Emotional Behavior Arbitration for Automation and Robotic Systems

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Abstract – **Robot-aided care for handicapped and elderly people is expected to be a key factor in future building automation. Teams of specialized service robots shall assist autonomously in tasks of everyday life. To fulfill the demands of this application field, robotic design has to face new challenges in behavioral design. In this paper a new approach for a general architecture of behavior for mobile robots and automation systems is presented. Based on the psychoanalytic model of the human mind, emotional evaluation mechanisms shall facilitate a fast estimation of complex and unpredictable situations based on environmental data acquired by the sensors of the robot. Emotional intelligence is used to narrow the focus of attention leading to a reduction of the computational load, and to improve the cooperative behavior among the robots. In order to show the advantages of the emotional arbitration architecture, the model has been tested in simulations based on the characteristics of an existing mobile robot.**

I. INTRODUCTION

Although the number of service robots for domestic and personal use has increased in the last two years, the scope of functions is still very limited. In the majority of cases the functions are reduced to vacuum cleaning, lawn mowing or the purpose of entertainment. Based on the assumable progress in technology in robotics and intelligent autonomous systems, it is expected that in the near future major tasks of every day life can be assigned to service robots which are part of home and building automation systems. Due to the significant increase of elderly and handicapped people in industrialized countries, a new demand on robotic assistants offering those people an independent life will arise.

Why is the design and construction of industrial robots so easy and the design and deployment of service robots for the household so hard? The answer lies mainly in the fact that an industrial robot gets along with a fixed sequence of operations in a well defined and allocated environment while a mobile service robot needs to master a more complex and unpredictable environment. Most factory sites have been adapted to be suitable for the installation of the required industrial robots. But in domestic use, *the robots* have to adapt to the environment. In order to achieve this objective, behavior patterns have to be grounded in a much broader "world model". However, so far the task of providing a robot with a human-like common sense for acting has not been achieved [1].

The traditional approach to robotic behavior is to implement solutions based on classical artificial intelligence (AI). This leads to robots performing deliberative reasoning algorithms which rely on the existence of comprehensive world models. This approach causes inappropriate computational effort and takes too much time to produce actions. Especially when acting in continuously changing environments, classical AI faces serious drawbacks: As mobile robots usually have only limited computational abilities, AI-based solutions for perception and action planning often have to be processed externally because they are too resource-demanding. Thus, robots have to follow externally computed instructions instead of "deciding for themselves". An approach to create mobile robots overcoming this difficulty and still showing robust behavior is described by Mochida et al [1]. They criticize that classical AI solely focuses on the intellectual aspects of the human mind whereas other aspects, like for example emotions, are neglected. In [2], Singh and Minsky come to a similar conclusion.

Although AI has been successful in deriving programs that at first glance seem to behave intelligently, the limitation of the majority of them immediately appears when they are confronted with one unexpected case. This is because their design is too ad-hoc. In order to expand the behavioral capacity of these programs, it would be necessary to intrinsically ground their knowledge in the environment. This insight leads to a shift of focus away from intelligent programs towards intelligent *agents*. Situated autonomous agents are the central role model of the field of embodied cognitive science. This approach is built upon the premise that intelligent autonomous agents, whether software or robotic, can only perform appropriately *on their own* in a variety of novel and challenging situations when they are inherently coupled with their environment [3]. They not only have to be able to extract relevant information from their environment, but also to actively explore their environment. Making use of the system-environment coupling can dramatically minimize the necessary amount of world modeling.

II. EMOTIONS IN COMPUTER SCIENCE

For a long time, emotions have been considered solely as disturbing influence to "rational" thinking. It was accepted only recently that they may be an important facet of intelligent behavior. The neuroscientist Damasio argues convincingly that emotions are crucially intertwined with cognitive problem solving and decision making [4]. Besides, emotions are an essential part for the establishment of social behavior as for example elaborated by the psychologist Frijda in [5]. However, the task of defining emotions in technical terms has often been accounted as not feasible. The main reason for this lies in the difficulty to

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reach a profound comprehension of emotional behavior. Nevertheless, an increasing number of researchers in the agent and robotic community believe that computational models of emotions will be needed for the design of intelligent autonomous agents in general, and for the creation of a new generation of robots able to socially interact with each other or people in special. As M. Minsky puts it: “The question is not whether intelligent machines can have emotions, but whether machines can be intelligent without any emotions” [6].

One approach dealing with emotions in robotic behavior was carried out by Pfeifer [7]. He started to implement the emotional behavior model of the Japanese psychologist Toda [8]. Instead of focusing on the traditional methods of cognitive psychology to analyze intelligent behavior, Toda designed abstract rules for an autonomous agent, the “fungus eater” robot, which performs foraging behavior in an artificially designed environment.

Mochida et. al created a behavioral architecture for autonomous agents based on the Braitenberg model [1]. The robot has a state variable called “frustration” rating its current situation either as pleasant or unpleasant. The implemented emotional mechanism is applied to an obstacle avoidance problem.

Shibata et al. [9] proposed an emotional architecture to produce cooperative behavior within a team of robots inspired by the neurologist and psychoanalyst M. Solms. The behavior of each robot depends on its own experience and the observed behavior of the other robots.

The approaches presented above deal with key factors of emotional intelligence. However, existing models of emotions either focus on ethnology-inspired low-level mechanisms (like the ones above), or on cognitively elicited emotions based on appraisal-theories (like for example the *Affective Reasoner* [10] or *WILL* [11]). What is missing is a *comprehensive* emotional model for autonomous agents.

III. EMOTIONAL BEHAVIOR ARBITRATION MODEL

The “Artificial Recognition System” (ARS) project [12] at the Institute of Computer Technology, Vienna, is an ongoing project that deals with the problem of situation recognition for robotic or ambient automation systems. The long-term goal of the work is to build intelligent autonomous systems which can deal with unforeseen situations in a flexible and reliable way without external help.

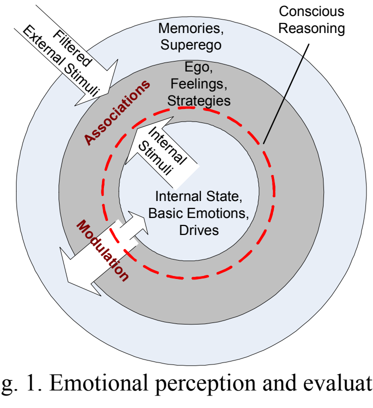

Fig. 1. Emotional perception and evaluation

The central part of the project is the creation of general control architecture. The resulting architecture is a hierarchical one that roughly fits into Sloman’s general multi-layer scheme [13]. It includes low-level forms of reasoning as well as high-level forms of reasoning. The integrating factor for the combination of the various levels is the psychoanalytic model of the human mind. Although the envisaged autonomous systems, e.g. mobile service robots, do not possess a body like living creatures, they are equipped with abstract emotional assessment mechanisms.

A. The Neuro-Psychoanalytical Picture

The neurosciences try to explain the functioning of the brain bottom-up. Psychoanalysis tries to do the same top-down. During the last years, a fruitful exchange between the two fields has started. The work of M. Solms [14] represents one approach to correlate psychoanalytic concepts with recent findings of the neurosciences. Based on this approach, an archetypical model of emotional situation evaluation has been designed (Fig. 1) by us. The most fundamental feature of the abstract, spherical model is that there are two sources of information for situation evaluation: external and internal stimuli.

External stimuli are continuously streaming into the system. The enormous amount of information has to be reduced dramatically in order to be manageable. To achieve this, the incoming information is condensed in a hierarchically organized matrix of symbols [15]. Thereby, low level symbols represent fragments of perceptual information (edges, brightness, etc.) and higher level symbols represent more complex features. On the low levels, different kinds of sensory values (optic, acoustic, etc.) are processed separately, on higher levels symbols are derived from various channels associated with each other. The results are assemblies of symbols (which can be combined to new symbols). By this method, the sensory input is transformed to “images” representing the outside world. To reduce the computational load, the whole perception process only calculates changes. Moreover, to recognize an object or scenario, the interpretation process vastly makes use of already memorized symbols and images. Therefore, human perception is not unbiased and neutral but shaped by previous memories. Perception is even more biased by the fact that input and evaluation of data are not arbitrary but organized as an *active screening process* searching for features that are required by the present internal state at any given moment in time.

Internal stimuli communicate “bodily” needs. They indicate the momentary internal physiological state, as given for example by the current energy level, and the current values of in-built “drives” and “basic emotions”. The most general purpose of emotions is to enable their carriers to distinguish between desirable and harmful situations. However, emotions do not appear on their own, they are connected to other components like “drives” and memory systems. Drives express the internal state of the body and, in case of an impending imbalance, initiate active search behavior. The outcome of this activity (registered in the next perceptual step) is rated on a pleasure-unpleasure scale. In the psychoanalytic model, pleasure-unpleasure play a very important role in that pleasure creates an urge for repetition of the pleasurable behavior while unpleasure leads to avoidance. This is important for learning. The pleasure-unpleasure system is the most basic emotional rating. Besides, there are other “basic emotions” like fear or anger that are linked to specific bodily reactions. Thus, basic emotions provide fast, stereotype responses to certain, often occurring categories of input situations. The world of drives constitutes one component of the psychoanalytic model of the mind, the *id*. Although we are not aware of its activity – as it remains unconscious – it has a big impact on our behavior.

Another component of the psychoanalytic model is the *superego*. It works as a counterpart to the id constraining drive activity according to the demands that outside reality and the requirements of our social world impose on us. The “social rules” it contains aim at establishing socially desirable behavior. This task is supported by social emotions, e.g. empathy, shame, guilt, envy, disgust, etc.

According to Damasio [4], the emergence of consciousness starts with the ability to experience the ongoing emotional evaluations in the form of *feelings,* whether “good” or “bad” or “happy”, etc. Consciousness arises from a kind of second-order association of emotional evaluations (representing the internal state) and outside world representations. What is essential is the ability to explicitly access past memories and future plans. In its richest form, the memory retrievals are carried out in terms of language. Conscious decision making delivers the best results in highly complex and unpredictable situations. According to psychoanalytic theory this is just the “tip of an iceberg”. A great deal of the decision process happens unconsciously relying on the basic processes described above. Higher-order and basic processes mutually affect each other, but the basic processes can influence or *modulate* the higher-order processes more than the other way round. Note that Freud’s notion of “ego” is not identical to consciousness but refers to all the images and processes within the brain, which are in principle consciously accessible.

B. Technical Analogy

The architecture implementing the combined neuro-psychoanalytic view of autonomous, emotionally supported reasoning for robots is presented in Fig. 2. The diagram shows the various modules of the architecture and how they are connected. All rectangular blocks in Fig. 2 represent functional units. There are modules for the following functionalities: external and internal perception, low-level and high-level emotional decision making, preparation and execution of selected actions. To fulfill their functions, the modules make use of several kinds of memory systems. The arrows in Fig. 2 indicate informational and/or control flows between the different functional blocks and the memory units.

Note that the architecture especially implements two key ideas of the neuro-psychoanalytic picture. The first is the fact that human intelligence is based on *a mixture of low-level and high-level* mechanisms. The low-level, relatively pre-defined responses may not always be accurate, but they are quick and provide the agents with a basic mode of functioning in terms of built-in goals and behavioral responses. The second key idea of the model is the usage of *emotions* as evaluation mechanism *on all levels* of the architecture. Emotions enable autonomous agents to learn *values* along with the information they acquire. In this respect, the introduction of an episodic memory containing emotionally evaluated previous experiences is a very important feature of the architecture.

There are several types of memories. *Image Memory* is the most basic one. It is used extensively by the external perception module while processing external input data. In the end of the hierarchical symbolization process, the created symbols representing the currently perceived situation are also stored there. The symbolization process needs knowledge stored in the *Semantic Memory* which contains facts and rules about the environment, e. g. what kinds of objects are there, how are they related to each other, what are the physical rules of the world the agents live in, etc. This knowledge describes possible associations between images. Whereas the semantic memory applies generally, the content of the *Episodic Memory* is much more agent-specific. It consists of previously experienced episodes which have been given an emotional rating. An episode is a sequence of situations. The various kinds of memories are linked together via the *Association* module.

The *SuperEgo* is a special part of the episodic memory containing rules for social behavior. Necessary information for the execution of routine behaviors is stored in the *Procedural Memory*.

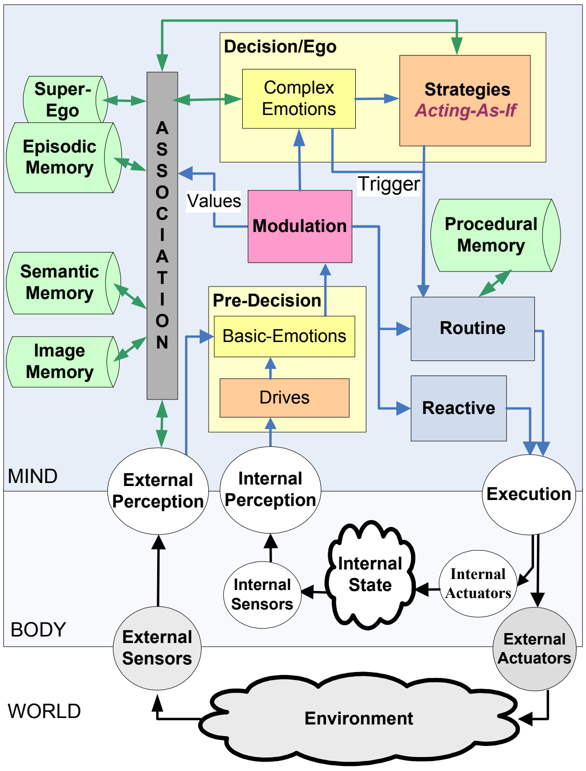

Fig. 2. Architecture of the Emotional Arbitration Model

The whole behavior selection process runs as a loop and can be described as follows:

- Perception: External stimuli originating from the environment are processed by the *External Perception* module using the knowledge stored in the image and the semantic memory. The resulting representation of the current situation is passed on to the basic emotions module of the pre-decision unit. Internal stimuli are perceived by the *Internal Perception* module. This module watches over the internal needs of the agent which are represented by internal variables. Each of these variables manages an essential resource of the agent that has to be kept within a certain range, for example its energy level.
- Low-level decision making: The *Pre-Decision* module consists of the *Drives* and the *Basic Emotions* module. When one of the internal variables is about to exceed its limits, the internal perception module signifies this to the drives module which in turn raises the intensity of a corresponding drive, for example *hunger* in the case of low energy. There is a threshold for hunger. When it is passed, the action tendency to search for food is invoked. In case that the basic emotions module does not release a competing action tendency, the decision to search for food is passed on to the routine module via the modulation unit. The basic emotions module gets its input from the external perception module and the drives module. It connects stereotype situations with action tendencies which are with high probability appropriate. For example, in case an object is hindering an agent to satisfy an active drive, it will become angry. Being angry leads to "aggressive" behavior where the agent "impulsively" tries to remove the obstacle. To do so, it quickly initiates a predefined coping reaction. When carrying out this action, the agent "mobilizes" its body and has a little bit more energy available than it would possess nominally at that time. The exact amount depends on the intensity of the invoked anger. Each basic emotion is connected with a specific kind of behavioral tendency, for example fear with fleeing (being cautious), disgust with the avoidance of contact, playfulness with the exploration of new situations. An important task of the basic emotions module is to label the behavior the agent has finally carried out as "good" or "bad". This rating is based on the perceived consequences (mainly on the internal state) of the executed actions. Successful behavior is rewarded with lust, unsuccessful behavior leads to avoidance. Basic emotions enable agents to switch between various modes of behavior based on the perception of simple, but still characteristic external or internal stimuli. This helps the agent to *focus* its attention by narrowing the set of possible actions *and* the set of possible "perceptions". The agent starts to actively looking for special features of the environment while suppressing others.

High-level decision making: Not every currently perceived situation is handed over to the *Decision* or *Ego* module, but only the ones where the pre-decision module has not already triggered a reactive or a routine response. Within the decision module, again an emotional rating takes place. This is done by the *Complex Emotions* module which matches the current situation with one or more social emotions like compassion, contempt, shame, etc. For this, it heavily interacts with the episodic memory and the superego (which is a special part of the episodic memory containing rules for social behavior). The complex emotions module searches the episodic memory for situations similar to the current one including their emotional rating. There can be more than one with varying emotions. In this case, the total sum of each of the different emotions is calculated whereby each situation contributes according to its similarity with the current situation quantified by the weighting factor w. Thus, the emotional state at time t can be represented by a vector $\vec{E}_t$ according to Equation (1). $\vec{E}_t$ is the sum of the stored emotion vectors of similar situations plus the current basic emotion vector $\vec{B}_t$ plus a contribution of the rest of the last emotion vector $\vec{E}_{t-1}$ acting like an emotional memory.

$$\vec{E}_t = \alpha \sum_i^N w_i \vec{E}_i + \beta \vec{B}_t + \gamma \vec{E}_{t-1}, \quad \alpha + \beta + \gamma = 1 \qquad (1)$$

Either the result contains an emotion that is so strong that it directly triggers a behavior or the final decision is done by the *Strategies* module. This module contains a strategic planning mechanism creating hypothetical representations of possible alternative behaviors. This mechanism is influenced by the past emotions invoked in the complex emotions module. A simple version of learning comes into place when newly experienced situations, including their emotional rating, enter the (episodic) memory, and thereby start influencing subsequent reflective processes. A more sophisticated variant of learning could be achieved via the implementation of a categorization algorithm, additionally generalizing newly experienced situations.

Action preparation and execution: There are two kinds of behaviors, routine and reactive behaviors. Reactive responses are simpler than routine behaviors. They are only released directly after the quick evaluation process of the pre-decision unit. Their purpose is to keep the agent from harm in dangerous situations. Routine behaviors consist of longer sequences of actions whereby the behavioral patterns are stored in a procedural memory. The execution of a routine behavior can be invoked either by the pre-decision module or by the decision module.

IV. SIMULATION AND EVALUATION

The derived general cognitive architecture can be applied within a wide range of automation and robotic systems. One of the biggest problems of autonomous decision making is how to cope with huge amounts of input data and a great variety of possible behavioral responses. The presented model addresses this problem with emotional evaluation mechanisms that not only support data reduction by influencing behavior selection but also "weight" perception itself. Emotions enable the system to switch its focus of attention according to the current internal and external needs. This concept reduces computational complexity. Together with the in-built social mechanisms, it is one of the most promising aspects of the architecture. The capability of these aspects is currently tested in a series of simulation experiments specially designed to form the basis for a real-world implementation into a mobile robot.

At the Institute of Computer Technology of the Vienna University of Technology, first valuable experiences dealing with the problem of situation recognition have been gained within the "Smart Kitchen" project aimed at creating an intelligent system in the field of building automation [16]. Another important preliminary work was the development of the Tinyphoon robot [17], a tiny, fully autonomous, mobile robot. Apart from its hardware realization, there is also a software simulation of the robot derived from its real world characteristics. This simulation is now subsequently equipped with the psychoanalytic behavior model.

For scalability, the software of the simulation experiments is split up in three major parts (Fig. 3):

- Behavior simulation: The various modules of the general behavior arbitration architecture have to be adapted to suit a specific environment. The tasks the robots need to fulfill require a specific set of behaviors. Moreover, the selectable action patterns need to be adapted to the "physical" capabilities of the robot. The selection of an action pattern is based on the emotional interpretation of incoming data. Therefore the robot needs to be equipped with a suitable set of drives and basic emotions.
- Robot simulation: The robot simulation represents the missing link between the simulation of the continually changing environment and the behavior simulation. The selected action patterns have to be transformed into executable commands. This transformation is robot-specific and depends on the capabilities and physical structure of the simulated robot. In the carried out simulations, an abstract model of the Tinyphoon robot was chosen.
- Environmental simulation: The environment contains sets of entities (robots) which can influence a variety of movable and non-movable objects. This is done according to given physical rules.

Separating the simulation of the environment from the simulation of the behavior of the robots and the simulation of their physical characteristics easily allows varying the simulation experiments. For the carried out simulations, an environment has been designed similar to that of the fungus eater:

- There are mandatory physical rules.
- To stay "alive", robots have to find energy resources.
- The total energy (environment and robots) is limited.
- A robot always consumes energy. The level of consumption increases with its level of activity. If the robot's energy falls below a certain threshold, it "dies".
- Two groups of robots act competitively trying to gain advantage over energy resources. The goal of each robot is to live as long as possible and to cooperate with the other robots of its group to keep them alive, too.
- The simulation does not end until one group dies out.

The individual robots slightly differ from each other specified by different values of emotional parameters, different memory entries, or different available action patterns. Thus, various configurations of the model are evaluated and compared to each other in search for an optimum behavior.

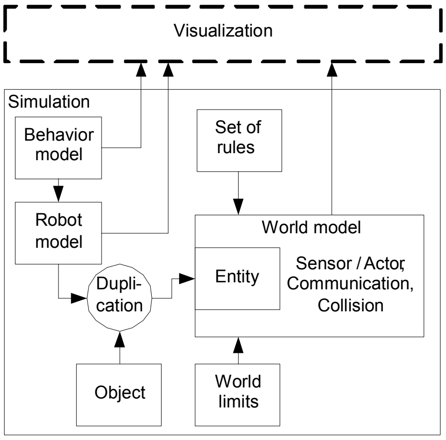

Fig .3. Schema of the simulation engine

The simulation experiments are done with Anylogic, a Java-based simulation framework. Java has been chosen because of its universality, speed, and simplicity of implementation. Anylogic provides abstract libraries for agent-based simulations that support and improve the simulation experiments of the behavior model. The three main parts of the simulation software (environment, robot, and behavior simulation) are set up within different libraries freeing the action module completely from the environment simulation. This structure facilitates the "wrapping" of the simulation and makes it possible to work with abstract action patterns rather than proprietary machine instructions. As a consequence, the behavior module can be simulated without the necessity of having a detailed knowledge of the functioning of the moving unit of the robot.

First evaluative tests have been made using two competitive teams of three robots each. In the simulations, the environment contains a varying number of energy resources (from one to six) randomly distributed. The number of energy resources is directly proportional to the playing time and can be used to vary the test length. One of the teams is facilitated with a first implementation of the emotional behavior arbitration model, and the opponent team is facilitated with a rule-based expert system showing four behavior schemes called *promenade*, *search_for_food*, *eat* and *escape* which can be chosen based on simple rules taking into account external influences and one internal parameter, the energy level.

The tests have shown that the robots equipped with the emotional behavior arbitration model might need more time to react, which might be a disadvantage in the beginning and lead to energy shortages under unfavorable conditions. However, when averaging over a lot of simulation runs, the robots of this team show a more flexible and adaptive behavior that outperforms the fixed rule-based behavior (in terms of average life time of all the robots of a team). The new model allows for more precise strategies under varying environment conditions. Moreover, the higher degree of team work gives the members of this team another advantage over their rule-based governed opponents. In the next steps team conflicts will be enforced and the functionalities of the opponents will be enhanced to increase the level of competition.

V. DISCUSSION AND OUTLOOK

In this paper a comprehensive behavior model for robots based on emotional evaluation mechanisms has been presented. It improves autonomous behavior arbitration in complex situations, and resource allocation when there are high amounts of input data. For evaluation, simulation experiments have been defined using the existing Tinyphoon robot as a role model. The first experiments implementing a simple version of the architecture show successful behavior arbitration on a low level. The results, based on drives like hunger and exploration and basic emotions like fear and anger, demonstrate that the robots are capable to perceive and handle critical situations and conflicts autonomously. The implemented pleasure-unpleasure mechanism helps to improve the avoidance of unsuccessful behavior patterns. This simulation will be extended iteratively using more and more complex algorithms for the various modules. Currently, an algorithm is designed to correlate the emotional ratings with the contents of the episodic memory. In the next steps, the simulated environment and the complex emotions module (responsible for social behavior) will be extended. The envisaged final real-world implementation into the Tinyphoon robots shall give a proof of the advantage of emotional behavior in a prototype. As emotional intelligence is best practice in nature since millions of years, emotional mechanisms seem to be capable of designing a powerful generation of autonomous mobile service robots socially interacting with each other and with humans.

VI. REFERENCES

[1] T. Mochida; A. Ishiguro, T. Aoki; Y. Uchikawa,; “Behavior arbitration for autonomous mobile robots using emotion mechanisms”. *Proceedings IEEE/RSJ Conf. on Intelligent Robots and Systems*, vol. 3, 1995 pp. 516-521.

[2] P. Singh; M. Minsky; “An architecture for combining ways to think”. *Proceedings Int. Conf. on Knowledge Intensive Multi-Agent Systems*, Cambridge, MA.; 2003, pp. 669-674.

[3] R. Pfeifer, C. Schreier, *Understanding Intelligence*, MIT Press, Cambridge MA, 1999.

[4] A. Damasio, *Looking for Spinoza: Joy, Sorrow, and the Feeling Brain*, Harvest Books, 2003.

[5] N. Frijda, *The psychologists’ point of view*, Lewis & Haviland-Jones, 2000. pp. 59-74.

[6] M. Minsky, *The Society in Mind*, Simon and Schuster, New York, 1986.

[7] R. .Pfeifer, “Emotions in robot design”, *Proceedings. 2nd IEEE International Workshop on Robot and Human Communication*, 1993, pp. 408 – 413.

[8] M. Toda, *Man, Robot and Society*; Martinus Nijhoff Publishing, 1982.

[9] T. Shibata, K. Ohkawa, K. Tanie, “Spontaneous behavior of robots for cooperation. Emotionally intelligent robot system”, *IEEE Proceedings on Int. Conf. on Robotics and Automation*, vol. 3, pp., 1996, pp. 2426-2431.

[10] C. Elliott, *The Affective Reasoner: A Process model of emotions in a multi-agent system*, PhD thesis, Northwestern University, Evanston, Illinois, 1992.

[11] D. Moffat, N. Frijda., “Where there’s a Will there’s an Agent.” *In: Intelligent Agents: ECAI-94 Wokshop on Agent Theories, Architectures, and Languages*, 1995, pp. 245-260.

[12] D. Dietrich, W. Kastner, T. Maly, Ch. Roesener, G. Russ, H. Schweinzer, “Situation Modeling”, *Proceedings 5th IEEE Int. Workshop on Factory Communication Systems WFCS04*, 2004, pp. 93-102.

[13] A. Sloman. “How many separately evolved emotional beasties live within us?”. *Emotions in Humans and Artifacts* (R. Trappl et al., eds), MIT Press, 2002, pp 35-114.

[14] M. Solms, O. Turnbull, *The Brain and the Inner World*, Karnac/Other Press, Cathy Miller Foreign Rights Agency, London, England, 2002.

[15] G. Pratl, B. Lorenz, D. Dietrich, “The Artificial Recognition System (ARS): New Concepts for building automation”, *Proceedings of 6th IFAC Int. Conf. on Fieldbus Systems and their Applications*, Puebla, 2005.

[16] G. Russ, *Situation Dependent Behavior in Building Automation*, PhD Thesis, TU Vienna, 2003.

[17] S. Mahlknecht, R. Oberhammer, G. Novak, "A Real-time Image Recognition System for Tiny Autonomous MobileRobots"; *Proceedings IEEE Real-Time and Embedded Technology and Applications,* 2004, pp. 324-330.