants that will manipulate the width of the emotional responses.

A. System implementing short-term emotional response

The first component of the emotional engine is designed to implement short-time emotional responses. These are temporally changed by the environment through the input vector. Figure 4 shows the used state space model. By design decision we excluded the direct connection between the input vector and the output vector.

$$\begin{aligned} \mathbf{x}[k+1] &= \mathbf{A}\mathbf{x}[k] + \mathbf{B}\mathbf{u}[k] \\ \mathbf{y}[k] &= \mathbf{C}\mathbf{x}[k] + \mathbf{D}\mathbf{u}[k] \end{aligned} \quad (1)$$

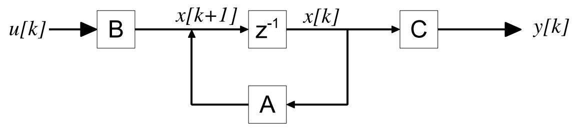


Fig. 4. Block diagram of the state space model of short-term emotion

Table II contains the dynamic changes of the inner states on the environmental impacts. In our state space model we achieve the adequate dynamics by the choice of the elements of the matrices $\mathbf{A}$ and $\mathbf{B}$. Through the $\mathbf{A}$ we can manipulate the width of the dynamics because the time constants influences the duration of the emotional reaction. Through both matrices we can influence the height of the dynamics. The matrix $\mathbf{C}$ serves to saturate the emotions, the saturation is attained by the use of a sigmoid function.

B. Extending the emotional model with medium-term emotion handling

We extended the system with a component that handles the medium-term emotions. We assume that medium-term emotional responses can be calculated by summing up the changes of short-term emotional responses and the current level of medium-term emotion. 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. The overall emotion of the system is calculated based on its medium-term emotion (which includes the history of its emotions), and the instantaneous emotional effect (short-term) caused by the environment. In other words, the happier the system, the less of a negative influence a negative impact will have on its emotional state.

When calculating of medium-term emotional level we take into account that the medium-term emotional level has to decline with time if no changes in short-term responses occur.

We obtain the result of the emotional response by adding the current short- and medium-term emotional levels. A very similar approach for handling the short- and middle-term emotional responses is presented in [23].

Figure 5 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

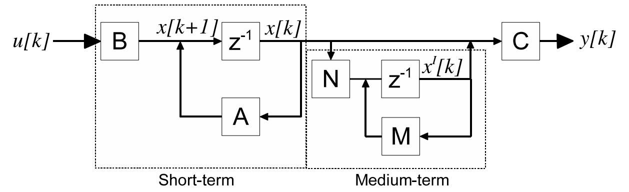


Fig. 5. Block diagram of the state space model handling short- and medium-term emotions

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. The equations in the state space system are shown in (2).

$$\begin{aligned}\mathbf{x}[k+1] &= \mathbf{A}\mathbf{x}[k] + \mathbf{B}\mathbf{u}[k] \\ \mathbf{x}^I[k+1] &= \mathbf{N}\mathbf{x}[k] + \mathbf{M}\mathbf{x}^I[k] \\ \mathbf{y}[k] &= \mathbf{C}(\mathbf{x}[k] + \mathbf{x}^I[k])\end{aligned} \tag{2}$$

C. System reduction and addition of long-term emotion handling

Before adding long-term emotion handling to our model, we simplify the model using the following rules:

$$\mathbf{x}_A = \begin{bmatrix} x \\ x^I \end{bmatrix} \qquad \mathbf{A}_A = \begin{bmatrix} \mathbf{A} & 0 \\ \mathbf{N} & \mathbf{M} \end{bmatrix}$$
$$\mathbf{B}_A = \begin{bmatrix} \mathbf{B} \\ 0 \end{bmatrix} \qquad \mathbf{E} = \begin{bmatrix} \mathbf{I} & \mathbf{I} \end{bmatrix}$$

The block diagram of the resulting model is shown in Figure 6 where the block for handling the long-term emotions (d) is depicted as well.

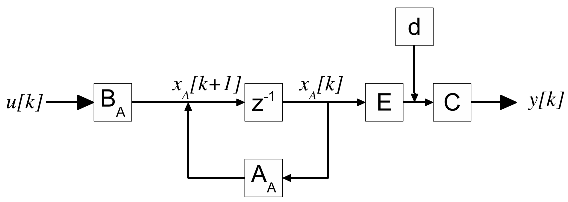


Fig. 6. Block diagram of the state space model handling the three types of emotions

In our approach long-term emotions represent basic emotional settings to which values of each identified emotion will converge if the model is not stimulated by the environment. The concrete basic setting can be set as pre-defined static values or can be dynamically generated based, for example, on long-term statistics of events that stimulated the system. Equation (3) describes the operation of the model.

$$\begin{aligned}\mathbf{x}_A[k+1] &= \mathbf{A}_A\mathbf{x}_A[k] + \mathbf{B}_A\mathbf{u}[k] \\ \mathbf{y}[k] &= \mathbf{C}(\mathbf{E}\mathbf{x}_A[k] + \mathbf{d})\end{aligned} \tag{3}$$

D. Adding probability to the model

Our last modeling task is to integrate the probabilistic behavior of emotional responses into the model. In human-dog interactions, dogs display some level of variability in their emotional behavior even in the same context. The differences in dog responses were considered using the *variance* attribute in Table II.

We make varied responses possible in our model by calculating the elements of the $\mathbf{B}$ matrix based on probability. In the preliminary stages of our model the elements of matrix $\mathbf{B}$ contained a static value for *arousal*. We define matrix $\mathbf{B}_M$ that includes the mean values – used previously as static values – and the matrix $\mathbf{B}_\sigma$ that contains the variance values. Based on the two matrices we calculate the single elements of matrix $\mathbf{B}'_A$ using the normal distribution, as shown in (4). We recalculate the elements of $\mathbf{B}'_A$ for every new stimulus coming from the environment.

$$\mathbf{B}'_A = N(\mathbf{B}_M, \mathbf{B}_\sigma) \tag{4}$$

Figure 7 depicts the block diagram of the final state space model. The equations describing the operation of our model are shown in (3). Matrix $\mathbf{B}_A$ is replaced by the dynamically generated $\mathbf{B}'_A$.

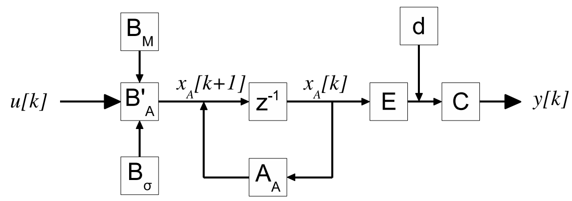


Fig. 7. Block diagram of the state space model of the final system

E. Numerical example

We briefly present our first simulation results. A scenario was set up to illustrate the changes of emotions with the following five events that served as inputs to the model:

- dog's owner enters the room,
- owner strokes (touches) dog,
- owner plays with dog,
- owner stops playing (does not react as expected),
- owner leaves the room.

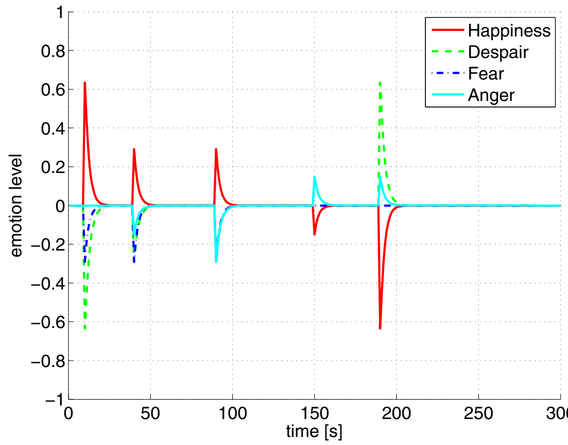
Figure 8 presents the simulation results at different stages of our modeling process. The values of the different matrices were tailored for a prototype robot used for demonstration purposes.

VI. CONCLUSION AND FUTURE WORK

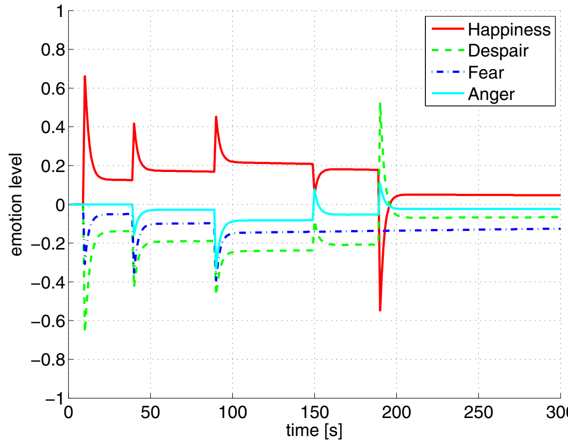
We proposed a state space model based approach to design an abstract emotional model of a non-human agent. We chose human-dog interaction as basis for our modeling work because ethological research showed that human-dog interaction is a good model for inter-specific social interactions. Though the dog has presumably few emotional states it interacts with humans successfully.

We have designed the abstract emotional engine and showed first simulation results for a defined scenario.

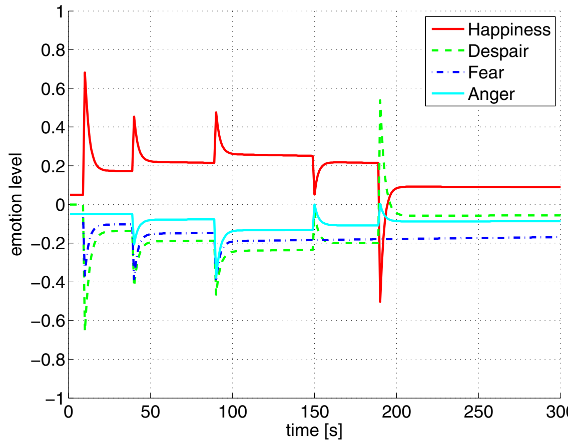
To integrate our abstract emotional model into a robot or another computing system the appropriate input and output middlewares have to be designed. Moreover, the time constants manipulating the width of the emotional responses



(a) Short-term handling



(b) Short- and middle-term handling



(c) Final model

Fig. 8. Emotional responses at different stages of our modeling process

have to be defined. At the moment, there are no experimental data on dogs which could help choose the particular time constants in our emotional model. Nevertheless, we argue that the time constants should be set based on human needs regarding the specific system and time constants may be defined in correlation with the usage time. In the future we would like to address these tasks in the context of a robot.

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