Affective Cognitive Modeling for Autonomous Agents Based on Scherer's Emotion Theory

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Abstract. In this article, we propose the design of sensory motor level as part of a three-layered agent architecture inspired from the Multilevel Process Theory of Emotion (Leventhal 1979, 1980; Leventhal and Scherer, 1987). Our project aims at modeling emotions on an autonomous embodied agent, a more robust robot than our previous prototype. Our robot has been equipped with sonar and vision for obstacle avoidance as well as vision for face recognition, which are used when she roams around the hallway to engage in social interactions with humans. The sensory motor level receives and processes inputs and produces emotion-like states without any further willful planning or learning. We describe: (1) the psychological theory of emotion which inspired our design, (2) our proposed agent architecture, (3) the needed hardware additions that we implemented on the commercialized ActivMedia's robot, (4) the robot's multimodal interface designed especially to engage humans in natural (and hopefully pleasant) social interaction, and finally (5) our future research efforts.

1 Introduction

Robotic agents have been of great interest for many Artificial Intelligence researchers for several decades. This field has produced many applications in many different fields, i.e., entertainment (Sony Aibo) and Urban Search and Rescue (USAR) (Casper, 2002; Casper and Murphy, 2002) with many different techniques – behavior-based (Brooks, 1989; Arkin, 1998), sensor fusion (Murphy, 1996a, 1996b, 1998, 2000), and vision (Horswill, 1993). As robots begin to enter our everyday life, an important human-robot interaction issue becomes that of social interactions. Because emotions have a crucial evolutionary functional aspect in social intelligence, without which complex intelligent systems with limited resources cannot function efficiently or maintain a satisfactory relationship with their environment, we focus our current contribution to the study of emotional social intelligence for robots. Indeed, the

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recent emergence of affective computing combined with artificial intelligence has made it possible to design computer systems that have "social expertise" in order to be more autonomous and to naturally bring the human – a principally social animal – into the loop of human-computer interaction.

In this article, *social expertise* is considered in terms of (1) internal motivational goal-based abilities and (2) external communicative behavior. Because of the important functional role that emotions play in human decision-making and in human-human communication, we propose a paradigm for modeling some of the functions of emotions in intelligent autonomous artificial agents to enhance both (a) robot autonomy and (b) human-robot interaction. To this end, we developed an autonomous service robot whose functionality has been designed so that it could socially interact with humans on a daily basis in the context of an office suite environment and studied and evaluated the design *in vivo*. The social robot has been furthermore evaluated from a social informatics approach, using workplace ethnography to guide its design *while* it is being developed (Lisetti et al., 2004)

2 Related Research

There have been several attempts to model emotions in software agents and robots and to use these models to enhance functionality. El-Nasr, (2002) uses a fuzzy logic model for simulating emotional behaviors in an animated environment. Contrary to our approach directed toward robots, her research is directed toward HCI and computer simulation.

Breazeal's work (2000, 2003) also involves robot architectures with a motivational system that associates motivations with both drives and emotions. Emotions are implemented in a framework very similar to that of Velasquez's work but Breazeal's emphasis is on the function of emotions in social exchanges and learning with a human caretaker. Our approach is different from Breazeal's in that it is currently focused on both social exchanges and the use of emotions to control a single agent.

Murphy and Lisetti's approach (2002) uses the multilevel hierarchy of emotions where emotions both modify active behaviors at the sensory-motor level and change the set of active behaviors at the schematic level for a pair of cooperating heterogeneous robots with interdependent tasks.

Our current approach builds on that work, setting the framework for more elaborate emotion representations while starting to implement simple ones and associating these with expressions (facial and spoken) in order to simultaneously evaluate human perceptions of such social robots so as to guide further design decisions.

3 Developing Socially Intelligent Agents

We focus on the study of *social expertise* for artificial agents in terms of:

1. internal motivational goal-based activities, and
2. external communicative behavior

As shown in Figure 1, we are focusing on the Socially Intelligent Agent architecture (within the red circle) of the **Multimodal Affective User Interface (MAUI)** paradigm proposed and developed earlier (Lisetti, 2002; Lisetti and Nasoz, 2004) for the design of affective socially intelligent agents. Our current work within the MAUI framework continues to focus on building user-specific emotional models of the user based on bi-modal bio-sensing of physiological signals associated with emotions – namely heart rate and galvanic skin response (Villon and Lisetti, 2006).

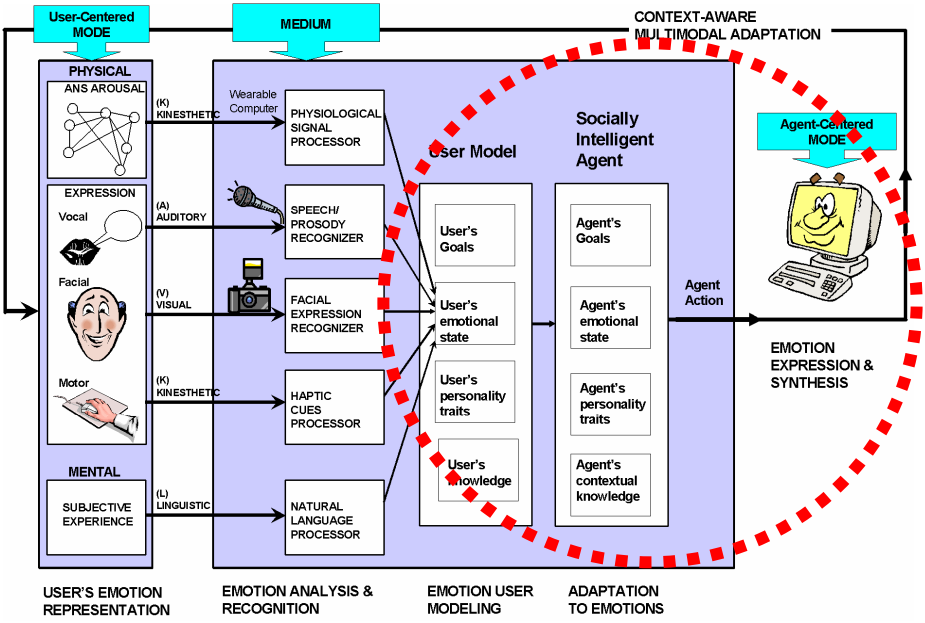


Fig. 1. Overall MAUI Paradigm for Multimodal Affective User Interfaces from (Lisetti and Nasoz, 2004)

We currently propose a psychologically-grounded framework for socially intelligent agents (corresponding to the modules of in the doted circle) based on Scherer's affective-cognitive theory of emotions. This architecture to be used for the development of artificial agents with diverse forms of embodiment such as vocal robots, graphical animated avatars, avatar-based interface on mobile robotic platform, anthropomorphic robotic platforms as shown later.

4 A Three-Layered Emotional State Generator

With recent advances in Psychology, many researchers have proposed theories on the mechanisms of producing emotions in humans. One of the theories of particular interest to us is the *Multilevel Process Theory of Emotion* (Leventhal 1979, 1980, Leventhal and Scherer, 1987), which we chose to inspire the design and the implementation of the Emotion State Generator (ESG) on our commercially available autonomous robot

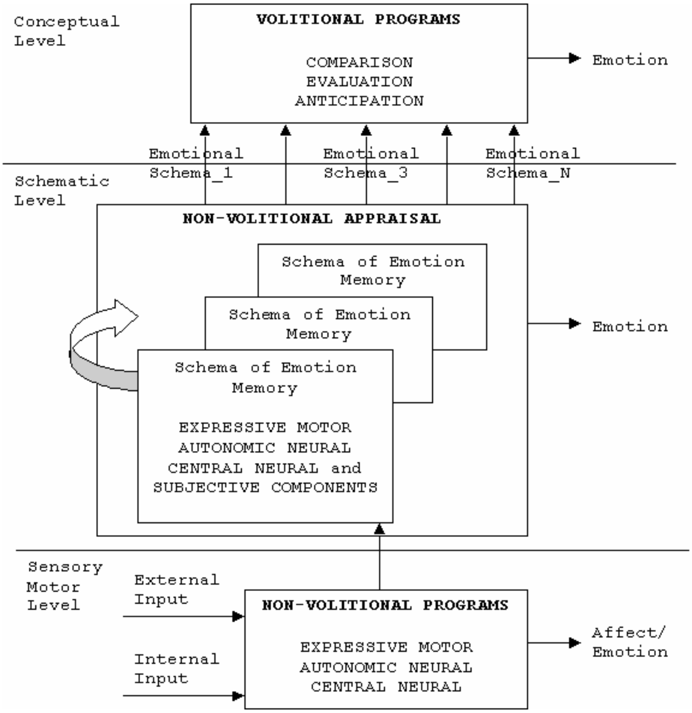


Fig. 2. Emotion State Generator (ESG) based on the Multilevel Process Theory of Emotion (Scherer, 1986)

PeopleBot (ActivMedia, 2002). Figure 1 shows the ESG three-layered architecture we use for generating emotion-like states for our autonomous agents.

Indeed, the Multilevel Process Theory of Emotion postulates that the experience of emotion is a product of an underlying constructive process that is also responsible for overt emotional behavior. It also describes that emotions are constructed from a hierarchical multi-component processing system. In short (Leventhal, 1980):

a. *Sensory motor level* – generates the primary emotion in response to the basic stimulus features in a non-deliberative manner;
b. *Schematic level* – integrates specific situational perceptions with autonomic, subjective, expressive and instrumental responses in a concrete and patterned image-like memory system;
c. *Conceptual level* – corresponds more closely to social labeling processes.

4.1 Sensory Motor Level

The *sensory motor or expressive motor level* is the basic processor of emotional behavior and experience that provides the earliest emotional meaning for certain situations. This level consists of multiple components: (a) a set of innate expressive-motor systems and (b) cerebral activating systems. These components are stimulated automatically by a variety of external stimuli and by internal changes of state that do not require deliberate planning.

Because there is no involvement of the willful planning and learning processes, the lifetime of the emotional reactions caused at this level may be short and will quickly become the focus for the next level, schematic processing. Action in the facial motor mechanism, as part of the expressive motor system, is the source of the basic or primary emotions of happiness, surprise, fear, sadness, anger, disgust, contempt, and interest (Leventhal, 1979). In this project, we are only modeling: happy, surprise, fear, sad and angry.

We briefly describe the schematic and conceptual levels for completeness sake, but we are currently focusing our design on the sensory motor level.

4.2 Schematic Level

The *schematic level* integrates sensory-motor processes with prototypes or schemata of emotional situations in order to create or to structure emotional experiences. But before entering this level, the input needs to be integrated with separate perceptual codes of the visual, auditory, somesthetic (related to the perception of sensory stimuli from the skin), expressive, and autonomic reactions that are reliably associated with emotional experiences.

Schemata - organized representations of other more elementary codes - are built during emotional encounter with the environment and will be conceptualized as memories of emotional-experiences. As shown in Figure 2, humans can activate these schemata by activating any one of its component attributes that is caused by the perception of a stimulus event**,** by the arousal of expressive behaviors or autonomic nervous system activity, or by the activation of central neural mechanisms that generate subjective feelings. The structure of the schematic memories can be thought of as codes, complex categorical units, a network of memory nodes, or perhaps as memory columns that are conceptualized.

The schematic processing is also automatic and does not require the participation of more abstract processes found at the conceptual level. This schematic level is more complex than the sensory motor level in that it integrates learning processes while building the complexities of schemata. At this level, emotion behavior also has a longer lifetime.

4.3 Conceptual Level

The *conceptual level* can be thought of as the system that can make conscious decisions or choices to some external inputs as well as to internal stimuli (such as stored memories of emotional schemata generated at the schematic level). It is the comparison and abstraction of two or more concrete schemata of emotional memories with certain concepts that will enable the humans to draw conclusions about their feelings to certain events. By comparing and abstracting information from these schemata with conceptual components – verbal and performance component - humans can reason, regulate ongoing sequences of behavior, direct attention and generate specific responses to certain events.

The *verbal components* are not only representing the feelings themselves but they are also communicating the emotional experiences to the subject (who can also choose to talk about his/her subjective experience). On the other hand, the *performance components* are non-verbal codes that represent sequential perceptual and motor responses. The information contained at this level is more abstract than the schematic memories and therefore the representations can be protected from excessive changes when they are exposed to a new experience and can be led to more stable states. Because this level is volitional, components can be more sophisticated through active participation of the agent. When performance codes are present, for example, the volitional system can swiftly generate a sequence of voluntary responses to match spontaneous expressive outputs from the schematic system. This volitional system can anticipate emotional behaviors through self-instruction.

4.4 Stimulus Evaluation Checks (SECs)

In order to produce emotion for each level, many researchers have hypothesized that specific emotions are triggered through a series of stimulus evaluation checks (SECs) (Scherer, 1984; Scherer, 1986; Weiner, Russell, and Lerman, 1979; Smith and Ellsworth, 1985). Inspired by (Lisetti and Nasoz, 2002), we link the SECs system that performs the emotion components' check in the Affective Knowledge of Representation (AKR) that produces a schema of emotion. This schema can be associated with a certain event and emotion and be part of the schema memory for further use. In AKR, each emotion has many components, e.g., valence, intensity, focality, agency, modifiability, action tendency, and causal chains.

Valence: *positive/ negative:* is used to describe the pleasant or unpleasant dimension of an affective state.

Intensity: *very high/ high/ medium/ low/ very low:* varies in terms of degree. The intensity of an affective state is relevant to the importance, relevance and urgency of the message that the state carries.

Focality: *event/ object:* is used to indicate whether the emotions are about something: an event (the trigger to surprise) or an object (the object of jealousy).

Agency: *self/ other:* is used to indicate who was responsible for the emotion, the agent itself *self*, or someone else *other*.

Modifiability: *high/ medium/ low/ none:* is used to refer to duration and time perspective, or to the judgment that a course of events is capable of changing.

Action tendency: identifies the most appropriate (suite of) actions to be taken from that emotional state. For example, happy is associated with generalized readiness, frustration with change current strategy, and discouraged with give up or release expectations.

Causal chain: identifies the causation of a stimulus event associated with the emotion. For example, happy has these causal chains: (1) Something good happened to me, (2) I wanted this, (3) I do not want other things, and (4) because of this, I feel good.

5 Affective-Cognitive Architecture and Embodiment Forms

5.1 Functionalities of Our Robot

Our robot, Petra, has the same tasks as Cherry (Lisetti, et al. 2004) and is designed so that she can socially interact with humans on a daily basis in the office suite environment especially on the second floor of the computer science building at the University of Central Florida. She has a given set of office-tasks to accomplish, from giving tours of our computer science faculty and staff suites to visitors and to engaging them in social interactions. With the sensors that she has (explained below), she is able to roam around the building using her navigational system, recognize someone through her face recognition algorithm, and greet them differently according to their social status (professor, students, staff).

In terms of architectures for autonomous agents and robots, the multi-level theory of emotions currently gets translated into the figure 3 below, of which we have implemented various levels and different types of embodiement forms, as shown in Figures 4 (b-c). We are currently in the process of building a platform independent architecture and an expression control mechanism to adapt to a multitude of robotic and graphical artificial agents such as for example the non-mobile Phillips iCat interactive toy-looking which we are currently working on shown in Figure 4a (Grizard and Lisetti, 2006; Paleari and Lisetti, 2006).

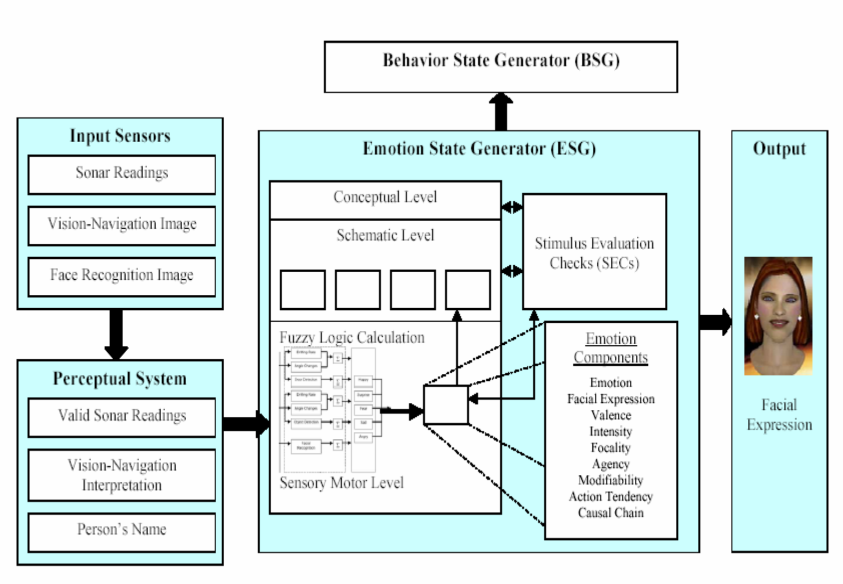
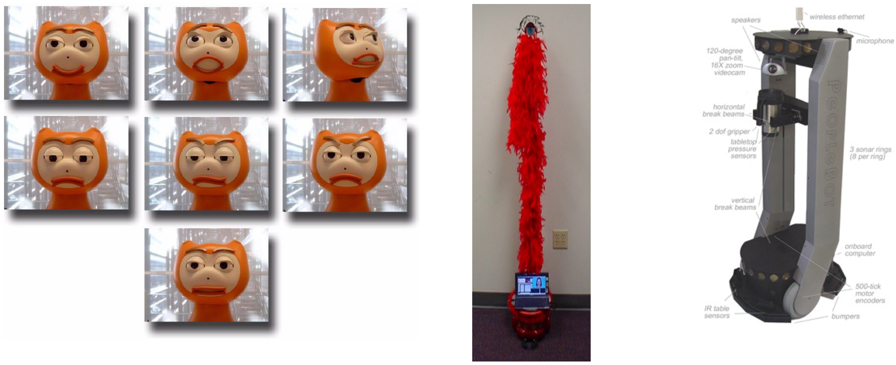


Fig. 3. Affective-Cognitive Three-Layered Architecture

We next describe how our ESG discussed in Section 2 is integrated in the overall affective-cognitive architecture shown in Figure 3 and implemented a mobile ActivMedia PeopleBot (ActivMedia, 2002). We called this robot or project Petra. Currently, Petra has three different sensors - twenty-four sonar, a camera for navigation, and a camera for face recognition to be used during navigation and social interaction. After sensing various stimuli from the real world (e.g., walls, floors, doors, faces), these are sent to the perceptual system. We designed the perceptual system as an inexpensive and simple system so that the information abstracted from the outside world has some interpreted meaning for the robot. For every cycle (in our case, it is 1000 mm travel distance), the sensors send the inputs read to the perceptual



(a) (b) (c)

Fig. 4. (a) iCat Platform; (b) Amigobot mobile Platform; (c) Peoplebot mobile Platform

system and these are then processed by the perceptual system as described below. Afterward, the perceptual system sends its outputs (valid sonar readings, vision-navigation interpretation, and person's name) to the sensory motor level, which triggers certain emotion-like states.

5.2 Navigation with Sonar and Vision

Sonar: In our design, the robot performs sonar readings every 200 mm, so for 1000 mm, we get five different readings. Out of these five readings, the system extracts the invalid information out and stores only the good ones for further use in the ESG model. The reading is invalid if the sum of the left-most and the right-most sonar readings are extremely more or extremely less than the distance between the aisle (1,500 mm for our case). And vice versa, the reading is valid if the sum of both readings is around 1,500 mm.

Camera: For every cycle, the camera captures an image and sends it to the vision algorithm. In this algorithm, the image is smoothened and edged by canny edge detector before calculating the vanishing point. In order to calculate the point, in addition to the canny method, we also eliminate the vertical edges and leave the image with the non-vertical ones (edges with some degrees of diagonality). With the edges left, the system can detect the vanishing point by picking up the farthest point in the hall. With this point, represented by the x- and y- coordinate, the system asks the robot to perform course correction, if needed, and uses it as an input for the ESG model. Besides having the capability to center between the aisles of the hallway, the robot is also able to detect some obstacles, i.e, garbage can, boxes, people, etc. When the robot finds the object(s), this detection information is also sent to the ESG model.

5.3 Integration of Face Recognition with Social Status Knowledge

The perceptual system receives input from the eye-level camera only when the robot performs the face recognition algorithm. In our current implementation, this algorithm starts when the robot asks someone to stand next to her and captures an image. Along with the FaceIt technology by Identix (Identix, 2002), our algorithm compares the input with the collection of images in her database of 25 images and when any matching is found, she greets that person. The result, recognized or unrecognized along with the person's name (to be used to greet him/her), is also sent as an input to the ESG model. At this level, the other information of the person whose image was captured and recognized (gender, social status, and social interaction value – the degree of her like/dislike toward that person) is not sent to the sensory motor level, but in the future, this information may be needed for the implementation of the schematic and/or the conceptual level where further learning and information processing will be performed.

6 Sensory Motor Level Design and Implementation

Since the information abstracted from the perceptual system does not go through willful thinking and learning at this level, it may contain some fuzziness to certain degree. Inspired by FLAME (El Nasr, 2002), this level is implemented with the Takagi, Sugeno, and Kang (TSK) fuzzy logic model (Takagi & Sugeno, 1985). Because of its simplicity, it can reduce the number of rules required for this level. Our proposed sensory motor level architecture is shown in Figure 5.

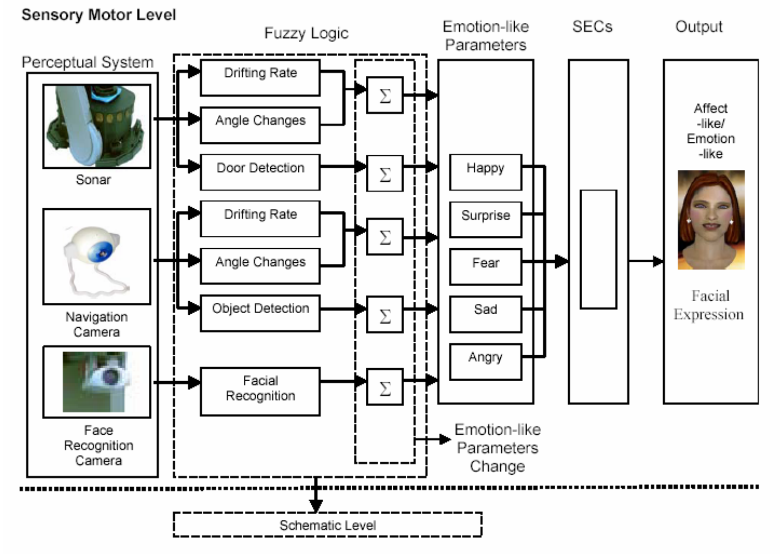


Fig. 5. Sensory Motor Level's sub-Architecture

The information received from the perceptual system is then processed further to determine the drifting rates and angle changes which are represented by five fuzzy values (small, medium-small, medium, medium-large, and large) and the door detection, the object detection, and the face recognition which are represented by boolean values (found and not-found or recognized and not-recognized). Below are the examples of fuzzy representations of the angle changes calculated from the sonar's valid readings (F_{angle_sonar}). Δ is determined by subtracting the current reading from the previous one.

The information (drifting rate, angle changes, door detection, object detection, and face recognition) is then further processed with the TSK model which gives the emotion-like-parameters-change represented by a numerical value which will add/subtract the numerical values of the emotion-like-parameters (happy, surprise, fear, sad and angry) based on the OR-mapping shown on Table 1.

Table 1. Mapping of the emotions' parameter changes

Parameter	Increased if	Decreased if
Happy	- Small to Medium-small value of the processed information from sonar or vision - Open door - Recognize someone	- Medium to Large value of the processed information from sonar or vision - Closed door - Not recognize someone
Surprise[1]	- Large value of the processed information from sonar or vision (on the first detection only)	- The robot is in the happy state
Fear	- Large value of the processed information from sonar or vision (medium repetition)	- The robot is in the happy state
Sad	- Medium to Medium-large value of the processed information from sonar or vision - Closed door - Not recognize someone	- Small to Medium-small value of the processed information from sonar or vision - Open door - Recognize someone
Angry	- Large value of the processed information from sonar or vision (high repetition) - Closed door (repetitively) - Not recognize someone (repetitively)	- Small to Medium-small value of the processed information from sonar or vision - Open door - Recognize someone

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[1] To show surprise, when the processed information from sonar or vision is large on the first detection, the weight of this emotion is highest among all.

After calculating the emotion-like state, the sensory-motor level performs the Stimulus Evaluation Check (SEC) process to check the emotion appropriate components and create a schema of emotion to be stored in the memory. The checkings are performed by assigning appropriate values to the emotion components (as described in the SEC section above), based on the checks (e.g. *pleasantness*, *importance*, *relevance*, *urgency).* Table 2 shows a schema when an unexpected moving object suddenly appears in the captured navigation-image, i.e, walking students. In this case, surprise will be activated as the final emotion, only for the current cycle.

A sudden appearance of a person in the navigation image is detected as an obstacle that can slow down the navigation process due to the course correction that needs to be performed should the person remain in the navigation image on the next cycle. Thus *intensity* is very high and the *action tendency* is to avoid potential obstacles. Since the face cannot be detected at farther distance, the *valence* is negative. And at current cycle, the *modifiability* is set to its default–medium because the robot has not performed the obstacle avoidance to change the course event.

Table 2. Schematic Representation for Surprise

Components	**Values**
Emotion	Surprise
Valence	Negative
Intensity	Very High
Focality	Object – walking student
Agency	Other
Modifiability	Medium
Action Tendency	Avoid
Causal Chain	- Something happened now - I did not think before now that this will happen - If I thought about it, I would have said that this will not happen - Because of this, I feel something bad


(a) (b) (c)

Fig. 6. Facial expressions for some of the modeled emotions a: Happy; b: Angry, c: Sad

After performing the SECs, the robot's facial expression is also adjusted to display her current internal emotion-like state. For every emotion-like that we are modeling, e.g., happy, surprise, fear, sad, and angry, we have designed their facial expressions based on the Facial Action Coding System (FACS) (Ekman and Friesen, 1978) as shown in Figure 6 (a-e).

6.1 Behavior State Generator (BSG)

A behavior is "a mapping of sensory inputs to a pattern of motor actions, which then are used to achieve a task" (Murphy, 2000). After determining the facial expressions, the processed information is sent to BSG. Through these, she can execute different behaviors depending on the input sources (sonar, camera for navigation, and camera for face recognition). Each behavior state is described below:

1. *INIT*: reset the emotion-like, the progress bars, and the starting position.
2. *STAY_CENTER*: center herself between the aisles to avoid the walls.
3. *AVOID_LEFT_WALL*: move right to avoid the left wall. This behavior is triggered when a course correction, calculated by sonar or vision, is needed.
4. *AVOID_RIGHT_WALL*: move left to avoid the right wall. This behavior is also triggered when course correction is needed.
5. *WAIT*: wait for a period of time when the face recognition algorithm cannot recognize anyone or the door is closed (in order to try again to avoid any false positive).

7 Integration on a Robotic Platform with Anthropomorphic Interface

The interface shown in Figure 7 is displayed through the touch screen wirelessly is a modified version of Cherry's (Lisetti et al., 2004). It integrates several components such as the avatar, a point-and-click map, the emotion changing progress bars, several algorithms (navigation system, vision and obstacle avoidance system, and face recognition system), several help menus, i.e., speech text box, search properties, and start-at-room option, and two live-capture frames.

The main improvements on Petra's interface from Cherry's are the progress bars, the two video frames, and navigational and vision algorithms. Through these bars, we

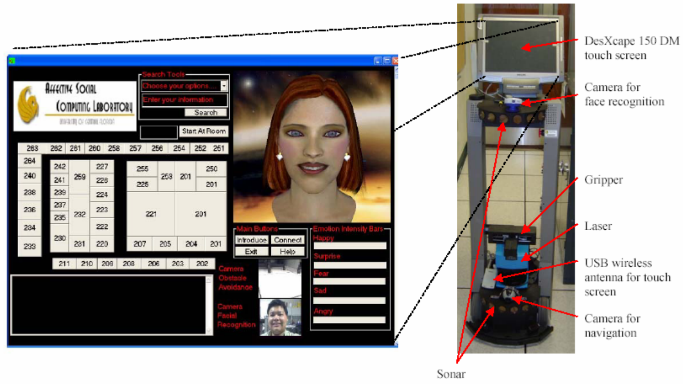

Fig. 7. Petra's Complete Interface and Hardware

are able to show the real-time changes of emotion-like state and which emotion-like state(s) is/ are affected by the stimuli accepted. One of the video streams has the same purpose as Cherry's vision for face recognition, and the other one is used for the vision for navigation system. The other two algorithms (navigation and vision) are designed to have a better and smoother navigational system.

8 Conclusion

The work presented represented a very small milestone toward achieving cognitive-affective architectures for socially intelligent agents. Our intention is to continue to base our work on psychological theories, in particular that of Scherer's because it psychologically links emotion recognition, with emotion generation at the affective-cognitive level and with emotion expression which allows to develop a completely psychologically grounded system for Human-Robot Interaction as depicted in the MAUI (Multimodal Affective User Interface) framework we presented as the basis for our work. Much more remains to be accomplished.

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