BEHAVIOURAL ADAPTATION OF REAL-TIME EMOTIONAL ROBOTIC AGENTS

Carlos Domínguez, Houcine Hassan, Alfons Crespo

Departamento de Informática de Sistemas y Computadores (DISCA)
Universidad Politécnica de Valencia (UPV)
Camino de Vera 14 - 46021 Valencia, Spain
{carlosd, husein, alfons}@disca.upv.es

Abstract: The interest of the application of emotional computational models to improve the design of intelligent robots has been growing in the roboticist community for the last years. Emotional models are used to modulate the robot cognitive system to improve its ongoing behaviour control. A key issue of the design is the selection and modulation of the cognitive behavioural load depending on the problem to be solved. To undertake the modulation, the agent is conscious of its mental capacities and it manages emotional appraisals that are dependent on the agent attitude, such as the expectation of success. This paper presents the modulation system of real-time emotional agents (RTEA) and shows how emotional appraisals, that have proven effectively in ethological systems, can influence the agent's decision making.

Keywords: Cognitive Agents, Emotional Systems, Robotics, Behaviour, Real-time Systems.

1. INTRODUCTION

The interest of the application of emotional computational models to improve the design of intelligent robots has been growing the last years in the roboticist community. This branch of robotics has recently been enabled and as such there is much more research to be done (Arkin 2004, Sloman 2004a).

In the context of neuroscientists an emotion is defined as the organised reaction to an event that is relevant to the needs, goals, or survival of the organism (Watson 2000). Whereas from a roboticist viewpoint, an emotion could be seen as a subset of motivations that can be used to dynamically modulate the robot cognitive system to improve the ongoing behaviour control to face complex and unpredictable environments (Arkin 2004).

A key issue of the design of emotional models is the selection and modulation of the behavioural load of the robot's cognitive system depending on the problem to be solved. To undertake the modulation, the agent is conscious of its mental capacities and it manages emotional appraisals, such as, the importance of the desires, the expectation of success or the urgency of the problem. These appreciations are dependent on the agent character and on its mood state that together determine the attitude of the agent behind each problem.

The agent should be capable of satisfying its own desires as a result of an emotional response. The aim is not only to select the desire, but also to modulate the intensity of the desire. This selection should consider the importance of the desire as well as the expectation of success which is related to the agent's conscience about its own capacities.

The set of goals in the agent's agenda are ordered by their importance. The satisfaction level, which is the motor of the agent behaviour, is related to how important are the desires. Apparently, performing tasks in sequence maximises the satisfaction. But the complexity of real problems and the big number of interactions makes usually this premise untrue.

The modelling of some behaviours that real agents exhibit are investigated in the paper. These behaviours which apparently seems to be "incoherent", finally obtain an improvement of the global satisfaction. The concept of urgency and how the appraisal of the urgency causes a temporal reorganization of the desire agenda are studied. It is shown how some desires of low importance level, due to their urgency, are satisfied before, and how other desires of high importance level, are put aside for a while, because they are not considered urgent.

This paper presents the modulation system of real-time emotional agents (RTEA) and shows how emotional appraisals can influence the agent's decision making. This type of appreciations has proven effectively for problem solving in ethological intelligent agents.

After the introduction, section 2 presents the state of the art on emotional models. The RTEA architecture is described in the section 3. Section 4 discusses the behaviour adaptation techniques based on the attitude. A robot navigation experiment faced with different attitudes and under different environmental conditions is described in the section 5. Finally, conclusions are summed up in the section 6.

2. RELATED WORK

In the literature, a variety of emotional models are found, however most of them are centred in the topic of human-robot interaction. An ethological model based on the praying mantis was proposed by Arkin et Al. (Arkin 2000). In this model the robot maintains three motivational variables that represent the robot's hunger, fear and sex-drive. These internal variables are modelled linearly with time. Action selection is used to enable the behaviour associated with the motivational variable with largest value.

Sony in collaboration with Ronald Arkin developed a computational model based on canine ethology and was used in the design of the Aibo entertainment robot (Arkin 2003). The model consists of six basic emotional states: happiness, anger, sadness, fear, surprise, and disgust. Each of them is reduced into three dimensions: pleasantness, arousal, and confidence. The levels of the internal variables are established and by relating the robot state with these threshold the emotional state can be assessed. The resulting emotional state affect the action-selection process in the behaviour eligibility. Based on the motivational space and action-selection mechanisms behaviours are scheduled for execution.

Moshkina has proposed the affect model Tame in order to assist in creating better human-robot interaction (Moshkina 2003). The model captures the interaction between different time varying affect related phenomena, such as traits, attitudes, moods, and emotions. In Tame, emotions are high activation and short term, while moods are low activation and relatively prolonged. Traits and attitudes determine the robot disposition and are time invariant. The affect model gets perceptual information and modifies the underlying behavioural parameters, which in turn, directly affect currently active behaviours. A partial integration of the affect model into the Missionlab system has been undertaken.

In the Social Robots group of the MIT Media Lab, Cynthia Breazeal, developed one of the first social robots: Kismet (Breazeal 2003). Kismet's motivation system consists of drives and emotions. The affective space is defined by three dimensions: arousal, valence and stance. The emotion is computed as a combination of contributions from drives, behaviours, and perceptions. The motivation is taken into account in the behaviour selection and in the activation of facial emotional expressions.

In general, the above described models are used in human-robot interaction (Arkin 2004, Breazeal 2003). These models are enough for non mobile systems (i.e. kismet), or in those where the dynamic temporal constraints are not critical (i.e. Aibo). However, an intelligent agent in mobile robotics should be adapted in real-time to the conditions of the environment based on its physical (actuators) and on its mental (processes) capabilities (Domínguez 2004). Therefore, endowing robots with realistic and complete emotional models requires to carry out much more work (Sloman 2004a, Arkin 2004). Conceptual frameworks that allow to express control concepts and higher level mental processes found in biological systems to help understand the kind of situations where emotional control states should be employed (Sloman 2004b), and more realistic models to analyse how changes the agent's emotional state based on new percepts (Nair 2004), are required.

3. RTEA ARCHITECTURE OVERVIEW

A RTEA agent is composed of the five principal systems of the Figure 1: Belief, Affective, Behavioural, Attention and Relation.

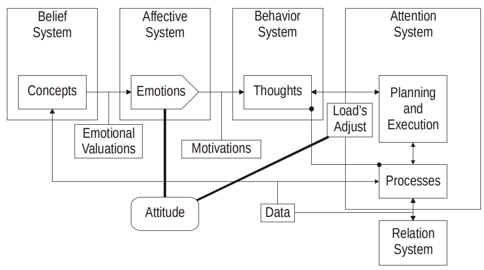

Fig. 1. RTEA subsystems and flow.

The belief system maintains a logical image of the environment. The processes in execution read and update this image permanently. The fundamental elements of this system are the concepts. They represent conscious abstractions of the data.

The affective system is the motor of the mental organisation. It manages a set of emotions as the basic mechanism of altering the mood. The mood is the degree of motivation of each of the active thoughts. An emotional state is activated by the assessment of the concepts, and the result is the adjustment of the motivation of the thoughts.

The behavioural system defines the behaviour of the robot. The main entity of this system is the thought. A thought is built associated to a special concept called desire. The motive of the thought is to satisfy the desire.

The attention system organises the execution of the processes. This system negotiates with the thoughts in order to get relevant information to guarantee their execution (security requirements) or to determine the degree of satisfaction of their desires (functional requirements).
Finally, the relation system communicates the agent with its environment.

4. BEHAVIOURAL ADAPTATION

The behaviour of an RTEA agent is based on its thoughts. The thoughts are processes executed with the aim of satisfying the desires. Once a desire is formulated its associated thought is activated.

4.1 Desire Model

The desire is represented by a situation in the environment. A situation is a state in a given time. The description of a desire is performed in a flexible way. It is desired a range of situations not only one concrete situation. Therefore, the agent could choose the most suitable situation for its capacities. The desire satisfaction model assess the possible situations in a range of 0 (unsatisfaction) and 1 (total satisfaction) as can be seen in the Figure 2a.

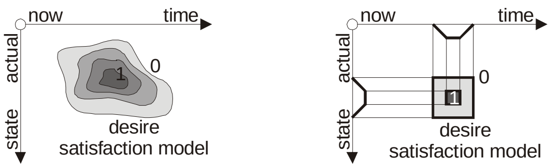

Fig. 2. a) Desired situations. b) Trapezoidal based satisfaction model.

The satisfaction models should be simple and fast to calculate the appreciation of the satisfaction. Hence, combinations of sigmoid, trapezoidal and lineal functions are used as can be seen in the Figure 2b.

4.2 Appreciations influencing the modulation

When a thought is activated a process is started for execution. The process is active or suspended depending on the agent's attention dedicated to the thought. The main activities of the process are: observation, decision and action.

The agent's actions aim to change the environment to satisfy the desire. While the thought is active a progress to the solution is performed. The thought knows the maximum possible progress because of the dynamic model it embeds. The decision consists of selecting the action intensity to progress over one of the progressing paths, as is shown in the Figure 3.

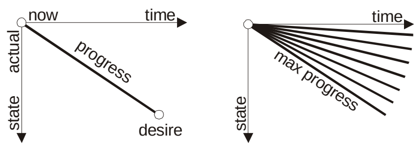

Fig. 3. Progress paths.

Normally, a thought becomes inactive when its desire is satisfied. However, it can be terminated also when the desire is obsolete (not useful) or when the satisfaction expectations vanish (there is a desire but there is not the capacity to satisfy it).

The environmental conditions are normally known at short term and the confidence of this knowledge decreases for the future as shows the Figure 4.

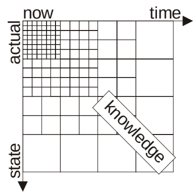

Fig. 4. knowledge evolution.

The duration of a thought is variable because of the environment uncertainty. Hence the thought ending time will be also variable (see Figure 5a). Therefore, the duration of the thought is estimated and updated in each attention cycle. The Figure 5b represents possible evolutions of the duration estimation.

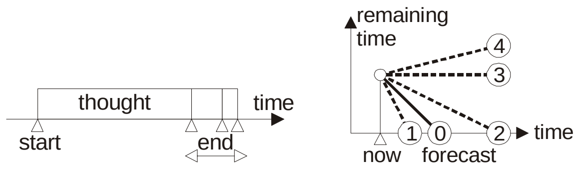

Fig. 5. a) Thought duration. b) Thought evolution.

If the estimation is correct the arrival will be "0". But if the navigation conditions complicate the problem, the arrival could be postponed: "2", or "3": there are no progresses to find the solution, or even "4": far from reaching the solution. Also, the expectations could ameliorate and then the thought could anticipate the solution: "1".

The progress depends on the action effort of the agent and on the problem conditions. The former presents conflict of interests since there are different problems to be tackled simultaneously. The latter are not controllable. The action effort is limited by the effector power and by the mental dedication. Different decisions could be taken to solve the conflicts: More dedication than the required by the current information of the problem? or less dedication? The action decision to solve this conflict is based on the different ways that the uncertainty of the future navigational conditions is perceived.

4.3 Attitude based modulation

The attitude of the agent influences its behavior. The agent attitude is the result of its character and its mood state.

The character is constant and defines the set of emotions and their structure. The character establishes the type of emotional appraisals of (the concepts contributing to the emotional state). The mood is variable and modulates the adjustment of the parameters of the emotions. It is defined by the set of active state variables, like the amount of thoughts, the stress, etc.

The influence of the attitude in the behavior is present at two levels: the motivation and the objective selection.

Influence in the motivation. The emotions establish the motivation of the thoughts. The attention system schedules the thoughts by prioritizing the more motivated ones. The attitude modulates the sensibility and the emotional response and hence it influences the motivation and finally the attention policy as can be appreciated in the Figure 6.

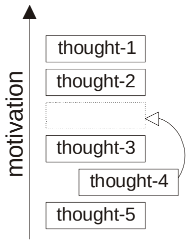

Fig. 6. Thought anticipation.

The thought motivation is derived from the desire importance, but other emotional appraisals, such as the *urgency* can alter the motivation. The urgency is an appraisal of the remaining time to satisfy the desire. When the remaining time reduces the maneuverability, the agent could increase the motivation of the thought as if the desire importance would be greater than the actual (see Figure 7).

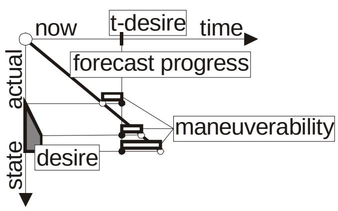

Fig. 7. Maneuverability urgency influence.

Due to its character, each agent has different appraisals of the urgency (emotional sensitivity), and once the emotional state has been reached, its response is also different (emotional control).

Related to the emotional sensitivity, different agent characters can be considered, for example: *Careless* and *Conservative*. The characters assess the urgency using the equation 1.

$$Urgency = \text{distance}\left(expectation,\ satisfaction\right) \cdot sensitivity \quad (1)$$

The *sensitivity* is a parameter that modulates the appraisal, its range is [0,1]. The *satisfaction* in the range [0,1] depends on the character.

For the previous characters:
- Careless Character: although the satisfaction is low, it thinks it is not urgent.
The satisfaction_level = min (low)
The sensitivity = 0.5 (medium)
- Conservative Character: even the satisfaction is complete, it thinks it is urgent.
The satisfaction_level = max (high)
The sensitivity = 0.75 (medium-high)

Related to the emotional control, different agent attitudes can be defined, for example: *Insensitive* and *Persuasible*. The attitudes use the equation 2 to determine the motivation variation.

$$\Delta motivation = response * urgency \quad (2)$$

The *response* in the range of [0,0.1] is the parameter that modulates the emotional response.

For the previous attitudes:
- Insensitive: this attitude is guided by the importance, so there is no variation on the motivation.
response = 0 → *Δmotivation* = 0
- Persuasible: this attitud is guided by the urgency.
response = 0.075

Influence in the objective selection. The attitude influences also the objective selection. As the desires are formulated in a flexible way, the thought has to choose a concrete objective. Different objectives require different mental dedications, and the agent should use specific attention criteria.

- In the attention system level, the agent uses a model that relates, for each active thought, the motivation to the minimum expected satisfaction. Figure 8 shows some typical models for some different agent attitudes.

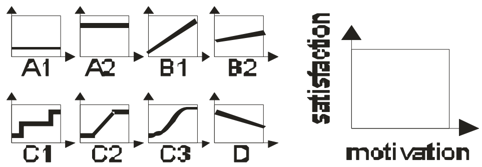

Fig. 8. Attention Model.

The agent in A1 executes many thoughts simultaneously, so, it expects low satisfaction in each of the thoughts. On the contrary, A2 expects high satisfaction, so, it will probably pay attention to a few thoughts. B1 and B2 are agents with non uniform attention criteria. Other models are C1, C2 and C3. D would be an unusual agent.

- In the thought level, the three models of the Figure 9 are defined to take part in this selection process.

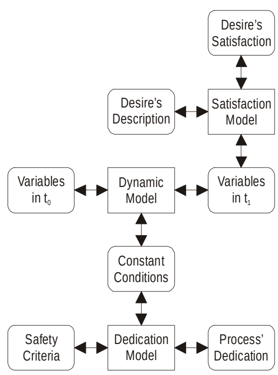

Fig. 9. Objective selection models.

The dedication model relates the controlled/uncontrolled conditions with the guaranteed dedication and security requirements. The dynamic model relates the conditions and the state variations. And the satisfaction model relates the state and the desire satisfaction degree.

The objective selection is performed in the negotiation phase that takes place between the thought and the attention system. They have to reach a trade-off, since the attention system requests to the thought a satisfaction desire degree while it has to guarantee him a minimum attention level.

5. EXPERIMENTAL EVALUATION

The experiment consists of analyzing how the desires of a mobile robot are achieved based on different attitudes embedded in the robot and under different navigational conditions.

5.1 Experiment statement

The robot starts from an initial (t = 0.0s , s = 0.0m) situation and has to reach a desired situation. A desire called *situation* is formulated with the satisfaction model of the Figure 10.

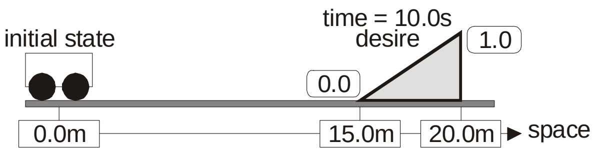

Fig. 10. Robot situations.

It is supposed that the *situation* desire has an initial importance of 0.5. The *move* thought is launched to satisfy the *situation* desire. It will compete for the agent attention with the list of thoughts of the Table 1. In each attention cycle the thoughts are prioritized by their motivation.

Table 1 Thought's motivations

Thought	Motivation
P1	0.7
P2	0.6
P3-move	0.5 + Δmotivation(urgency)
P4	0.4

The *move* thought inherits the motivation (0.5) of the *situation* desire. But the urgency can modulate its motivation. The rest of the thoughts are supposed to have the motivations derived from their respective desires.

The attention policy presented in the Figure 11 has been supposed.

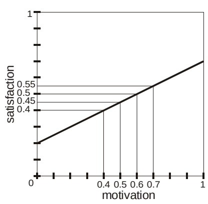

Fig. 11. Attention model example.

The satisfaction of the *move* thought depends on the urgency that influences its motivation.

The navigational conditions include aspects such as the type of terrain, the obstacle density, etc. The three different navigational conditions of the Figure 12 are considered.

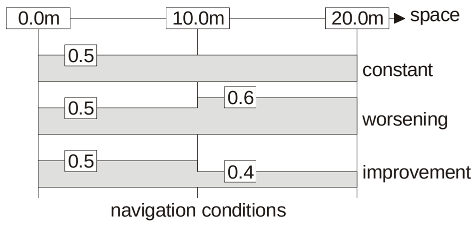

Fig. 12. Navigation difficulty degree.

In the first case the difficulties are constant, in the second case they get worse and in the third case they improve.

Given the expected satisfaction and the navigational conditions the thought decides the action based on its dynamic model. The robot action is associated to its mean speed along the decision period.
Likewise, given the security requirements and the navigational conditions, the action decision will be related to the dedication based on the dedication model. The Table 2 summarises both the models (dynamic and dedication).

Table 2 Dedication requirements

Thought	Satisfaction	Dedication
P1	0.55	0.2
P2	0.5	0.3
P3-move	0.45 + Δsat	see Table 3 model
P4	0.4	0.1

The dedication of P1, P2 and P4 are constant, while *move* has a dedication that depends on the urgency.
The dynamic model of the *move* thought is simplified to a cinematic model with a limit in the maximum speed. The dedication model and the navigational conditions are related to determine the maximum speed as can be seen in the Table 3.

Table 3 Maximum speed

Navigational Conditions	Dedication									
	0.1	*0.2*	*0.3*	*0.4*	*0.5*	*0.6*	*0.7*	*0.8*	*0.9*	*1.0*
0.4	1.7	1.7	1.8	1.8	1.9	1.9	2.0	2.0	2.0	2.0
0.5	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.0
0.6	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9

The urgency is defined as the temporal distance between the expected situation and the desired situation. The minimum satisfaction situation is t=10 s, s=15 m, and the maximum satisfaction situation is t=10 s, s=20 m.

The robot has been endowed with the characters *Careless*, *Conservative, Insesitive* and *Persuasible* described in the paragraph 4.3 to evaluate their influence in the final desire satisfaction.

5.2 Experimental results

The progress of the robot towards the proposed desire under the considered navigational conditions faced with the predefined attitudes is summarised in the Figure 13.

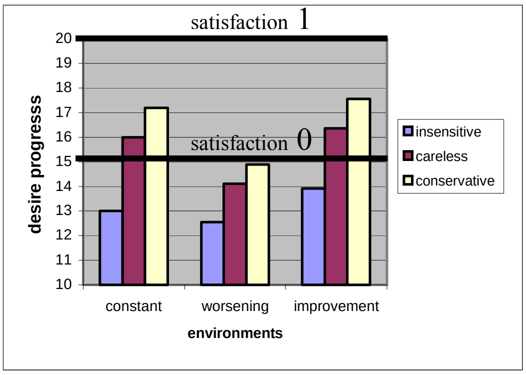

Fig. 13. Desire satisfaction.

When the robot is insensitive to the urgency, the desire is unsatisfied because the dedication of the move thought is insufficient, since its motivation is lower than the rest of the thoughts and it has not been increased by the effect of the urgency.

The desire satisfaction can be improved when the robot is not insensitive to the urgency.
If the robot is careless the desire is satisfied only when the environmental conditions are favourable (constant and improved).
If the robot is conservative the satisfaction desire is improved. However for the worsening conditions the desire continues unsatisfied.

When the urgency is considered, the *move* thought can be anticipated to other thoughts. Hence the extra mental dedication could facilitate the desire satisfaction.

The final satisfaction depends on the unpredictable navigational conditions. The hard conditions of the environment in the worsening case makes difficult to reach the minimal satisfaction requirements levels. But even though the future conditions are not completely predictable, the conservative attitude has anticipated the possibility of the future worst conditions better than the other attitudes. In this experiment, the robot conservative attitude presents the best progress and desire satisfaction results.

6. CONCLUSIONS

A real-time emotional agent architecture (RTEA) has been presented. The behaviour adjustment issue of RTEA agents has been discussed. The behavioural adaptation mechanisms based on the agent attitude have been detailed. An experiment analysing the degree of fulfilment of the desires of a mobile robot depending on different attitudes and environments has been carried out.

The future work will focus on improving the definition of the affective system, experimenting with more emotional appraisals and attitudes in more rich environments and designing an adaptable attention system to carry on the real-time robotic load. A real-time linux architecture of the emotional agent is currently being completed to be finally embedded in mobile robotic platforms.

ACKNOWLEDGEMENTS

This work has been partially funded by the Spanish Generalitat Valenciana government under grant GV04B/431.

REFERENCES

Arkin, R.C., Ali, K., Weitzenfeld, A., and Cervantes-Perez, F., (2000). Behavioral Models of the Praying Mantis as a Basis for Robotic Behavior, Journal of Robotics and Autonomous System, **32** (1), 39-60.

Arkin Ronald C., Fujita M., Takagi T. and Hasegawa R. (2003). An Ethological and Emotional Basis for Human-Robot Interaction, Journal of Robotics and Autonomous Systems, **42,** 191-201.

Arkin, R.. (2004). Moving Up the Food Chain: Motivation and Emotion in Behavior-Based Robots, In: Who Needs Emotions? The Brain Meets the Robot (JM Fellous and M. A. Arbib. Ed.). Oxford University Press.

Breazeal C., (2003). Emotion and Sociable Humanoid Robots. International Journal of Human Computer Studies, **59**, 119-155.

Domínguez C., Hassan H., Crespo A, (2004). Real-Time Robotic Agent Based On Emotions. International Symposium on Robotics & Applications. World Automation Congress 2004. Sevilla, Spain, 28-30 June.

Moshkina, L., and Arkin, R.C., (2003). On TAMEing Robots. Proc. IEEE International Conference on Systems, Man and Cybernetics, Georgia Tech., Atlanta, GA, USA 5-8 October.

Nair, R., Tambe, M., and Marsella S., (2004). The Role of Emotions in Multiagent Teamwork. In: Who Needs Emotions? The Brain Meets the Robot. (JM Fellous and M. A. Arbib. Ed.). Oxford University Press.

Sloman, A., (2004a). What are emotion theories about?, Invited Talk in Architectures for Modeling Emotion. American Association for Artificial Intelligence. Stanford University, Palo Alto, California, March 22-24.

Sloman, A., Chrisley, R., Scheutz, M., (2004b). The Architectural Basis of Affective States and Processes. In: Who Needs Emotions? The Brain Meets the Robot. (JM Fellous and M. A. Arbib. Ed.). Oxford University Press.

Watson, D., (2000). Mood and Temperament, The Guilford Press, New York.