Conceptual Spaces and Robotic Emotions

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1. Introduction

In recent years, there has been a growing interest in modelling emotional responses inside the perception—action loop of an autonomous robot. One of the motivations of this trend is that an emotional system could introduce complex decision making capabilities in robots in a faster and more flexible way than symbolic deliberative architectures.

However, recent proposals in literature model emotions at a very low level (Arkin et al., 2003, Murphy et al., 2002). Briefly, a robot emotional state is simply associated with suitable parameters of the reactive behaviors. Instead, emotions may have an important role at a higher, conceptual level of reasoning of the robot.

It is claimed that the emotional states of an agent may be related with its internal motivations (Balkenius, 1995). For example, an agent has a *pleasure* response when its motivations are well satisfied. More in details, a difference is usually made between *primary* and *higher-order* emotions. *Primary* emotions are related with the immediate perceptions and motivations of the agent. They can be hardwired or, if learned, they are difficultly forgotten. *Higher-order* emotions are instead related with the long—term motivations of the agent; in general they are learned during the operation tasks.

In the proposed system, both *primary* and *higher-order* robot emotions are represented in terms of a *conceptual space* (Gärdenfors, 2000). The system has been implemented in the autonomous robot operating at the Robotics Laboratory of the University of Palermo (a *RWI B21* equipped with laser and stereo head). The task of the robot is to offer guided tours in the Museum of Electrical Equipments at the Department of Electrical Engineering.

2. Conceptual Spaces

A *conceptual space* CS is a metric space whose dimensions are related with the quantities processed by the robot sensors. Dimensions do not depend on specific linguistic descriptions; examples could be color, pitch, volume, spatial co-ordinates.

A *knoxel* $\mathbf{k}$ is a point in CS and it represents the epistemologically primitive element at the considered level of analysis. In the described system, only visual features are taken into account: in the case of static scenes, a *knoxel* corresponds to a 3D geometric primitive (Chella et al., 2000). The robot itself, other robots, the surrounding obstacles, correspond to suitable sets of *knoxels* in the robot's CS. Some dimensions are related with the *knoxel*'s shape, while other dimensions are related to its displacement in space.

The prominence of the *knoxel* $\mathbf{k}$ in the current situation is modelled by means of a circle in CS centered on $\mathbf{k}$ with radius r. If $\mathbf{k}_1$ is more prominent than $\mathbf{k}_2$ in the current situation, then $r_1 >> r_2$ holds: i.e., the *prominence circle* of $\mathbf{k}_1$ is greater than the *prominence circle* of $\mathbf{k}_2$.

To account for the representation of dynamic scenes, the robot CS is generalized to represent moving and interacting entities (Chella et al., 2000). In this case, an intrinsically dynamic conceptual space DCS is adopted. Simple perceived motions are categorized in their wholeness, and not as sequences of static frames. Every *knoxel* now corresponds to a simple motion of a 3D primitive, expressed by adding suitable dimensions in CS that describe the variation in time of the *knoxel*. For example, considering the *knoxel* describing a rolling ball, the robot's DCS takes into account not only the shape and position of the ball, but also its speed and acceleration as added dimensions.

The link between the conceptual space representation of the robot and the robot behavior system is described in details in (Chella et al., 2001).

3. Robotic emotions

The role of the emotional system in the proposed architecture is to associate the perceived *knoxels* with the corresponding emotional responses. The emotional system employed in the current implementation is based on the *gated dipole* neural networks (Grossberg, 1988) that learn to associate *prototypical* emotional responses with perceptual information coming from the vision system and according to the robot internal motivations.

The output of the emotional system is the emotional response associated with a *knoxel*. This response in turns influences the *prominence circle* of the *knoxel* itself. In this way, a *knoxel* with its *prominence circle* now describes not only the shape and the motion of the corresponding object, but also the agent emotional response. The vision system of the robot thus generates the perceptive part of the *knoxel* and the robot emotional system generates the corresponding emotional response, represented in CS by means of the *prominence circle*.

The emotional response also depends on the current robot motivations: the same *knoxel*, in different situations, may not be associated with the same response. A perceived ball may generate *pleasure* when the current motivations drive the robot to search for smooth objects. In this case, the associated *prominence circle* is increased. The same perception may generate an opposite response of *frustration* when the motivations drive the robot to search for squared objects: the *prominence circle* associated to the ball is now decreased.

Emotions may be more or less related with specific objects: for example, when the robot is in the *arousal* state, its emotional system generates a response for all of the perceived objects. Instead, in the *fear* state, the emotional system generate a response only for the possibly dangerous objects (e.g., obstacles). In the former case, the emotional system affects the *prominence circles* of all of the perceived *knoxels*, while in the latter case, the emotional system only affects the *prominence circles* of the *knoxels* corresponding to obstacles.

It should be remarked that the emotional system continuously learns the associations among perceived *knoxels*, motivations and emotional responses, to better adapt the robot to the committed tasks. Emotional responses may thus change during robot operations, because of evolving adaptations.

Higher-order emotions are modelled by means of *anticipative* representations in the dynamic conceptual space. The DCS representation lets the robot to anticipate possible future interactions with the objects in the environment. The interaction between the robot and an object (e.g., a box-shaped object) is represented as a sequence of sets of *knoxels* in DCS representing the possible actions of the robot (e.g., bouncing, avoiding, stopping). This sequence of actions can be *imagined* and simulated in the robot's DCS before the interaction happens in the real world. In this case, the system associates the perceived objects with the emotional responses generated by the simulations of possible interactions. For example, when the robot perceives the big box-shaped object, it generates the anticipative representations related with the robot interactions. These representations are evaluated by the emotional system, as if they were actually perceived, in order to generate the corresponding emotional response.

4. Experimental setup

In the current experimental setup, the motivations and the emotional system are designed so that the robot performs guided tours in an Electrical Equipment Museum. In this setup, an emotional response of *pleasure* corresponds, for example, to a situation where the robot is searching for people to offer a tour and it is perceiving a person that accepts the tour. The emotional system thus generates *pleasure*; i.e, the *prominence circle* of the *knoxel* corresponding to the perceived person is increased.

An emotional response of *frustration* corresponds, for example, to a situation where the robot is searching to go near an interesting artifact but the path is blocked by other people. In this case, the robot generates anticipative representations of itself repeatedly trying to avoid the block. If the robot is not able to anticipate a sequence of actions that let itself to succeed, the emotional system generates *frustration*; i.e, the *prominence circle* of the *knoxel* corresponding to the artifact is decreased.

To conclude, subsequent developments of the system concern the recognition of emotions from human actors also using audio and other sensor modalities. For example, during the tour, the robot may understand that the persons following the tour are bored and consequently it may change its tour to better respond to the persons interests.

References

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