Emotion Based Control Architecture for Robotics Applications (extended version)

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Abstract. Assistance and service systems are one of the main research topics in robotics today. A major problem for creating these systems is that they have to work and navigate in the real world. Because this world is too complex to model, these robots need to make intelligent decisions and create an intelligent behavior without knowing everything about the current situation. For these aspects, the importance of emotion increases, because the emotional influence helps human beings as well as animals to make their decisions. To enable a robot to use emotions, a concept for an emotion based control architecture was designed. The basis of this architecture is a behavior based approach. This paper presents the developed architecture. Furthermore two application possibilities are presented, where parts of the architecture were already tested and implemented.

Key words: control architecture, behavior based control, intelligent robotic systems

1 Introduction

The combination of intelligent machines and emotions is a topic of research for several decades. M. Minsky [1] told in his book "Society of Mind":

> *The question is not whether intelligent machines can have any emotions, but whether machines can be intelligent without any emotions.*

The realization of emotions should be a central aspect of any intelligent machine. Rational and intelligent behavior is needed in nearly every autonomous robot system. These robots have to make decisions depending on their sensor data. Neuroscience, psychology and cognitive science suggest that emotion plays an important role in rational and intelligent behavior [2]. Because of this it is very important to use the emotional component in a robot system that should work and decide autonomously.

Worldwide, several research projects focus on the development of emotional control architectures for robot systems, like e.g. [3] or [4]. In [5] a survey of artificial cognitive systems is presented. Different models, theories, and paradigms of cognition addressing cognitive approaches, emergent systems approaches, encompassing connectionist, dynamical, and enactive systems. Furthermore several cognitive architectures drawn from these paradigms are presented.

A main research area for emotion based architectures is human robot interaction. In [6] an emotional architecture is presented that is used for generating emotional expression. These expressions should help to create a better human robot interaction. The design of the described architecture is based on information of neuroscience as well as cognitive science. Because of this the set up architecture is very well. The main disadvantage of this approach is that there are only a fix number of emotions that can be realized. Because of this the architecture can only be used for generating emotional expressions. To control a whole robot system and allow this system intelligent behavior the emotional representation had to be more flexible.

An approach that uses emotion for behavior selection is presented in [7], [8]. This architecture consists of drives that determine a goal and emotions that determine the behavior of the system to reach this goal. The disadvantage here is that the only goal realized in this architecture is the representation and selection of emotions. Only 4 emotions are realized but at least the 6 basic emotions and fusions of them are needed to generate every possible emotion. Furthermore the selection of the different emotions is very simple: happiness if something good happens, sadness if something bad happens etc. This is too simple if all relevant emotions should be realized.

2 Emotional Architecture

Depending on psychological theories [9] [10] an emotion based robot control architecture was designed. In the following section the concept of this architecture will be described in detail. The whole architecture is shown in Fig. 1. The architecture consists of 3 main parts: behavior, emotion, and cognition. All possible movements of the robot from simple reflexes up to high level motor skills are located in the behavior group. These behaviors are activated in different ways, e.g. directly depending on sensor data, depending on the emotional state of the machine or deliberately by the cognition part. That means within this architecture there are 3 layers of information flow. A reactive layer which realizes primitive reflexes, an emotion layer which enables emotional behavior depending on drives and emotional expressions depending on the actual emotional state, and an cognitive layer that generates plans to reach a certain goal. In the following subsections this behavior group and the 3 main layers of the architecture are explained.

2.1 Behavior

Every single behavior is represented by a so called behavior-node, see Fig. 2. Such a behavior-node has 3 data inputs and 3 data outputs. The definition of the in- and outputs is as follows: $a =$ the activity, $r = targetrating$, $\iota =$ the activation,

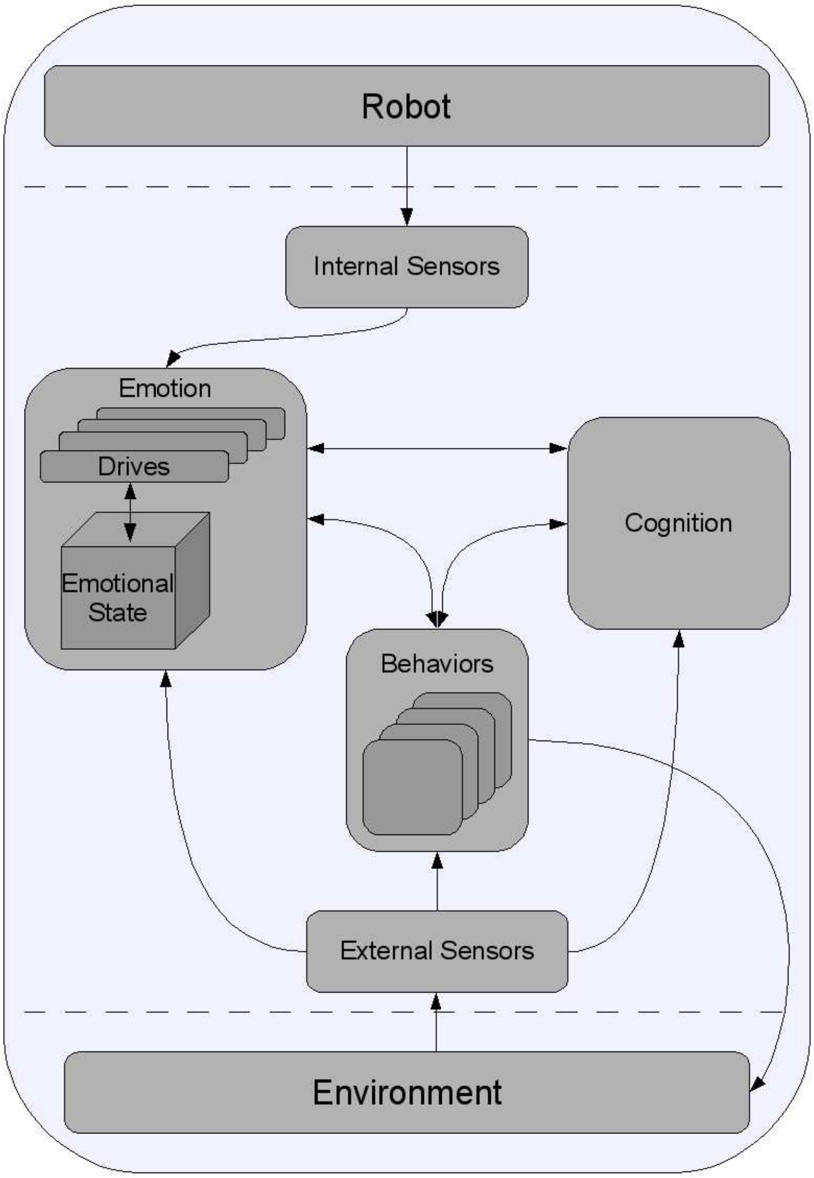

Fig. 1. The concept of the emotion based control architecture. The architecture consists of 3 main groups: Behavior, Emotion and Cognition. There are 3 layers of information flow within this groups: reflexes, emotional behavior and planned behavior.

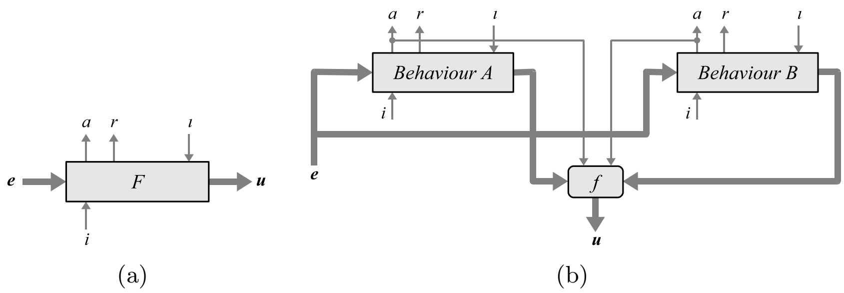

Fig. 2. 2(a): A single behavior node. All realized behaviors are build out of these modules. 2(b): The output of several modules can be merged by using a so called "Behavior Fusion"-Function f. The fusion depends on the activity of the modules. It could be either a winner takes all fusion or a weighted fusion.

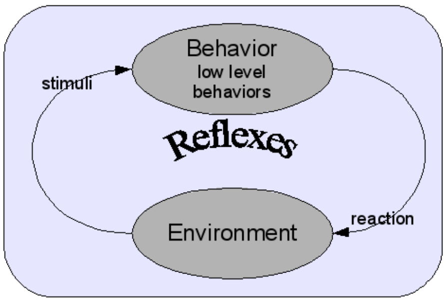

Fig. 3. The information flow of a reflex. A reflex is created just depending on sensor data.

$\vec{e}$ = input, i = inhibition and $\vec{u}$ = the output. This output is calculated by the transfer function $F(\vec{e}, \iota, i)$. A more detailed description and the basic concept of our behavior nodes are presented in [11].

Depending on these behavior-nodes all different kinds of behaviors can be realized. Low level behaviors that moves the different motors to one direction like e.g. reflexes or high level behaviors that represent complex motor skills. These behaviors are activated by different parts of the architecture. The more high level behaviors are mostly activated by the emotion and especially by the cognitive part. Whereas the low level behaviors are also activated directly by sensor input. These low level reflexes directly activated by the sensor perception build the reactive layer of our architecture. In Fig. 3 the information flow of this reactive system is displayed.

2.2 Emotion

The emotion group consists of 2 parts. The emotional state which is just for the representation of the actual internal emotional state of the robot and drives.

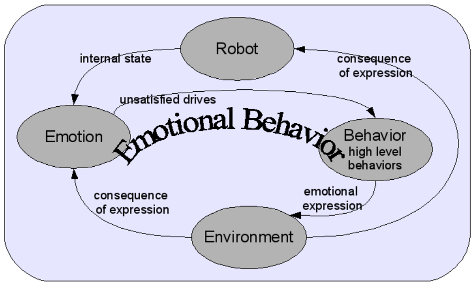

Fig. 4. The information flow for emotional behavior. An emotional behavior depends on the satisfaction of the different drives. If a drive is unsatisfied it tries to get satisfied again by changing the robots behavior.

The drives represent low level goals of the robots behavior like e.g. survival or energy consumption etc. In the following these 2 parts of the emotion group are explained in more detail.

Drives: The drives are also build out of the above mentioned behavior-nodes. A drive has two internal functions. The first function $r()$ calculates the discontent of the drive depending on sensor data and cognitive influence. The other function is the activity $a(r(), i)$ (Eq. 1), where $i \in [0, 1]$ means the inhibition input. The activity is a piecewise defined function in which the interval$[0, t_0]$ means the inactive area of the drive, $[t_0, t_1]$ means the area in which the activity is calculated based on the *sigmoid* function Eq. 2 and $[t_1, 1]$ means the satisfaction area. The codomain for the discontent function just as for the activity function is $[0, 1]$.

$$a(r(), i) = \tilde{a}(r()) \cdot (1 - i)$$

$$\tilde{a}(t(s)) = \begin{cases} 0 & \text{if } r() < t_0 \\ 1 & \text{if } r() > t_1 \\ sigmoid(t()) & \text{else} \end{cases} \tag{1}$$

$$sigmoid(x) = \frac{1}{2} + \frac{1}{2} \cdot sin\left[\pi \cdot \left(\frac{x - t_0}{t_1 - t_0} - \frac{1}{2}\right)\right]. \tag{2}$$

As described the drive gets active if the discontent value is over t_0. The drive than calculates parameters that change the emotional state and that select the behaviors of the robot. The aim of the drive is to reach a saturated state by the selection of the behaviors. If the saturation of the drive is getting higher the activity of the drive is getting lower. When after a certain time the drive is saturated, the activity will turn to 0 again. The information flow for such an emotional behavior is shown in Fig 4.

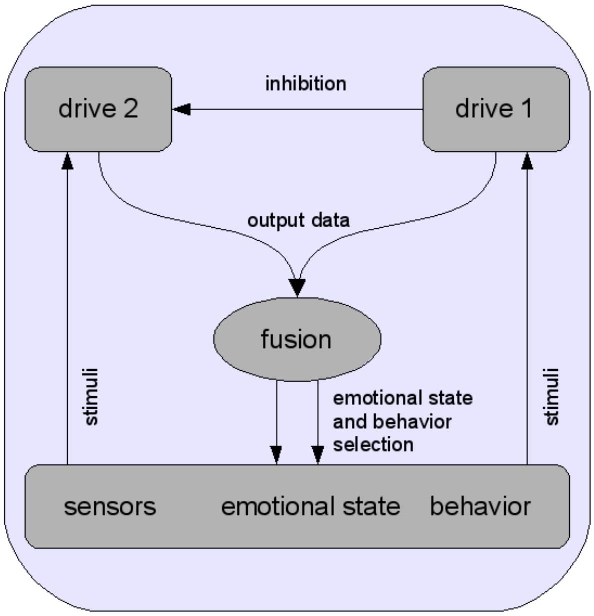

Fig. 5. The interaction of two drives, where "drive 1" has a higher priority level than "drive 2".

To expend the number of drives easily a hierarchical drive system is implemented. That means every drive has a certain priority level. The drives of a higher level inhibit the drives of a lower level. This is realized with the inhibition input of our drive nodes. Because of a fusion of the drives output only the drive with the highest activity is able to determine the actions of the robot (see Fig. 5). This means that if a new drive should be added to the architecture only the priority level has to be determined. Then the connections of the inhibition output of the drives of the next higher priority had to be connected to the inhibition input of the new drive. Its inhibition output has to be connected to all drives of the next lower priority level.

Emotional State: By creating an emotion based control architecture one of the first questions is: How to describe an emotional state for using it in a machine? Therefore so called emotion spaces are used. In these spaces an emotional state is represented by its coordinates. According to [12] and [13] the emotional space shown in Fig. 6 was developed.

The 3 axis of this emotional space are arousal (A), valence (V), and stance (S). That means every emotion is described by these 3 parameters. Arousal specifies how arousing a stimulus is to the robot. It roughly corresponds to the activity of the whole system. Valence describes how favorable or unfavorable a stimulus is to the system. High valence means the robot is very content in

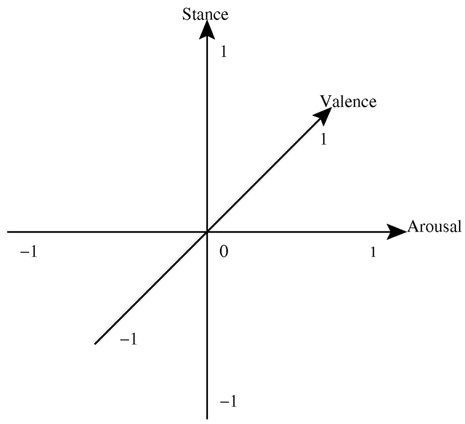

Fig. 6. The emotional space of the emotion based control architecture. This space is used to define the actual emotional state of the system. Every emotion can be described by the 3 parameters arousal, valence, and stance.

the situation and low valence means the robot is discontent. Stance specifies how approachable the robot is in a certain situation. High stance means the robot is willing to get new stimuli, low stance means the robot does not. In most emotional spaces for every emotion a certain area in the emotional space is reserved. If the actual emotional space is in this area the corresponding emotion is activated. That means every emotion that should be used has to be defined. The problem is that psychologists say that there are a lot of emotions and they do not even know all of them. But most of them agree that all emotions are build out of the 6 basic emotions: anger, disgust, fear, happiness, sadness, and surprise [14]. This is because the architecture does not work with a predefined number of emotions, but with the 3d-coordinates of an emotional state. That brings 2 advantages: First of all every emotion whether it is known or not known can be represented in the emotional space. And second this representation allows to describe a certain emotion much more in detail. Because in the common spaces 2 emotional states that are located in the same emotion area can not be differed. Where in this approach they can be differed if only a single coordinate is different. These better description possibilities allow the control architecture a more intelligent behavior and decision selection.

2.3 Cognition

The cognition should generate a plan to reach a certain goal by combining several behaviors of the system. Therefore it can use sensor information as well as emotional information and behavior information. As mentioned above, especially the emotional state is a main factor to create an intelligent decision. According to a human the cognitive part is also able to suppress the emotional state for a while or to influence deliberately the expression of the emotional state to reach

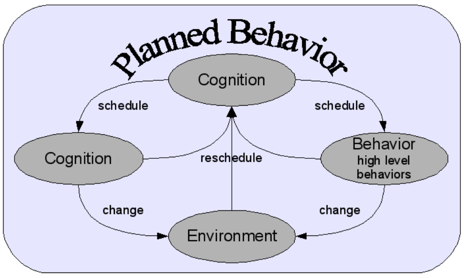

Fig. 7. The information flow for planned behavior. A planned behavior means that the robot changes behavior consciously to reached a certain goal.

a certain goal. The cognitive layer then creates a chain of behaviors. Running this chain should lead to the goal. If something unexpected happens during this run the cognitive layer has to reschedule this chain. For this reschedule decision the emotional state is of enormous importance if the system should work in a real world environment. Because you can't model the real world an intelligent decision is only possible by using an emotional state.

In Fig. 7 the information flow for planned behavior is displayed. The cognition generates a chain of behaviors that should lead to a certain goal. This behaviors change the environment. Because of some unexpected influences the environment changes and the planned behaviors will not lead to the goal. Then a new plan had to be generated. The behavior of the robot had to be changed and so on.

3 Possible Applications of the Emotional Architecture

3.1 Humanoid Robot Head ROMAN

The humanoid robot head ROMAN (see Fig. 8) is a test-platform with the research topic man-machine-interaction. The interaction between man and robot is often limited to input devices like keyboards and mice. Future applications of mobile robots will use natural interaction. Service robots for example should be able to help a human doing his housework. It is necessary to control such a robot without specific technical knowledge. Especially old people want to communicate in a natural way.

The mechanics of the humanoid head consists of a basic unit of mounting plates which is fixed to the 4 DOF neck. These plates are the mounting points for the eyes (3DOF), the servo motors for facial movements, and the cranial bone consisting of lower jaw, forehead and the back of the head. The artificial skin[1] of the robot is glued onto the cranial bone and can be moved with 8 metal plates, which are connected to 10 servos via wires. The positions of theses movable metal

[1] The silicon skin of ROMAN was produced and designed by Clostermann Design Ettlingen.

Fig. 8. The humanoid robot head "ROMAN" (ROMAN = RObot huMan interAction machiNe) of the University of Kaiserslautern.

plates are selected according to Ekman‘s action units. The plate areas as well as its fixing positions on the skin and the direction of its movement are optimized in a simulation system according to the basic emotions which should be expressed. Additionally, a single servo motor is used to raise and lower the lower jaw. Fig. 9 shows an overview of the hardware system including all necessary connections to sensors and actuators. For a more detailed description of the mechatronics system of the robot head see [15] and [16].

The emotional architecture was already used for the humanoid robot head ROMAN. Because of the actual emotional state the corresponding facial expressions are generated (see [17]). Every basic emotion (anger, fear, disgust, happiness, sadness, and surprise) is realized as a behavior and is placed in the emotional space (see Fig. 10). Depending on the actual emotional state the different emotion behaviors are activated. The output of these emotions is merged depending on their activation. That way more than just the 6 basic emotions can be expressed and weak tansitions between the different expressions are realized. This approach also regards the theory of psychologists that every emotion can be set up of the basic emotions. Because more than 60% of human communication is conducted non-verbally by using facial expressions and gestures this could be used to realize a better human-robot interaction.

The architecture was also used to realize a drive-based behavior of the robot. That means within the architecture different drives like e.g. exploration and communication are defined. These drives determine the goals of the robots behavior and the emotional state of the robot (see [18]). The drives calculate their satisfaction because of the sensor data. The most unsatisfied drive determines the behavior of the robot and tries to reach a satisfied state again. The different behaviors are performed corresponding to the actual emotional state. If the robot wants to say something and it is very nervous it will speak faster. That means the drives determine "What to do" and the emotional state determine "How to do". In our emotional architecture 7 different drives are realized.

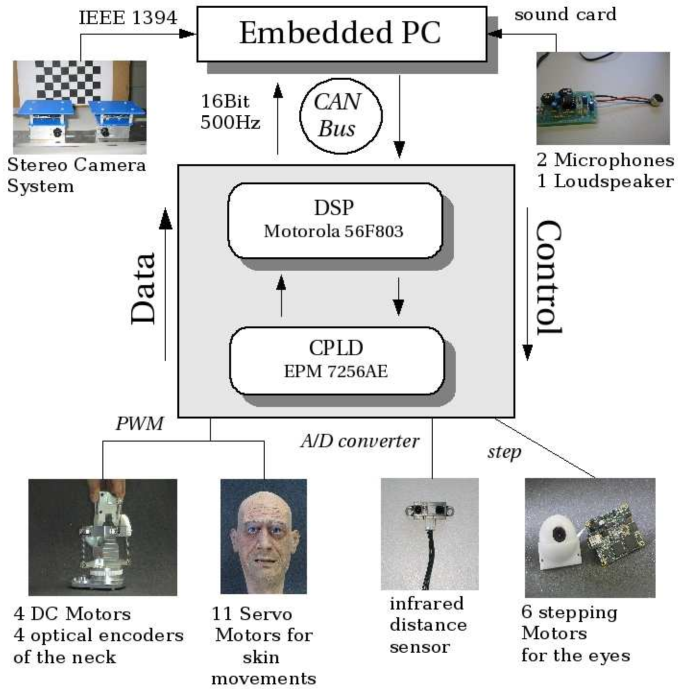

Fig. 9. Hardware architecture including sensor systems and actuators as well as all necessary connections to the embedded computer.

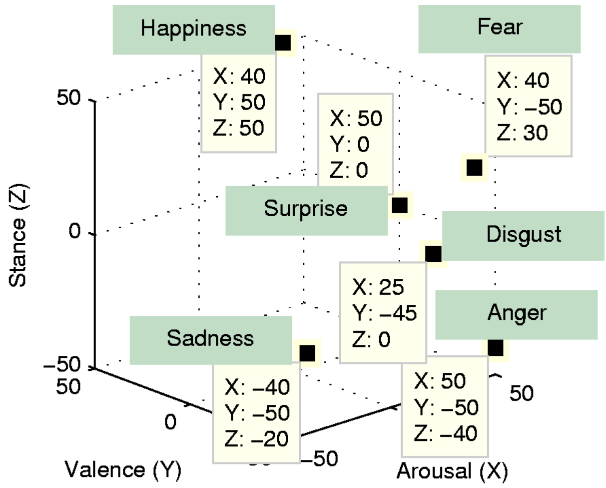

Fig. 10. The 6 basic emotions positioned in the emotional space. They are used for generating emotional expression. Because every possible emotion is build out of the 6 basic emotions every emotion can be realized.

One of the next steps in this project will be the usage of the cognitive layer of the proposed architecture. The robot should use its expressions to reach a certain goal within an interaction. That means the robot should be able to control an interaction by generation a chain of different expressions and behaviors. This is only possible if the robot is able to understand the whole situation of the interaction. That means it needs information on the interaction partner, the environment, the interaction itself, and of its own internal state. The cognitive part of the architecture than needs to generate a chain of different behaviors depending on these information.

3.2 Mobile Robot RAVON

Another application possibility for the emotional architecture described in this paper arises in the path planning component of the mobile outdoor robot RAVON (Fig. 11). Here, the introduction of an 'emotional state' into the robots' navigational layer allows the system to solve the 'action-selection' type problem of choosing a path from the set of currently possible trajectories in a psychologically plausible way. Using the emotional state as an abstracted indication of the overall robot situation (considering navigational capabilities, battery state and/or available mission time), the path planner can weight the different factors that influence the path finding decision appropriately and select a solution that is globally optimal.

In order to prepare for a more detailed discussion of the emotional model employed in RAVON and its connection to the path finding problem, we first give a very short overview of the system and the general control concept.

Fig. 11. The mobile robot "RAVON" (RAVON = Robust Autonomous Vehicle for Off-road Navigation) of the University of Kaiserslautern

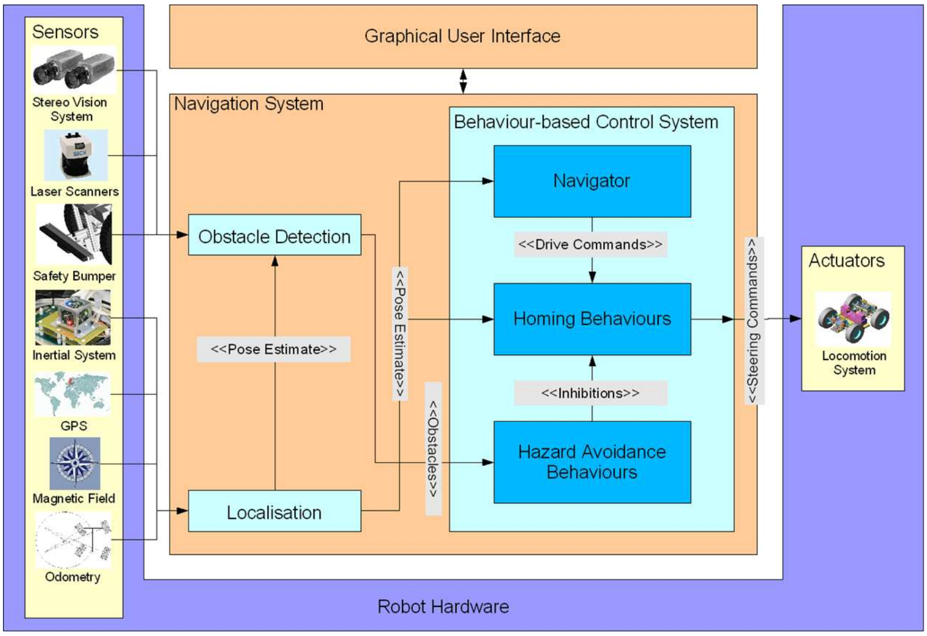

Fig. 12. Overall Architecture

The research performed on the RAVON platform focuses on the development of a robust, biologically motivated navigation system, which encompasses local tasks such as obstacle detection and avoidance as well as more global tasks like mapping, path planning and path optimization. The vehicle itself resembles a small golf car with dimensions of 2.4m x 2.4m x 1.2m and a weight of approx. 400 kg. It is powered by 4 DC motors with a power of 900W each which allows a maximum velocity of 3 m/s or a maximal slope of 45 degrees. This, combined with a ground clearance of 30 cm and separately steerable front and rear axis results in very good driving characteristics in rugged or vegetated terrain. As show in Figure 12, the complete navigation system is split into local and global scale navigational components. The local navigational layer is modeled as a behavior-based system according to the definition in [19] and contains over 30 behaviors that allow the robot to detect and avoid obstacles based on stereo camera and laser scanner data [20]. Target positions are fed to this local layer from the global layer, which is responsible for mapping and path planning.

To facilitate path planning, the robot employs a topological graph that stores navigational relevant locations as graph nodes along with drivable connections between them in the form of graph edges (Fig. 13). Each time the robot traverses the corresponding edge, these connections get annotated with measures of three different aspects estimating their suitability for inclusion into future paths. The first of these aspects is the inherent *risk* of driving from the start location to the end location, which summarizes dangerous environmental conditions like the number of obstacles or critical terrain slopes. The second aspect *effort* captures how much energy the robot must invest and is thus a different, but also important characteristic of a connection. The third and last aspect *familiarity* is not directly connected to the crossed terrain, but is rather a property of the topological graph itself. It is a measure of how often a connection has been traveled and correlates with the accuracy of the risk and effort estimates.

The emotional architecture presented in this paper comes into play whenever RAVON needs to calculate a path to a desired goal location. For this, the path planner must compute a single cost measure for each connection, based on the previously accumulated risk, effort and familiarity estimates. In order to achieve biologically plausible and intuitively adjustable navigation behavior, we derive the relative influence of the three aspects on the final cost measure on an emotional ('motivational') state of the robot. We model the current emotional state of RAVONs navigation system as a point $P = (\alpha, \beta, \gamma)$ in the emotional space spanned by the arousal, valence and stance axes depicted in Fig. 6 and restrict it to a plane by enforcing $\|P\| = 1$. We then weight the risk estimate of the edge with the arousal component α of the current emotional state, the effort with the valence component β and the edge familiarity with the robots stance value γ. This influences the final cost estimates used by the path planning algorithm in a psychologically plausible way. For instance, a fearful emotional state characterized by high arousal, low valence and medium stance represented with normalized emotional coordinates $(0.89, 0, 0.44)$ results in high costs for risky connections, while edge familiary has medium effect and the required traversal

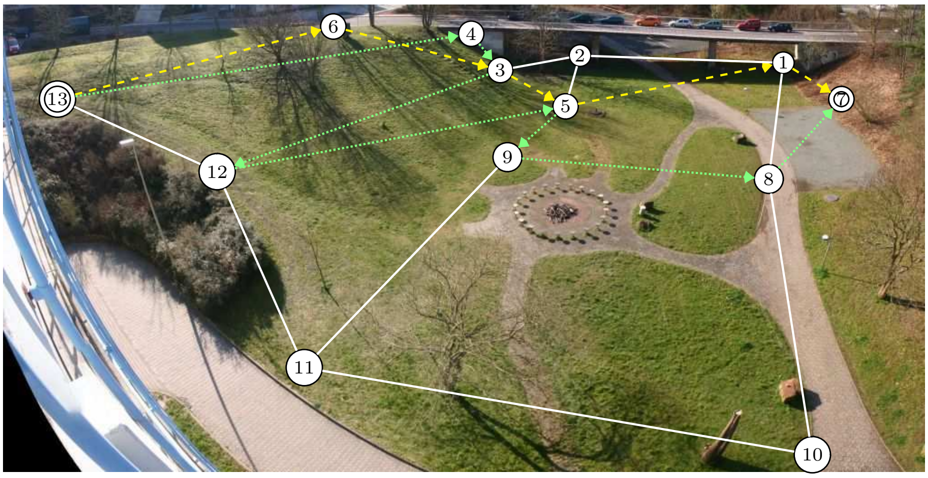

Fig. 13. Influence of the emotional state on path planning
The image shows two paths planned by the path planner of RAVON in different emotional states. Both times, the robot was instructed to travel from node 13 to node 7. The path shown with green, dotted arrows was computed based on a maximally 'fearful' state $(\alpha, \beta, \gamma) = (1, 0, 0)$, leading to a path with lengthy detours but minimal exposure to obstacles. Most significantly, the robot completely avoids the hedge on the left side of the image. The yellow striped path was computed based on a maximally 'impatient' state $(\alpha, \beta, \gamma) = (0, 1, 0)$, resulting in a path across the most extreme slopes (requiring almost no internal energy), but striking across the very narrow areas around node 1 and between 6 and 3.

effort no influence at all. This causes the path planner to choose (whenever possible) easy, fairly well known routes that can possibly include long detours to avoid problematic connections. This behavior closely matches that of a fearful human traveler. Two examples of the influence of emotions on path planning from a real-world experiment are shown in Fig. 13.

With the basic emotionally influenced cost model for path planning in place, the project currently focuses on adding the drives component described in this paper in order to adjust the motivational state of the robot according to success and failure in exploration and exploitation of the topological map. It is planned to combine drives modeling self-preservation, curiosity and fatigue for this.

4 Summary and Outlook

The concept of an emotion based control architecture for autonomous robots is presented. This architecture consists of 3 main parts: Behavior, Emotion, and Cognition. Within these parts exist 3 layers of information flow: reflexes, emotional behavior, and planned behavior. The main parts and the 3 layers of information flow are described in detail. Furthermore 2 possible applications for this architecture are presented. Within the control of these robots some parts of the proposed architecture are already implemented and tested. The great advantage of the introduced architecture, in comparrison to the ones mentioned in section 1, is that it can be used in completely different systems, as described in section 3.

In the future the proposed architecture had to be improved with the help of psychologists, sociologist, biologists. In addition the parts that had not been implemented and tested till now has to be realized on robots. And finally the whole system has to be tested on different robots.

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