Proceedings AAAI FSS'04, Fall Symposium on The Intersection of Cognitive Science and Robotics: From Interfaces to Intelligence, October 22-24, 2004, Washington, USA

Multilevel Emotion Modeling for Autonomous Agents

Andreas H. Marpaung
Department of Electrical Engineering and Computer Science
University of Central Florida
Orlando, Florida 32816
marpaung@cs.ucf.edu

Christine L. Lisetti♀
Department of Multimedia Communications
Institut Eurecom
Sophia Antipolis, France
lisetti@eurecom.fr

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 and Scherer, 1987). Our project aims at modeling emotions on an autonomous embodied agent, Petra, a more robust robot than our previous prototype - Cherry. Petra has the same tasks as Cherry. Petra 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. 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, (3) Petra's multi-modal interface designed especially to engage humans in natural (and hopefully pleasant) social interaction, and finally (4) our future research efforts.

Introduction

Robotic agents have been of great intense interests 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). Furthermore, when a relatively new field arose, Affective Computing, new interests of modeling emotion have emerged with the field of Artificial Intelligence and Robotic agents. Picard (1997) defines this new field as computing that "relates to, arises from, or deliberately influences emotions".

Along with the growth of the Affective Computing, researchers have been trying to model emotion in intelligent agents for various applications. Fuzzy Logic Adaptive Model of Emotions (FLAME) is an example of emotion modeling in a non-robot domain (El-Nasr, 2000). The model was implemented using fuzzy logic that combines the affected goals, degree of impact, desirability level, and the goals importance with inductive learning algorithm in an animal simulation – PETEEI (A Pet with Evolving Emotional Intelligence). Implementations on robots have also been explored. Kismet (Breazeal and Scassellati, 2000; Breazeal, 2003), Graduate Student Attending Conference (GRACE) (Simmons et al, 2003), Cathexis at Virtual Yuppy (Velasquez, 1996, 1998), Leguin and Butler (Murphy et al, 2002) are several robotic agents that include emotion in their designs. Kismet, which was built by the perception, motivation, attention, behavior, and motor systems, interacts with its caretakers by perceiving a variety of inputs from its visual and auditory channels and gives feedback to them through its gaze direction, facial expression, body posture, and vocal babbles (Breazeal & Scassellati, 2000). GRACE, an autonomous agent's entry at the 2002 AAAI Robot Challenge, has an expressive face on the screen and sensors that include a microphone, touch sensors, infrared sensors, sonar sensors, a scanning laser range finder, a stereo camera head on a pan-tilt unit, and a single color camera with pan-tilt zoom capability. With these sensors, GRACE succeeded in completing her tasks to move from its starting point to the registration counter and then, to the conference hall and give the speech about itself with few human's involvements.

We, in particular, are extending the architecture model proposed by Murphy et al. (2002) for their two waitering robots Leguin and Butler, an entry at the 2000 AAAI Mobile Robot Competition's *Hors D'Oeuvres, Anyone?* event which has won the *Nils Nilsson Award*. Part of the design was an Emotion State Generator (ESG), which is expanded in our model to process the inputs in more detail that will include willful planning and learning.

♀Part of this work was accomplished while the author was at the University of Central Florida.

Multilevel Process Theory of Emotion

With recent advances in Psychology, many researchers have proposed the mechanism of producing emotions in humans. One of the theories of particular interest to us is the *Multilevel Process Theory of Emotion* (Leventhal and Scherer, 1987), which we chose to inspire the design and implementation of the Emotion State Generator (ESG) which we build to enhance our commercially available autonomous robot PeopleBot (ActivMedia, 2002). Figure 1 shows the ESG three-layered architecture we use for generating emotion-like states for our autonomous agents.

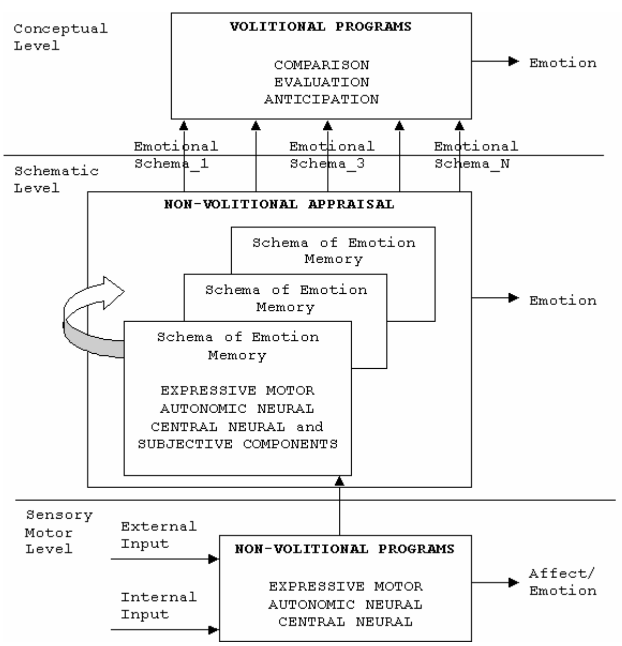


Figure 1 Multilevel Theory of Emotion/
Emotion State Generator (ESG)

Indeed, the multi-level process theory of emotion (Leventhal and Scherer, 1987) 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.

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 a 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.

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. 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 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.

Conceptual Level

The *conceptual level* can be thought 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 agent to draw conclusions about its feelings to certain events. By comparing and abstracting information from these schemata with conceptual components – verbal and performance component - the agent 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 they also 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.

Our Agent Three-Layered Architecture

Our ESG is being developed in our robot - Petra, an ActivMedia PeopleBot (ActivMedia, 2002) following the overall architecture shown in figure 2, which uses the ESG architecture shown in figure 1 and discussed in the second section. Currently, Petra has three different sensors – twenty-four sonar, camera for vision, and 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 a simple system so that the robot can recognize the information abstracted from the outside world has some interpreted meaning. For every cycle (in our case, it is 1000 mm travel distance), the sensors send the inputs read to the perceptual system and these are then processed by the perceptual system as described below. Afterward, the perceptual system sends its output to the sensory motor level, which triggers certain emotion-like states and to the Behavior State Generator (BSG) in order to execute appropriate behavior.

Sonars

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 extremely exceeds 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 vision

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, shown by the x- and y- coordinate, the system can ask the robot to perform course correction, if needed, and can use 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.

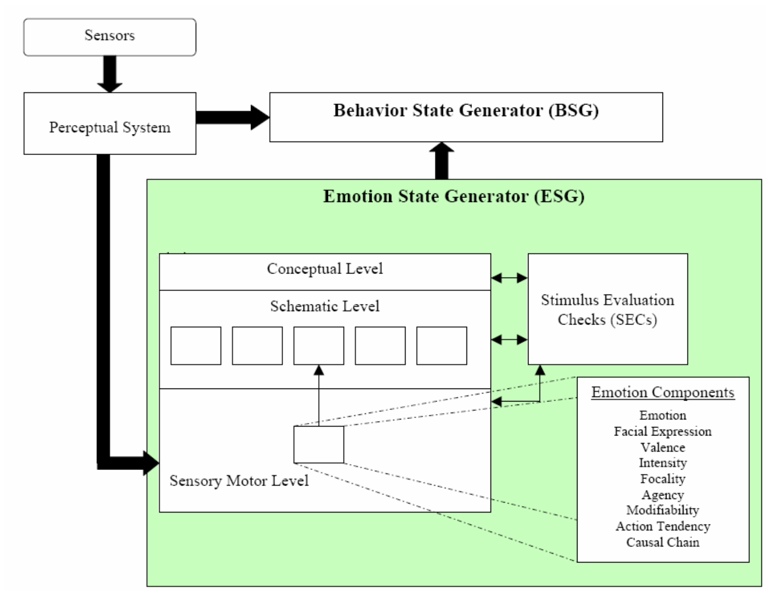


Figure 2 Petra's Detailed Three-Layered Architecture

Camera for face recognition

The perceptual system receives an input from this camera only when the robot performs the face recognition algorithm. At our current implementation, this algorithm starts when the robot asks someone to stand next to her and capture an image as an input to it. Along with the

FaceIt technology by Identix, our algorithm compares the input with her collection of images in her library and when any matching found, the robot will greet that person. The
result, recognize or unrecognizable, is also sent as an input to the ESG model. At this level, the information of person whose image was captured 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 done.

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). Along with that, inspired by (Lisetti and Bianchi, 2002), we link the SECs system that performs the emotion components' check that produces a schema of emotion. This schema can be associated with certain event and emotion and be part of the schema memory for further use. Lisetti and Bianchi proposed the Affective Knowledge of Representation (AKR) where each emotion has many components, e.g., valence, intensity, focality, agency, modifiability, action tendency, causal chains.

Valence: *positive/ negative* is the product of innate feature detectors to describe the pleasant or unpleasant dimension for the affective phenomena.

Intensity/Urgency: *very high/ high/ medium/ low/ very low* is the degree of the affective phenomena that measures the importance, relevance and urgency in order to meet basic needs or goals.

Focality: *event/ object* is the indication whether the affective phenomena is caused by an event or an object.

Agency: *self/ other* is the thing/person that was responsible to the creation of certain emotion in order to deal with an event to maximize the interactions.

Modifiability: *high/ medium/ low/ none* is the ability to judge whether a current course can be changed in the next period of time.

Action tendency: identifies the most suitable actions or behaviors to take for current emotional state that has been (evolutionarily) selected as appropriate. For example, happy is associated with generalized readiness, frustration with change current strategy, and discouraged with give up or release expectations.

Causal chain: describes the subjective cognitive experience components that are associated with the emotion. For example, surprise has these causal chains: (1) Something happened now, (2) I did not think before now that this will happen, (3) If I thought about it, I would have said that this will not happen, and (4) Because of this, I feel something. On the other hand, 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.

Sensory Motor Level Design

Since the information abstracted from the perceptual system does not go through willful thinking and learning at this level, thus they 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's architecture is shown in figure 3.

The information received from the perceptual system are then processed further to determine the drifting rates and angle changes which are represented by five fuzzy

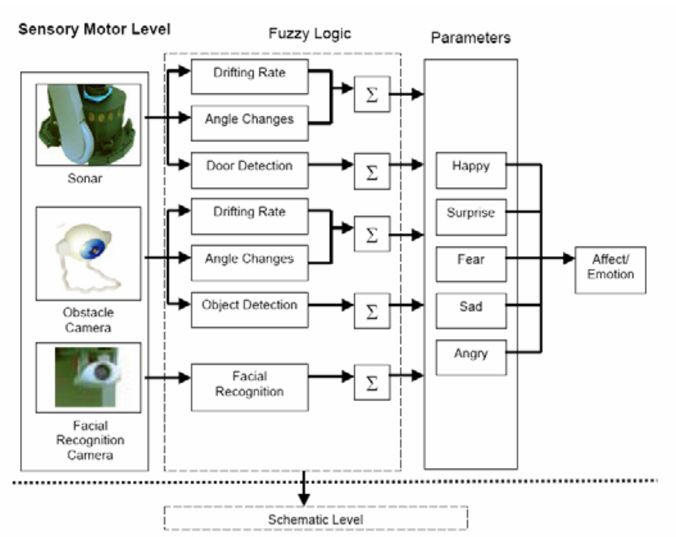


Figure 3 Sensory Motor Level's Architecture

values (small, medium-small, medium, medium-large, and large) and door and object detections and face recognition which are represented by boolean values (found and not-found or recognize and not-recognize). Below is an example of fuzzy representations of the angle change (along with their negative values) calculated from the sonar's information (F_{angle_sonar}).

Small_Angle - Δ angle is between 0^O and 18^O
Medium-small_Angle - Δ angle is between 18^O and 36^O
Medium_Angle - Δ angle is between 36^O and 54^O
Medium-large_Angle - Δ angle is between 54^O and 72^O
Large_Angle - Δ angle is between 72^O and 90^O

Afterward, they are calculated with TSK model that will give the emotion-parameter-change, which will change the quantity of emotion parameters (happy, surprise, fear, sad and angry) based on the OR-mapping shown on table 1.

$$\sum_{i=0}^{n} \text{Fuzzy\_function}(i) \ \ldots\ldots (1)$$

where n represents the numbers of stimuli.

With these three stimuli, equation (1) then can be expanded into:

$$\sum_{i=0}^{n} \text{Fuzzy\_function}(i) = f(\text{drift-rate, angle-changes}) + g(\text{door-detection}) + f(\text{drift-rate, angle-changes}) + g(\text{object-detection}) + g(\text{face-recognition}) \ldots (2)$$

where f( ) is a fuzzy function that calculate the variables with fuzzy values (an example is shown in equation 3 below) and g( ) is a fuzzy function that calculate the variables with boolean values.

$$f(\text{drift, angle-changes}) = \frac{\alpha_{drift\_sonar} * x_{drift\_sonar} + \alpha_{angle\_sonar} * y_{angle\_sonar}}{\alpha_{drift\_sonar} + \alpha_{angle\_sonar}} \ldots (3)$$

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

Table 1 Mapping of the emotions' parameter changes

where x_{drift_sonar} (ε F_{drift_sonar}) is the fuzzy value's output for drifting detected by sonar, y_{angle_sonar} (ε F_{angle_sonar}) is the fuzzy value's output for angle change detected by sonar, α_{drift_sonar} is the matching degree for drifting detected by sonar and α_{drift_angle} is the matching degree for angle change detected by sonar.

Based on the mapping from table 1, the emotions parameters are either increased or decreased based on the emotion-parameter-change result. If there is a highest parameter, its emotion is concluded as the final one. Otherwise, when there are ties, we only pick the most highest emotion among the ties in the following rank: happy, surprise, fear, sad, and angry.

After concluding the final emotion, this level performs SECs that checks the emotion components and creates a schema of emotion to be stored in the memory. The checkings are done by assigning appropriate values to the emotion component, as described in the SECs section above, based on the pleasantness, importance, relevance, urgency, etc. Table 2 shows a schema when an unexpected moving object suddenly appears in the captured navigation-image, i.e, walking students. For this case, surprise will be chosen as her final emotion, only for this cycle.

Components	Values
Emotion	Surprise
Valence	Negative
Intensity	Very High
Focality	Object
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

Table 2 A surprise schema

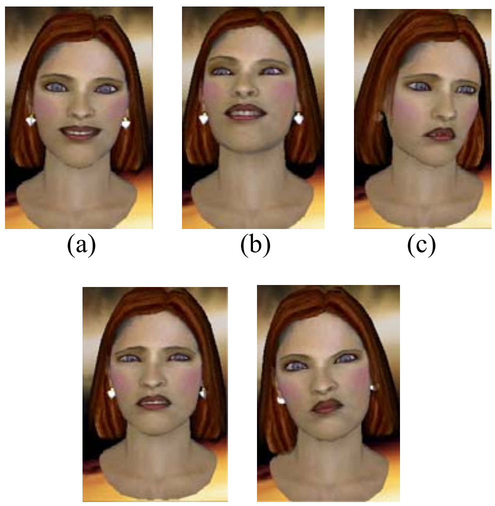
Besides performing SECs, Petra's facial expression also needs to be changed to show her current emotion. For every emotion that we are modeling, e.g., happy, surprise, fear, sad, and angry, we have designed their facial expressions based on the Facial Action Coding System (FACS) (Ekman and Friesen, 1978) as shown in figure 4 (a-e).

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"

[1] To show surprise, when the summation of sonar and/or vision is large, the weight of this emotion is the highest among all.

(Murphy, 2000). After the perceptual system filters all the inputs from the stimuli, besides sending them to the ESG, the system also sends them to the BSG. Through these output from the perceptual systems, the robot can execute different behaviors depending on the input source. Each behavior state is described below:



(a) (b) (c)

(d) (e)

Figure 4 Five facial expressions for the modeled emotions (a) Happy, (b) Surprise, (c) Fear, (d) Sad, (e) Angry

1. *INIT*: reset the emotion, 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 and/ 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 give another try to avoid any false positive).

Introducing Petra

Petra is a continuation of our previous project – Cherry the AmigoBot, the little red robot (Brown et al 2002, Lisetti et al 2004). Cherry, a robot with no formal emotion modeling representation, was developed as a prototype for Petra.

Our main reason of switching from an AmigoBot to the PeopleBot was the size. Realizing that our main goal is to enhance Human-Robot Interaction (HRI), it is better to have a human's height autonomous agent (compared to Cherry). Besides the size, another reasons were the weight limitation, stability, accuracy, and on-board computer. With higher weight limitation and better stability and accuracy, we were able to put more hardware that can support our HRI's goal, e.g., DesXcape 150 DM, two USB cameras (with 320x240 resolutions), wireless antenna for DesXcape touch screen communication, and laser (for future use). Our hardware designs are shown in figure 5.

Figure 5 Complete Petra's Hardware

Petra's Interface

Through the on-board computer, we are able to execute the interface (fig. 6) that we had created and display it through the touch screen wirelessly. The interface, the modified version of Cherry's, integrates several components such as the avatar, an anthropomorphic face, point-and-click map, emotion changing progress bars, 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 image. Further information on most of these components can be found in (Brown et al, 2002). The main differences of Petra's interface from Cherry's are the progress bars, the two video frames, navigational and vision algorithms. Through these bars, we are able to show the real-time changes of emotion and which emotion(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 better and smoother navigational system.

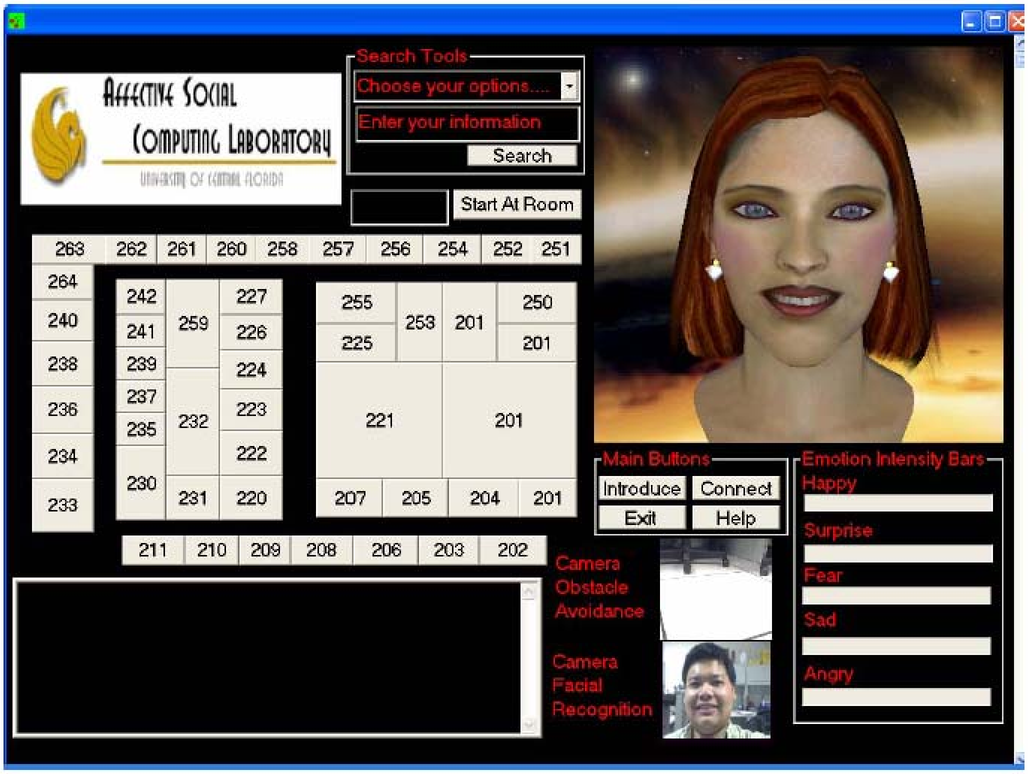


Figure 6 Petra's Complete Interface

Our Future Goals:

Implementing Schematic and Conceptual Levels

After implementing the sensory motor level, we want to continue our effort to model emotions to the next levels – schematic and conceptual levels, where further thoughtful reasong, learning, etc happen.

More Personality for Petra

Besides having emotions, we would also plan to create more "personality" for Petra, i.e., sing a song when she is happy, humming as she travels, getting excited when finding someone she loves, etc. In the future, we also can tailor her conversation to the interests of the other person that she speaks to. With these human-like behaviors, we hope that the human-robot interaction can be enhanced so it can be more like human-human interaction.

Acknowledgements

The authors would also like to thank the *Office of Naval Research* for partial funding for this research project.

References

ActivMedia. www.activmedia.com, 2002.

Arkin, R. C. *Behavior-Based Robotics*, Cambridge, MA: MIT Press, 1998.

Breazeal, C. and Scassellati, B., "Infant-like Social Interactions Between a Robot and a Human Caretaker". To appear in *Special issue of Adaptive Behavior on Simulation Models of Social Agents*, guest editor Kerstin Dautenhahn. 2000

Breazeal, C. "Emotion and sociable humanoid robots". *International Journal of Human Computer Studies.* Vol. 59. pg. 119 – 155. 2003

Brooks, R and Flynn, A. "Fast, Cheap, and Out of Control", AI Memo 1182, MIT AI Laboratory, 1989.

Brown, S. Lisetti, C. and Marpaung, A. Cherry, the Little Red Robot with a Mission and a Personality. In *Working Notes of the AAAI Fall Symposium Series on Human-Robot Interaction*, Menlo Park, CA: AAAI Press. Cape Cod, MA, November 2002.

Casper, J. "Human-robot interactions during the robot-assisted urban search and rescue response at the World Trade Center." MS Thesis, Computer Science and Enginerring, University of South Florida, April 2002.

Casper, J. and Murphy, R. "Workflow study on human-robot interaction in USAR." In *Proceedings of ICRA 2002*, pp. 1997 – 2003. 2002.

Ekman, P and Friesen, W. "The Facial Action Coding System". Consulting Psychologist Press, San Francisco, CA, 1978.

El-Nasr, Magy Seif. Yen, John. Ioerger, Thomas. FLAME - A Fuzzy Logic Adaptive Model of Emotions, *Automous Agents and Multi-agent Systems,* 3, 219-257, 2000.

Identix Inc. www.identix.com, 2002.

Leventhal, H. "A perceptual-motor processing model of emotion." In P. Pilner, K. Blankenstein, & I.M. Spigel (Eds.), *Perception of emotion in self and others. Vol. 5* (pp. 1 – 46). New York: Plenum. 1979

Leventhal, H., "Toward a comprehensive theory of emotion." In L. Berkowitz (Ed.), *Advances in experimental social Psychology. Vol. 13* (pp. 139 – 207). New York: Academic Press, 1980

Leventhal, H. and Scherer, K. "The relationship of emotion to cognition: A functional approach to a semantic controversy." *Cognition and Emotion.* Vol. 1. No. 1. pp. 3 – 28. 1987.

Lisetti, C. Brown, S. Alvarez, K. and Marpaung, A. A Social Informatics Approach to Human-Robot Interaction with an Office Service Robot. *IEEE Transactions on Systems, Man, and Cybernetics - Special Issue on Human Robot Interaction,* Vol. 34(2), May 2004.

Lisetti, C. and Bianchi, N. Modeling Multimodal Expression of User's Affective Subjective Experience. *User Modeling and User-Adapted Interaction, An International Journal,* Vol. 12(1): 49-84. 2002

Marpaung, A. "Social Robots with Emotion State Generator Enhancing Human-Robot Interaction (HRI)". Master's thesis. University of Central Florida. in progress 2004.

Murphy, R. R. Use of Scripts for Coordinating Perception and Action, In *Proceedings of IROS-96* , 1996a.

Murphy, R. R. Biological and Cognitive Foundations of Intelligent Sensor Fusion, *IEEE Transactions on Systems, Man and Cybernetics*, 26 (1), 42-51, 1996b.

Murphy, R. R. Dempster-Shafer Theory for Sensor Fusion in Autonomous Mobile Robots, *IEEE Transactions on Robotics and Automation*, 14 (2), 1998.

Murphy, R. R. *Introduction to AI Robotics*. Cambridge, MA: MIT Press, 2000.

Murphy, R. R., Lisetti, C. L., Irish, L., Tardif, R. and Gage, A., Emotion-Based Control of Cooperating Heterogeneous Mobile Robots, *IEEE Transactions on Robotics and Automation*, Vol. 18, 2002.

Picard, Rosalind W. Affective Computing, Cambridge, Mass.: MIT Press, 1997.

Scherer, K. "Emotion as a multicomponent process: A model and some cross-cultural data." In P. Shaver (Ed.), *Review of personality and social psychology.* Vol. 5. *Emotions, relationships and health* (pp. 37 – 63). Beverly Hills, CA: Sage. 1984

Scherer, K. "Vocal affect expression: A review and a model for future research." *Psychological Bulletin.* 99. pp. 143 – 165. 1986

Smith, C. A., Ellsworth, P.C. "Patterns of cognitive appraisal in emotion." *Journal of Personality and Social Psychology*. 48. pp. 813 – 838. 1985

Simmons, R. Goldberg, D. Goode, A. et al. GRACE An Autonomous Robot for the AAAI Robot Challenge. *AI Magazine.* Vol. 24. No. 2. p. 51 – 72. 2003

Sony. www.us.aibo.com. 2004.

Takagi, H. and Sugeno, M.. "Fuzzy identification of systems and its application to modeling and control". *IEEE Transactions on Systems, Man and Cybernetics*, 15 (1), 1985.

Velasquez, Juan. "Cathexis, A Computational Model for the Generation of Emotions and their Influence in the Behavior of Autonomous Agents". Master's thesis. Massachusetts Institute of Technology. 1996

Velasquez, Juan. "Modeling Emotion-Based Decision Making". *In proceedings of AAAI Fall Symposium Emotional & Intelligent: The Tangled Knot of Cognition.* 1998

Weiner, B., Russell, D., Lerman, D. "The cognition-emotion process in achievement-related contexts. *Journal of Personality and Social Psychology,* 37, pp. 1211 – 1220. 1979