A Design for Using Physiological Signals to Affect Team Game Play

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ABSTRACT

This paper presents a prototype digital game that integrates team communication and psychophysiological measures as components of play. Our game, PhysiRogue*, adds an affective dimension to the location-aware augmented reality game,* Rogue Signals*. We are using this experimental platform to explore the complementary roles of human-to-human and computer-to-human communication in team cognition. Physiological signals are acquired and processed to form psychophysiological measures. These measures affect game play both through team understanding and altered game mechanics. We are investigating the role of physiological state in immersion and implicit coordination in distributed teams.*

In PhysiRogue*, a human team is split into two parts, each with access to different aspects of the game's information.* PhysiRogue's *implementation is a simulation of our location-aware game,* Rouge Signals *with the addition of psychophysiological measures. As components of the simulation,* seekers*, who form most of the human team, move in the "real world" and are "tracked" in an overlaid virtual world. The seekers, who must gather treasures in the "real world", are chased in the virtual world by* predators*, which they cannot see. The* coordinator *is another human player who acts as the team leader and is not co-located with the seekers. The coordinator can only see the "virtual world" and thus can see the predators, but is limited to the perceptions of the network. Since the information contained on each side of the team is different, the two sides need to coordinate and communicate in order to succeed. This ability is limited due to cognitive bandwidth and the need for turn taking in meaningful verbal communication. Combined, the components of the system mimic the dynamic coordination requirements of real-life teams deployed in high-stress situations.*

With PhysiRogue *we are integrating psychophysiological measures into digital game play. Electrodermal and electromyographic activity are simultaneously captured from players during game play. Such activity is indicative of increased attention, effort, and stress. The equipment used to measure this activity is portable and non-invasive. The physiological signals are processed to produce a real time "activation" level. Predators are able to track players based upon their "activation" levels, meaning that the computer opponents "sense" activation in the live players. They pursue seekers with higher "activation" levels. We hypothesize that this will lead to new game play strategies, a greater level of immersion, and new forms of focused involvement. In addition, visualizations of the seekers' activation level provide the coordinator with additional team status information, affording the coordinator the ability to modify strategy more effectively. We are investigating designs for the visualization and the game mechanics, and how these factors affect team cognition and immersion.*

1 INTRODUCTION

Individuals working in distributed teams over dangerous environments need to have a firm grasp of one another's state in order to facilitate safety and the accomplishment of goals [MacMillan, Entin & Serfaty, 2004]. Many teams implicitly coordinate and communicate using face-to-face communication and low-bandwidth voice channels [MacMillan et al., 2004]. We propose the use of physiological data as a means of inferring the internal state of team members, and that this information is useful to a team leader when making time-restricted decisions with limited information. We have developed a game to simulate dangerous situations and study their effects on team members' physiological states, and the consequence it has on the overall effectiveness of the team. In addition to displaying a player's "activation" level to a team leader, *PhysiRogue* uses the players' activation level to affect the outcome of gameplay, making the environment more "dangerous" when players are "activated".

PhysiRogue is based upon the *Rogue Signals* game, in which players move in the real world looking for hidden treasures while they are being chased in a virtual world overlay. These players, called *seekers*, communicate with each other over radio while a *coordinator* oversees their movements through a virtual world interface [Toups Dugas et al., 2005]. The intention of *Rogue Signals* is to enhance players' ability to implicitly coordinate their team, so that they can work in concert without excessive amounts of communication [Entin & Serfaty, 1999].

There are two differences between *PhysiRogue* and *Rogue Signals*. The first is that *PhysiRogue* gathers physiological signals unobtrusively from the players acting as seekers. These signals are processed and then used to create a visualization that indicates to the coordinator the relative "activation" level of each player and to affect game rules. The second difference is that *PhysiRogue* is a "sit-down" game, in which players move through keyboard input, rather than a location-aware game like *Rogue Signals*, in which players move by walking in the physical world, because of the current difficulty in interpreting the psychological significance of physiological signals during vigorous physical activity [Gratton, 2000].

PhysiRogue can be an experience in ways that differ from *Rogue Signals*, because each player's internal physiological state affects gameplay. Players are more likely to believe that virtual predators are chasing them when the predators can sense their internal state and react accordingly.

2 BACKGROUND

This section explores prior work, discusses team cognition, explains the physiological signals used and their meanings, and gives background on the original *Rogue Signals* game and how the *PhysiRogue* simulator is based upon it. Team cognition provides a means of looking at how teams as a whole "think" and informs the design of our system. Physiological signals measured from the body can be used to infer psychological state; when used in this way, they become psychophysiological measures. Finally, *Rogue Signals* is our location-aware game and the basis for *PhysiRogue*.

Systems that respond to users' "activation" levels have been studied extensively. [Balk, 2003] describes a biofeedback system to detect operator drowsiness and emotional involvement using electrodermal activity, general somatic activity, temperature, heart rate, and blood pressure. Tarnanas and Tsirgogianni (2003) explored ways to monitor the overall emotional level of a team during a simulated emergency and to communicate this level to individual team members. One group viewed a five-minute situation through virtual reality, while the other attempted to imagine the situation. Tarnanas & Tsirgogianni (2003) collected information about participant posture, electrodermal activation, heart rate, and speech tone. In the environment presented, the "stress" of one team member could affect the performance of another. Specifically, the mean stress level of the team was used to misbalance the navigation controls of the system [Tarnanas & Tsirgogianni, 2003].

2.1 Team Cognition

In strongly coordinated teams, it is possible to look at the team as an entity, with thoughts, communications, perceptions, etc. [MacMillan, Entin & Serfaty, 2004]. An important component of team cognition is implicit coordination, where team members are able to reduce their communication overhead and still work in a coordinated manner [MacMillan et al., 2004; Serfaty, Entin & Deckert, 1993].

PhysiRogue seeks to enhance a team's capacity for implicit coordination by unobtrusively collecting physiological signals and using them as a means of making the team's state visible, potentially improving situational awareness [Tarnanas & Tsirgogianni, 2003; Endsley, 1995]. By making the information visible, it is communicated without the need for speech.

2.2 Psychophysiological Measures

We use physiological signals from players to collect information about them while they play. These signals are processed together to generate an "activation" level: a psychophysiological measure that maps the physical state of the player's body to an interpreted psychological state.

Mandryk and Inkpen (2004) studied co-located collaborative game play using physiological signals. They looked at pairs of gamer students playing a commercial video game, either together or against a computer, and recorded physiological signals and facial expression [Mandryk & Inkpen, 2004]. They matched the mean signal values against subjective reports of fun, frustration, challenge, boredom, etc. [Mandryk & Inkpen, 2004]. Mandryk and Inkpen (2004) found that there is a correlation between some of the signals they measured and what the players reported.

There were several criteria for choosing which physiological signals to use in *PhysiRogue*: unobtrusive measurement, so that players would not be distracted or inhibited by the sensors while playing; measures that directly correlate to stress; and hardware constraints, which only allow for two signals to be measured. We chose to use electromyography (EMG) of the trapezius muscle and electrodermal activity (EDA) from the fingers, as these signals have been shown to indicate stress in subjects, can be measured easily, and satisfy our hardware constraints.

2.2.1 Electromyography

EMG measures the electrical signals emanating from muscle activation [Tassinary & Cacioppo, 2000]. The trapezius is a muscle on the back of the neck and shoulder that tenses readily when a subject is exerting mental effort [Tassinary & Cacioppo, 2000]. It also has the advantage of being a large muscle and in a location that affords easy application and removal of EMG sensors. Eason and White (1961) recorded EMG activity over certain muscles in the neck, back, and arm, including the upper and lower trapezius while subjects performed vigilance tasks. They found that the level of EMG activity, especially over the neck muscles, correlated to the effort a subject put into a task. Waersted and Westgaard (1996) found that attention-related activity could clearly be observed in the upper trapezius.

2.2.2 Electrodermal Activity

EDA reflects the dynamic conductivity of skin, normally measured with two electrodes attached on the hand or foot [Dawson, Schell & Filion, 2000]. The conductivity of the skin is directly related to sweat gland activity, which correlates to activation of the sympathetic nervous system [Dawson et al., 2000]. EDA is a very broad measure that does not correlate to any specific emotional response; instead it is a general indicator of the current state of the sympathetic nervous system. Any change in a subject's focus or emotional state will potentially trigger a change in EDA [Dawson et al., 2000].

2.3 *Rogue Signals*

Rogue Signals is an outdoor location-aware augmented reality game. Components of this game are simulated by *PhysiRogue*, including the wireless technologies that constrain the original game. In *Rogue Signals*, players wear computer systems that use global positioning systems (GPS) and 802.11x wireless (WiFi) networking to track the players' movements and communicate with a central game server. There are natural holes in the virtual reality created by these technologies: GPS satellite locks can be lost, and wireless connectivity is not always assured [Borriello, Chalmers, LaMarca & Nixon 2005]. As such, these seams have been incorporated into the design of the game, and players may utilize them as safe areas where they are "offline" [Borriello et al., 2005]. The seams are an integral part of the simulation game play, and the game's internal maps include information about the connectivity of the playing field. More information about *Rogue Signals* and its core rules can be found in [Toups Dugas et al., 2005].

3 "ACTIVATION" AFFECTING PLAY

Players in *PhysiRogue* are monitored for "activation" while they play, and this influences the game. In order to measure the "activation" levels of seekers, physiological sensors are used. *PhysiRogue* relies on EMG and EDA to infer the overall amount of "activation" the seekers are undergoing as they play the game. These signals are psychophysiological indicators of "activation": as a person is increasing engaged in the game, their shoulder/neck muscles tense and they start to perspire more.

3.1 Signal Processing

The seeker "activation" level is composed of four components, phasic EMG, phasic EDA, tonic EMG, and tonic EDA. Each of these may contribute between 0 and 1 additively to the level (resulting in a total level between 0 and 4). The phasic components of both types are processed in the same way, but with different sample and update rates, as are the tonic readings.

For the phasic measures, the signals are sampled at the rates and for the measure period listed on Table 1. Over the period, data points of the signal amplitude against the measurement time are recorded. At the end of the period, the correlation coefficient of the points is computed, and 1 minus the coefficient is used as the contribution to the "activation" level. This works as a way of counting how "jittery" the signal is from the player: the better the points fit a linear regression, the more stable the signal is, indicating that the player is more focused.

For the tonic measures, the same sample rates are used, but with a longer measurement period (see Table 1). The sample amplitudes are fed into a Kalman filter, to smooth the points [Welch & Bishop, 2001]. At the end of the period, the prediction from the Kalman filter is used to create an end point for a line running through the first point in the period. The slope of this line is then used to determine the contribution to the "activation" signal: if the slope is positive, a 1 is added, otherwise a 0 is added. The tonic measures determine if the player is slowly becoming more and more engaged over time by capturing gradual increases or decreases in the signal amplitudes.

Table 1. Summary of Physiological Signal Measurements

	Sample Rate	Measure Period
Phasic EMG	10 Hz	1 s
Phasic EDA	1/3 Hz	30 s
Tonic EMG	10 Hz	6 s
Tonic EDA	1/3 Hz	300 s

3.2 Game Logic Effects

In *Rogue Signals* the predators chased the seeker that was closest to them within the virtual space and the fastest moving (players have the option to walk, temporarily run, or sneak). In *PhysiRogue* we have altered the game logic to take into account the physiological state of each seeker in the determination of which one is "closest" to the predator. Each seeker's stress level adjusts the desirability of their avatar, and the predators chase the most desirable seeker. Each predator uses Equation 1 to determine the desirability of the seekers. Thus, a highly "activated", running, far-away seeker will be preferred over a less "activated", sneaking, nearby seeker.

$$desirability_{xy} = activation_x + \left(\frac{speed_x}{2}\right) + \left(\frac{1}{distance_{xy}}\right)$$

Equation 1. Desirability of seeker *x* by predator *y*; desirability ranges between 0 and 3, and must be greater than 1.5 in order for a predator to consider chasing.

3.3 Visualization

Besides informing the game logic, the "activation" measures gathered from each seeker are used to create a visual representation of player state for the coordinator. Each seeker's "activation" level is shown in a side information panel, along with other information about the player's state (see the right column in Figure **1**). This panel contains a variety of information about the player, including their color (used to differentiate the players visually), username, simulated GPS and WiFi connectivity, facing, and position. The "activation" level is represented as a color-contextualized bar graph with the GPS and WiFi connectivity meters. The bar graph becomes larger horizontally and runs through a spectral shift from green to red as the seeker's "activation" measure increases. More complex indicators were considered, however, we decided that a single bar graph was the best representation, because it is easy to quickly process.

4 SYSTEM ARCHITECTURE

4.1 Hardware

PhysiRogue is played as a "sit-down" game, which makes use of personal computers with keyboards and mice as the primary direct interface for the game. A central server, wired into the network, runs the game logic and tracks the seekers.

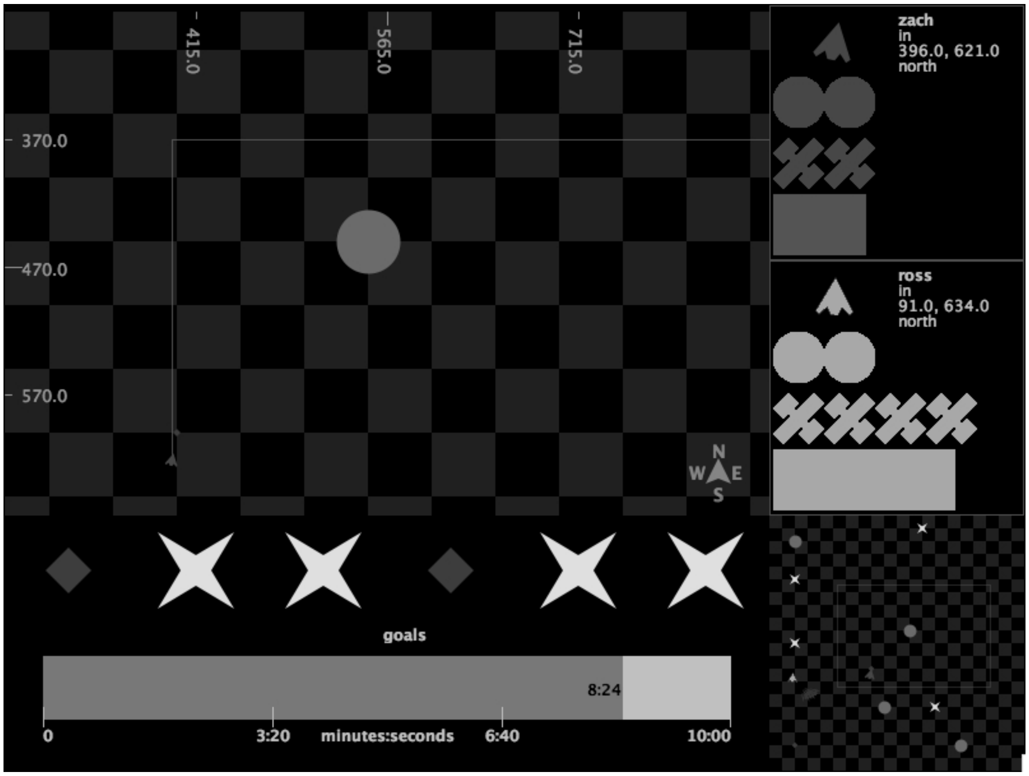

Figure 1. The Coordinator interface in *PhysiRogue*. In this example, the game's two seekers are zach and ross. Zach has a lower "activation" level (the rectangular bar-graph) than ross, and has just finished collecting a treasure.

Signals are also continuously captured from each seeker with a ProComp2 device [Biofeedback Equipment]. Each seeker's ProComp2 is set up to capture EDA and EMG signals. Once the raw signals are sampled, a custom C++ program interprets the serial communication from the ProComp2 and creates packets in the Open Sound Control (OSC) protocol to be transmitted to the central server. These packets are sent to the *PhysiRogue* server using user datagram protocol (UDP). On the server, the UDP packets are translated back into OSC and then parsed as data for the game. The data is matched to a player by checking the internet protocol address of the packets against those of the players.

4.2 Software

PhysiRogue uses several pieces of software developed at the Interface Ecology Lab. It is an extension of *Rogue Signals* (implemented in Java), which is built upon the Lab's libraries for data translation, logging, and networking. The code for interfacing with the ProComp2 is written in C++, and we have custom components to facilitate its network communication. Finally, we use the Oursland Java libraries for the Kalman filter (tonic signal interpretation) [Oursland].

Seekers run the game software on individual terminals where much of the game logic is resolved. They also run the software that interfaces with the ProComp2. These two programs (the *PhysiRogue* client and the ProComp2 driver) run at the same time, and communicate with the server over the network independently. Coordinators also run on remote terminals, and receive the most recent information about the game from the game server, including the "activation" levels of the seekers and other game state information.

The server handles coordinating all of the game logic, as well as synthesizing the "activation" level for each seeker. The server drives the artificial intelligence for the predators in the game, taking into account the "activation" level of the seekers.

5 DISCUSSION AND FUTURE WORK

We have discussed our design for serious digital game deeply involving psychophysiological measures. *PhysiRogue* leverages these measures both to enhance situational awareness and to make the game experience more immersive. We are currently designing experiments around the *PhysiRogue* platform to evaluate how effective it is at improving immersion and developing coping strategies.

Although the original *Rogue Signals* uses GPS to enable location-aware game play, the implementation of *PhysiRogue* uses traditional keyboard input in a "sit-down" setup. This change was necessitated by the fact that physical exertion has a significant effect on human physiology, causing all of the signals used to activate [Gratton, 2000]. This makes it extremely difficult to differentiate from changes in physiology related only physical exertion and those due to a change in psychological state [Gratton, 2000]. In the future, it may be possible to use other sensors to determine physical activity during play, and use that information to isolate the psychological factors in the signals.

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