ABE: An Agent-Based Software Architecture for A Multimodal Emotion Recognition Framework

Conference Paper · June 2011

DOI: 10.1109/WICSA.2011.32

4 authors, including:

Javier Gonzalez-Sanchez
Arizona State University

Maria-Elena Chavez-Echeagaray
Arizona State University

Winslow Burleson
New York University

2011 Ninth Working IEEE/IFIP Conference on Software Architecture

ABE: An Agent-Based Software Architecture for A Multimodal Emotion Recognition Framework

Javier Gonzalez-Sanchez, Maria Elena Chavez-Echeagaray, Robert Atkinson, Winslow Burleson
School of Computing, Informatics, and Decision Systems Engineering
Arizona State University
Tempe, Arizona, US
e-mail:{javiergs, helenchavez, robert.atkinson, winslow.burleson}@asu.edu

***Abstract*—The computer's ability to recognize human emotional states given physiological signals is gaining in popularity to create empathetic systems such as learning environments, health care systems and videogames. Despite that, there are few frameworks, libraries, architectures, or software tools, which allow systems developers to easily integrate emotion recognition into their software projects. The work reported here offers a first step to fill this gap in the lack of frameworks and models, addressing: (a) the modeling of an agent-driven component-based architecture for multimodal emotion recognition, called ABE, and (b) the use of ABE to implement a multimodal emotion recognition framework to support third-party systems becoming empathetic systems.**

Keywords - affective computing; architecture; framework; agent-based; multimodal; emotion recognition; empathetic systems

I. INTRODUCTION

A key concept in this work is empathy, i.e., to enable a system to recognize and understand human emotions and react appropriately in consequence with those understandings. Enabling computers to be empathetic has implied the convergence of affordable wireless sensors and the application of novel machine learning and data mining algorithms to deal with the vast amounts of data generated by the sensors [1].

On the one hand, there are several examples of research conducted on creating empathetic systems to support learning [2][3][4], health care [5] and videogames [6]. But the majority of the research does not focus on the creation of reusable software, software frameworks or the best methodological practices for those purposes [7]. Each attempt either develops its own system, or uses a legacy system. They are focused on creating a proof-of-concept system to collect data and validate technology approaches.

On the other hand, some of the best-known existing architectures and libraries that provide support for emotion recognition use monomodal or bimodal approaches. For example the project described in [8] is an open-source implementation that combines speech emotion recognition with facial expressions analysis and head movement tracking. The multimodal proposal in [9] could be considered an antecedent of this work due the use of multiple sensors and their integration in a client-server structure although software architecture is not described and the definition of a framework to enable others to integrate emotion recognition into their systems was not a goal.

To the best of our knowledge there are no architectures, frameworks, libraries or generic software tools, that allow software engineers to easily integrate true multimodal emotion recognition into their software projects, such as the ones that exist for computer vision [10], web platforms [11] or database management [12].

Accordingly, the work reported here offers a first step toward filling the gap in the lack of frameworks and models, addressing: (a) the modeling of an agent-driven component-based architecture for multimodal emotion recognition, called ABE (for Agent-Based Environment), and (b) the use of ABE to implement a multimodal emotion recognition framework, under the paradigm of "highly reusable software components", which can be integrated into third-party systems and provide them with the ability to become an empathetic system, as needed.

It is important to clarify that the primary contribution of this work is related to software architecture and it is not about new algorithms for emotion recognition or new hardware devices for sensing human signals indicating emotional changes.

This paper is structured as follows. Section II reviews the related background about sensing devices and some related terminology. Section III presents the architecture and framework. Section IV exemplifies the use of ABE framework by describing how it was integrated in two demo systems. Section V presents an evaluation of the framework in terms of performance while used in the demo systems. Section VI presents conclusions and ongoing work.

II. BACKGROUND

Because this work is related to emotions and to the intention of enabling computers with the ability to recognize them, this section provides background information to clarify some terminology used within this paper and describes the sensing devices and perception mechanisms used in this work.

A. Definitions

In the rest of the paper we use these definitions for the related concepts.

978-0-7695-4351-2/11 $26.00 © 2011 IEEE
DOI 10.1109/WICSA.2011.32

IEEE computer society

1) Sensing device. These are hardware devices that collect quantitative data as measures of physiological signals of emotional change.

2) Raw data. We call the measures provided by the sensing devices "raw data". These are data packages that sensing devices send to the computer.

3) Sensed value. This refers to the raw data after being parsed into a software data structure. Sensed values are useful by themselves and also help to infer emotions. For example, face sensed values are "actions units"; action units are standard values used to categorize facial expressions and they have proven being useful to recognition of basic emotions [13].

4) Perception mechanism. These are algorithms that infer emotions using sensed values as input. An example of this is the act of inferring emotions from facial expressions sensed by a video camera.

5) Belief. Perception mechanisms provide "beliefs" about their understanding of the user's emotional change.

6) Multimodal. It refers to combining several sensing devices (i.e., perception mechanisms), either to recognize a broad range of emotions or to improve the accuracy of a process. The multimodal strategy provides more than one way to recognize an emotion.

7) Emotional state. Represents the user emotion in a time `t`. This is developed from the integration of beliefs in that time `t`.

B. Sensing and Perceiving

Several existing systems are able to detect a single emotion or a reduced set of emotions. One of our goals was to make significant advances to emotion recognition by integrating and encapsulating pre-existing software components into our implementation to sense and recognize a wide range and diverse set of emotions.

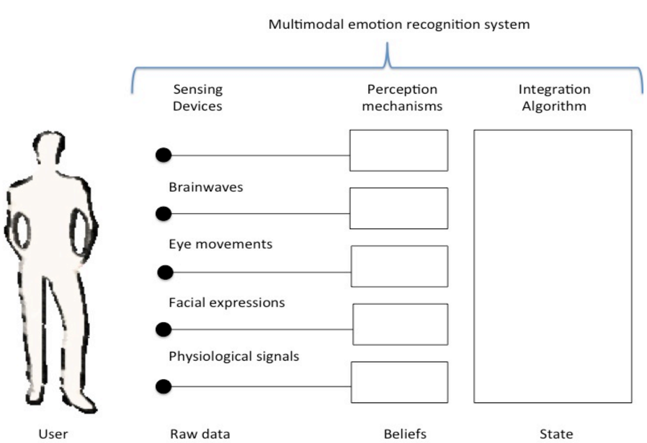

Figure 1. Multimodal emotion recognition includes: sensing brainwaves, eye tracking, facial expression analysis and physiological signals (skin conductivity, posture, and finger pressure). Beliefs are inferred from raw data and emotional states correspond to the integration of beliefs from several sources in a time `t`.

Our multimodal approach includes: brain-computer interfaces, eye tracking systems, face-based emotion recognition systems, and sensors to measure other physiological signals (skin conductivity, posture, and finger pressure). Fig. 1 shows the elements related to our approach of a multimodal emotion recognition system. The description of each element is as follows:

1) Brainwaves. We incorporate the Emotiv© EPOC headset, an inexpensive wireless hardware device, which uses EEG technology to sense electroencephalography activities [14].

2) Eye movement. We incorporate the Tobii© Eye Tracking System. An eye tracker provides data about a user's focus of attention and focus time while the user performs a task on the computer [15].

3) Facial expressions. We incorporate MindReader, an inference system developed at MIT Media Lab, which infers, in real-time, emotions from facial expressions and head movements [16].

4) Skin conductivity. This sensor measures the electrical conductance of the skin, which varies with its moisture level that depends on the sweat glands, which are controlled by the sympathetic and parasympathetic nervous systems. Skin conductance is an indicator of psychological or physiological arousal. We use a wireless Bluetooth skin conductance device developed at MIT Media Lab [17].

TABLE I. INFERRED EMOTIONS AND SENSED VALUES

Sensing Device	Sampling Rate (in ms)	Inferred emotions
Emotiv© headset	125	Excitement, engagement, boredom, meditation and frustration.
Webcam and MindReader software	100	Agreeing, concentrating, disagreeing, interested, thinking and unsure.
		Sensed values
Emotiv© headset	7	EEG activity. Reported in 14 channels, labeled: AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, and AF4 [18].
Emotiv© headset	125	Blink, wink (left and right), look (left and right), raise brow, furrow brow, smile, clench, smirk (left and right), and laugh.
Skin conductance sensor	500	Arousal.
Pressure sensor	150	One pressure value per sensor allocated into the input/control devices.
Tobii© Eye Tracking	16	Gaze point (x, y).
Posture sensor	500	Pressure values in the back pad and the seat cushion (in the right, middle and left zones).

5) Posture. We use a low-cost, low-resolution pressure sensitive seat cushion and back pad with an incorporated accelerometer to measure elements of users' posture and activity, developed at ASU based on experience using a more expensive high resolution unit from the MIT Media Lab. The use of this sensing device to recognizing naturally occurring postures and associated emotional states is describe in [19].

6) Finger pressure. Based on pressure sensors we detect the increasing amount of pressure that the user puts on a mouse, or any other controller (such as a game controller). These measures are correlated with levels of frustration. Mouse implementation is described in [20].

Sensed values, inferred emotions and sampling rates are listed in Table I. Given this collection of sensing devices with proven functionality when used independently, the research question we posed was how to achieve a framework where all of them work together. We sought to create a framework that can be used and reused without a cumbersome installation or adaptation (re-programming) process.

C. Agents and Agent Federation

Agents are autonomous pieces of software that allow us to encapsulate sensing devices and their perception mechanisms into independent, individual and intelligent components [21] [22].

When several agents need to interact, it is important to establish an organizational strategy for them, which defines authority relationships, data flows and coordination protocols. To articulate the organizational strategy we define an agent federation. An agent federation is conformed by a group of agents that cede some amount of autonomy to a single delegate, which represents the group. The delegate is a "distinguished" agent that acts as an intermediary between all the agents in the group and the outside world [23].

III. IMPLEMENTATION

We propose an agent-based model as the most appropriate solution because we need to deal with several different sources of data flows, where each flow proceeds along different time intervals, and furthermore, these multiple highly varying inputs can be used as a whole or as a subset. Our model takes into account that it may be necessary, in the future, to add even more sources of sensed values.

ABE follows the federation organizational strategy as shown in Fig. 2. The structure is composed of:

1) Specialist agents. These are responsible for: (a) collecting raw data, (b) parsing it into sensed values and inferring beliefs, and (c) communicating their beliefs with the head of their federation.

2) Centre agent or simply Centre. This is the name of our delegate or "distinguished" agent to which the rest ceded some amount of autonomy, and which acts as the head of the federation. Specialist agents are in permanent communication with Centre, contributing with data. Centre implements the integration algorithms that convert, in real-time, the beliefs reported by the Specialist agents into emotional states. For third-party systems Centre acts as a facade that hides the internal complexity of the federation. As shown in Fig. 2, third-party systems are able to contact Centre and subscribe to receive information about the emotional state of the user.

3) Internal communication. The communication structure between Specialist agents and Centre is made by data flows moving messages from one point to another. Specialist agents encapsulate information in packages with: (a) a header composed of timestamp, in milliseconds, and an agent ID, and (b) a body composed of an array of rational numbers.

4) External communication. The federation, through Centre, offers a service-oriented behavior using a publish-subscribe style. The underlying concept is that the agent federation provides a service and other systems can subscribe to the service and customize which information they are interested in receiving.

Both internal and external communications are achieved using TCP/IP connections, so agents can run within one computer or be distributed among several computers.

The elements in Fig. 2 constitute a federation unit. One federation unit can take care of one user. This means that, during runtime, there is one agent of each kind related to each sensing device for each user. Several federation units can be instantiated and communicated with to establish the emotional state of a group of users. The following sections provide a detailed description of the architecture, framework and data management.

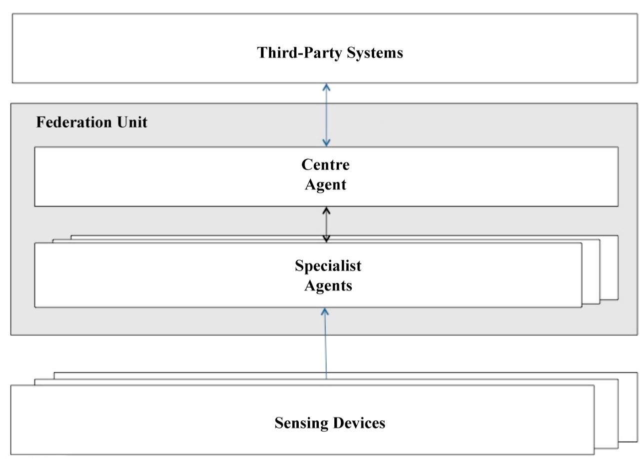

Figure 2. ABE follows the organizational strategy of federation. The federation assigns one Specialist agent to collect raw data from each sensing device. Specialist agent implements the perception mechanism for its assigned sensing device to map raw data into beliefs. Beliefs are reported to Centre, which integrate them into one emotional state report. Third-party systems are able to obtain emotional state reports from Centre in a publish-subscribe style.

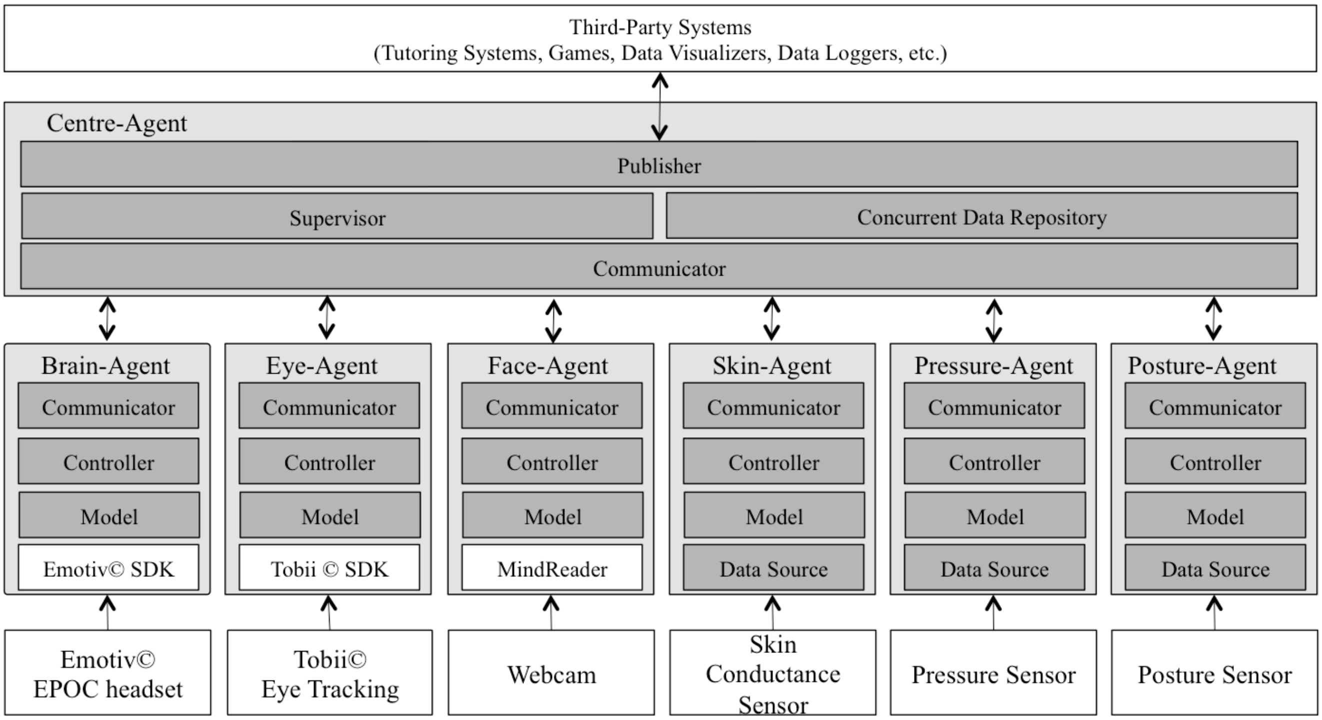

Figure 3. Architecture. Specialist agents (brain, eye, face, skin, pressure and posture) deal with sensing devices and encapsulate parsing, inference, and communication functionalities. They work as a federation, which implies that they send resources (beliefs) and subordinate their behavior to the head of the federation. Centre acts as the head of the federation. Centre's responsibilities include integrating beliefs to create emotional state reports that can be shared with third-party systems in a publish-subscribe style

A. *The Architecture*

Fig. 3 shows the macro-level [24] view for the ABE agent-based multilayer distributed architecture, as it is currently designed, where all the agents are represented along with their components and communication channels. Each component is described below.

1) Specialist agent. One Specialist agent is included for each sensing device listed in Table I, they are labeled as brain-agent, eye-agent, face-agent, skin-agent, pressure-agent, and posture-agent. A Specialist agent is divided into four components: (a) Data Source, (b) Model, (c) Controller, and (d) Communicator. Each component implements one agent responsibility.

a) Data Source. Data Sources access raw data from the sensing devices, parse the raw data into sensed values, and provide those sensed values to the component in the next layer. Two types of Data Sources are defined: Wrappers and Drivers. On the one hand, Wrappers encapsulate legacy systems making calls to their SDK methods; Data Sources for brain-agent, eye-agent and face-agent wrap Emotiv© SDK, Tobii© SDK and MIT MindReader System respectively. On the other hand, Drivers communicate with sensing devices through the computer bus or communication subsystems (such as serial or USB ports); skin-agent, pressure-agent, and posture-agent implement serial port communication to read data from the corresponding sensors.

b) Model. Model obtains sensed values from a Data Source and uses a perception mechanism to infer beliefs. Model is also responsible for filtering, labeling, time stamping, packaging beliefs, and sending packages to Centre.

c) Controller. Controller implements a configuration mechanism. It receives requests from Centre and modifies the behavior of the Specialist agent according to the received requested. Configuration parameters include change sampling rate and change filtering strategy.

d) Communicator. Communicator provides networking capabilities to send beliefs to Centre.

2) Centre Agent. Centre is divided into four components, each of them implements one agent responsibility: (a) Communicator, (b) Supervisor, (c) Concurrent Data Repository, and (d) Publisher.

a) Communicator. It connects with the communicator component of the Specialist agent to receive beliefs.

b) Supervisor. It is the component that takes beliefs as input for its integration algorithms and generates emotional states. Since sensing devices and their associated Specialist agents have different sampling rates, part of the responsibility of Supervisor is to standardize the sampling rates. Thus, Centre is able to report emotional states with the requested sampling rate.

c) Concurrent Data Repository. The Data repository is explained in the Data Management section below.

d) Publisher. Publisher is the component that acts as the facade of the agent federation to the outside world implementing the publish-subscribe functionality. A third-party system can express interest in receiving reports of the emotional state of the user by sending a "subscribe" message. The subscription includes the specification of the periodicity that is desired (starting in 1 millisecond) and the composition of the data of interest (e.g., all sensors, emotions and eye tracking, posture and facial expressions, only positive emotions, only negative emotions). From that point forward Publisher will be sending reports about the emotional state of the user to that third-party system.

B. The Framework

The definition of the micro-level architecture [24] uses a pattern-based approach [25]. The use of software design patterns populated our framework and SDK. The process of moving from macro-level architecture to the micro-level architecture is described in detail in [26]. In order to build upon ABE framework, developers are required to do the following:

1) Create new Specialist agent. To create new types of Specialist agents developers are responsible for:

- Implementing the interface Agent in a new class.
- Creating the associated Data Source implementing a class from `DataSourceWrapper` interface (to encapsulate a legacy SDK) or a class from `DataSourceDriver` interface (to access a new sensing device).
- Completing the implementation of an **`ADAPTER`** pattern, for `DataSourceWrapper`, or completing the implementation of a **`DELEGATE`** pattern, for `DataSourceDriver`.
- Programming the Model component of the agent (i.e. complete a **`STRATEGY`** pattern implementation).
- Using the communicator facilities to send information to Centre (i.e. implement `Communicator` interface).

2) Extend Centre capabilities. Centre's capabilities can be extend in order to handle new types of beliefs (coming from new types of Specialist agents) by:

- Completing the implementation of a **`STRATEGY`** pattern to define new integration algorithms.
- Implementing a new knowledge source in a **`BLACKBOARD`** pattern.
- Using communicator facilities to receive information from a new Specialist agent.

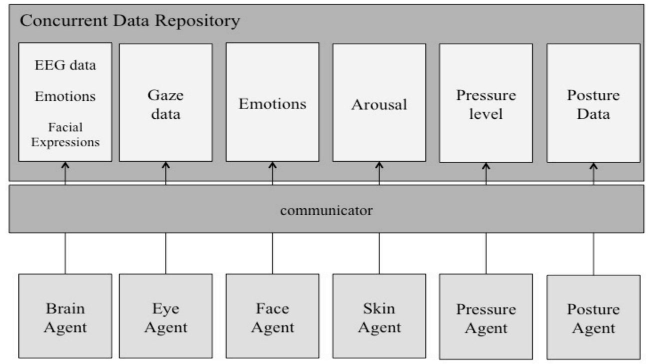

Figure 4. The Concurrent Data Repository, located in Centre Agent, has one data-item mapped to each agent.

C. Data Management

Centre provides a concurrent control mechanism for data collection: a concurrent data repository in which each data-item is mapped to one of the Specialist agents and stores the set of sensed values provided by that Specialist agent. Each data-item stores the most recent information provided by its Specialist agent without interfering with the information provided by the others Specialist agents. In this way we solve the problem of different sampling rates across diverse sensing devices, Fig 4.

Reading the data repository content in a time `t` provides us with the user's emotional state for `t`. Data items store the last provided value until a new one arrives. Table II shows how this is handled in the data repository across time. Each row corresponds to the data repository in a time `t`, and represents the integration of the beliefs reported by the Specialist agents into one emotional state. As can be observed skin conductance remains the same from t_1 to t_4 since the sensor device related with that information has the slowest sampling rate (500 ms).

IV. USAGE EXAMPLES

We have evaluated the suitability of ABE to our needs both at the architectural and runtime levels. The six Specialist agents and Centre agent have been implemented and ABE has been tested in two different kinds of scenarios, in a gaming environment study and in an intelligent tutoring system development project.

A. Gaming Environment Study

The purpose of this study was to measure the correlation of the engagement/boredom of the player (depending on his/her level of expertise) while playing different difficulty levels in Guitar Hero© video game.

TABLE II. INTEGRATION OF EMOTIONAL STATES IN TIMES T_N

Time	Brain	Eye	Face	Skin	Pressure	Posture
t_1	*v1*	*v1*	*v1*	*v1*	*v1*	*v1*
t_2	*v1*	*v2*	*v2*	*v1*	*v1*	*v1*
t_3	*v2*	*v3*	*v3*	*v1*	*v2*	*v2*
t_4	*v2*	*v4*	*v4*	*v1*	*v2*	*v2*
t_5	*v3*	*v5*	*v5*	*v2*	*v3*	*v3*

Guitar Hero© is a game in which players use a guitar-shaped game controller to simulate playing lead, bass guitar, and rhythm guitar across numerous rock music songs. Players match notes that scroll on-screen to colored fret buttons on the controller, strumming the controller in time to the music in order to score points, and keep the virtual audience excited [27].

ABE was applied in a lab setup where 21 students were asked to play Guitar Hero© (as a learning experience, learn to play). The scenario involved the user wearing the skin conductance bracelet and the Emotive© EPOC headset while being tracked by the MIT MindReader System and by Tobii© Eye Tracking System. The game controller was modified by adding a pressure sensor to each of the colored fret buttons, on the arm of the guitar. Users were asked to play their choice of a single song at each of four different levels (easy, medium, hard and expert), from a pre-selected list of songs. ABE provided access to the sensed data and provided mixing functionality. Centre sends data to a logger component (developed for this experiment). Two data streams were provided to create two dataset files, one with 1/128 s rate and other with 1s rate. Each dataset was requested for a different data mining approach.

Fig. 5 shows one of the results of this study where Centre provided integrated data from eye tracking and brainwaves. The figure shows the Guitar Hero© screen; the superimposed dots (in black) indicate that at one or more times, throughout the session, while the user was looking at that location on the screen frustration was detected by ABE. The Guitar Hero© screen is composed of an image that resembles the arm (or frets) of a guitar, in the middle of the image; overlaid on this image, musical notes scroll down toward the bottom of the screen. Each note is mapped according to the color of a physical button that the user should actuate before the note moves off the screen. The scene is decorated with stage items, instruments and performers.

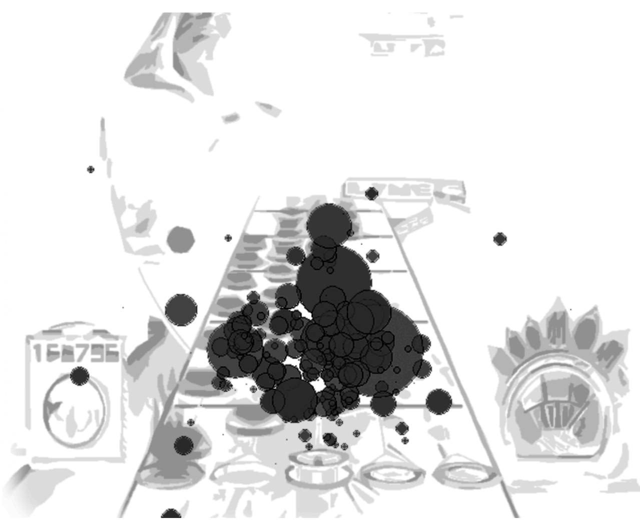

Figure 5. Mixed data from eye tracking system and frustration measurement for a single novice user playing Guitar Hero©. Black dots correspond to places where the player was looking while feeling frustrated. The image was converted to gray scale, the contrast incremented and the tones inverted to facilitate its print.

The frustration points were the `x, y` coordinates of the user gaze while feeling frustrated. A circle represents each frustration point and its size is equivalent to the time spent by the user staring at that location. Since the subject was a novice user of this videogame, this data shows how the user feel frustration looking into the notes while they scroll on-screen.

B. Intelligent Tutoring System

In a second case, we are currently working on the development of an intelligent tutoring system applying ABE to generate better and more accurate hints and feedback to the student with the intention of creating a more empathetic learning process and environment, reducing student frustration and avoiding student quitting.

During a pilot test in July 2010, the intelligent tutoring system [28] was enriched with the sensing devices and agents related to: (a) skin conductance bracelet, (b) Emotiv© EPOC headset, (c) the MIT MindReader System, and (d) pressure sensors on the mouse. Students were asked to perform a task (about system dynamics modeling) using the intelligent tutoring system. While the student was working on this task, the intelligent tutoring system collected data using ABE. During this study the data was collected for post analysis and review what information the student reported. The next step in the project will consist on using this information to create a student model and adjust the behavior of the intelligent tutoring system in response to the emotional state of the student.

V. PERFORMANCE

ABE framework components were created to be as lightweight as possible to run in the background of an existing system. The goal was to avoid creating a dominant, “star player” system, but rather to provide a platform that could operate behind the scenes, to improves and complements other systems. Table III shows the result of memory load and processor usage running each of the agents in a system with the following characteristics: Intel Xenon CPU W3520 at 2.67 GHz with 4 cores, 3.50 GB of RAM, and running Windows XP professional with Service Pack 3.

It is important to mention that for face, brain and eye agents the values reported in Table III include the load caused by the agent and by the underlying system: MIT MindReader System, Emotiv© EPOC SDK and Tobii© Eye Tracking SDK, respectively.

TABLE III. PERFORMANCE OF SPECIALIST AGENTS

Agent	Performance	
	% CPU	Memory (Kb)
Skin	8 - 15	14,100 - 15,200
Face	34 - 43	60,000 - 110,000
Brain (for emotion)	9 - 16	8,260 - 8,500
Brain (For physiological signals)	6 - 15	7,200 - 7,800
Pressure	8 - 14	15,900 - 16,200
Eye	15 - 25	169, 500 - 170,000

VI. Conclusions and Ongoing Work

In this paper we have presented ABE as our architectonical proposal for a multimodal emotion recognition framework that supports the creation of empathetic systems. This work is rooted in an agent-based approach under a multilayer-distributed architecture oriented to create highly reusable, flexible and extensible software components. We have achieved the integration of both novel and well-known sensing devices into ABE including brain computer interfaces, eye tracking systems, computer vision systems and physiological sensors. We illustrated the use of ABE in practice, building software for two different scenarios: one was a gaming study in which we sensed emotional status of students while playing a video game, and a second one into an affective tutoring system development project. In both scenarios it was seen that the integration of ABE was a reasonably easy experience with good performance results. We are excited and encouraged to continue with the next step in this process and deploy ABE externally in order to have others research and development groups using and testing ABE by themselves without support from our engineering team. The next steps for ABE are focused on: (a) refactoring components (b) deploy API's documentation, (c) adding support agents such as loggers and visualizers to conform a dashboard interface. Beside that, looking into test-case scenarios for reactive systems, has become more relevant to maintain latency in a useful level for real-time interaction, therefore integration of parallel and multicore computing models is also in our list of next steps.

Acknowledgment

This research was supported by Office of Naval Research under Grant N00014-10-1-0143 awarded to Dr. Robert Atkinson.

References

[1] R. W. Picard, Affective Computing, MIT Press, 1997.

[2] I. Arroyo, D. G. Cooper, W. Burleson, F. P. Woolf, K. Muldner, and R. Christopherson, "Emotion Sensors Go to School," Proc. Artificial Intelligence in Education: Building Learning Systems that Care: from Knowledge Representation to Affective Modelling, (AIED 09), V. Dimitrova, R. Mizoguchi, B. du Boulay & A. Grasser (Eds.), IOS Press, July 2009, vol. Frontiers in Artificial Intelligence and Applications 200, pp. 17-24, doi: 10.3233/978-1-60750-028-5-17.

[3] B. Woolf, W. Burelson, and I. Arroyo, "Emotional Intelligence for Computer Tutors," Supplementary Proc. 13th International Conference on Artificial Intelligence in Education (AIED 07), July 2007, pp. 6-15.

[4] S. D'Mello, R. W. Picard, and A. Graesser, "Toward an Affect-Sensitive AutoTutor," IEEE Intelligent Systems, July/August 2007, vol. 22 no. 4, pp. 53-61, doi:10.1109/MIS.2007.79.

[5] X. Chao, and F. Zhiyong, "A Trusted Affective Model Approach to Proactive Health Monitoring System," Proc. International Seminar on Future BioMedical Information Engineering (FBIE 08). IEEE Computer Society, 2008, pp. 429-432, doi:10.1109/FBIE.2008.52.

[6] K. Gilleade, A. Dix and J. Allanson, "Affective Videogames and Modes of Affective Gaming: Assist Me, Challenge Me, Emote Me," Proc. Digital Games Research Association, Changing Views – Worlds in Play (DiGRA 05), June 2005.

[7] R. E. Johnson, "Components, frameworks, patterns," Proc. Symposium on Software Reusability (SSR 97), Medhi Harandi (Ed.). ACM, Feb. 1997, pp. 10-17, doi:10.1145/258366.258378.

[8] M. Schroder, "The SEMAINE API: towards a standards-based framework for building emotion-oriented systems," Advances in Human-Computer Interaction, vol. 2010, 2010, doi:10.1155/2010/319406.

[9] W. Burleson, R. Picard, K. Perlin, and J. Lippincott, "A platform for affective agent research", Workshop on Empathetic Agents, International Conference on Autonomous Agents and Multiagent Systems, Columbia University, New York, NY, (2004),

[10] ReacTIVision - a toolkit for tangible multi-touch surfaces. Retrieved April 4, 2011, from http://reactivision.sourceforge.net.

[11] Apache Http Server Project. Retrieved April 4, 2011, from http://httpd.apache.org.

[12] MySQL – open source database. Retrieved April 4, 2011, from http://www.mysql.com.

[13] P. Ekman and W. Friesen, "Facial Action Coding System: A Technique for the Measurement of Facial Movement," Consulting Psychologists Press, 1978.

[14] Emotiv - Brain Computer Interface Technology. Retrieved April 4, 2011, from http://www.emotiv.com.

[15] Tobii Technology - Eye Tracking and Eye Control. Retrieved April 4, 2011, from http://www.tobii.com.

[16] R. El Kaliouby, and P. Robinson, "Generalization of a vision-based computational model of mind-reading," Proc. First International Conference on Affective Computing and Intelligent Interaction (ACII 05), Springer-Verlag, Oct. 2005, pp. 582-589, doi:10.1007/11573548_75.

[17] M. Strauss, C. Reynolds, S. Hughes, K. Park, G. McDarby, and R. W. Picard, "The HandWave Bluetooth Skin Conductance Sensor," Proc. First International Conference on Affective Computing and Intelligent Interaction (ACII 05), Springer-Verlang, Oct. 2005, pp. 699-706, doi:10.1007/11573548_90.

[18] F. Sharbrough, G. E. Chatrian, R. P. Lesser, H. Luders, M. Nuwer, and T. W. Picton, "American electroencephalographic society guidelines for standard electrode position nomenclature," J. Clin. Neurophysiol., vol. 8, 1991, pp. 200-202.

[19] S. Mota, and R. W. Picard, "Automated Posture Analysis for Detecting Learners Interest Level," Proc. Computer Vision and Pattern Recognition Workshop (CVPRW 03), IEEE Press, June 2003, vol. 5, pp. 49, doi:10.1109/CVPRW.2003.10047.

[20] Y. Qi, and R. W. Picard, "Context-Sensitive Bayesian Classifiers and Application to Mouse Pressure Pattern Classification," Proc. International Conference on Pattern Recognition (ICPR 02), Aug. 2002, vol 3, pp. 30448, doi:10.1109/ICPR.2002.1047973.

[21] F. Tuijnman, and H. Afsarmanesh, "Distributed objects in a federation of autonomous cooperating agents," Proc. International Conference on Intelligent and Cooperative Information Systems, May 1993, pp. 256-265, doi:10.1109/ICICIS.1993.291763.

[22] M. Wood, and S. DeLoach, "An overview of the multiagent systems engineering methodology," Agent-Oriented Software Engineering, (AOSE 2000), Springer-Verlag, 2001, pp. 207-221, doi:10.1007/3-540-44564-1_14.

[23] B. Horling, and V. Lesser, "A survey of multi-agent organizational paradigms," The Knowledge Engineering Review, Cambridge University Press, 2005, vol. 19, pp. 281-316, doi: 10.1017/S0269888905000317.

[24] J.E. Hollingsworth and B.W. Weide, "Micro-Architecture vs. Macro-Architecture", Proceedings of the Seventh Annual Workshop on Software Reuse, (1995),

[25] E. Gamma, R. Helm, R. Johnson, and J. Vlissides. "Design patterns: Abstraction and reuse of object-oriented design," Proc. 7th European Conference on Object-Oriented Programming (ECOOP 93), Springer-Verlag, July 1993, vol. 707, pp. 406–431.

[26] J. Gonzalez-Sanchez, M.E. Chavez-Echeagaray, R. Atkinson, and W. Burleson," Affective computing meets design patterns: a pattern-based modeling of a multimodal emotion recognition framework," in submission.

[27] Guitar Hero. Retrieved April 4, 2011, from http://www.guitarhero.com.

[28] Affective Meta Tutor – Arizona State University. Retrieved April 4, 2011, from http://amt.asu.edu.