A.M.B.E.R. Shark-Fin:
An Unobtrusive Affective Mouse

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***Abstract*—Analysing, measuring, recognising and exploiting emotion is an attractive agenda in designing computer games. The current devices for imputing physiological modalities are usually awkward to wear or handle. Here we propose a Shark-fin Mouse which streams three signals in real-time: pulse, electrodermal activity (EDA, also known as galvanic skin response or GSR) and skin temperature. All sensors are embedded into a fully functional computer mouse and positioned so as to ensure maximum robustness of the signals. No restriction of the mouse operation is imposed apart from the user having to place the tip of their middle finger into the Shark-fin hub. Boundary tests and experiments with a simple bespoke computer game demonstrate that the Shark-fin Mouse is capable of streaming clean and useful signals.**

***Keywords*-Interaction device; Affective gaming; Physiological sensors; Biometric feedback; Emotion**

I. INTRODUCTION

The video game industry, formally known as the interactive entertainment industry, has enjoyed perpetual growth since its foundation [8]. Video games are now experiencing the same level of financial-investment as seen in the film industry. The video game industry is among the largest entertainment industry worldwide, taking an estimated global income exceeding $50 billion in 2011 [15]. As computer systems have developed more processing power, video games have become more realistic and accompanied by the ever growing use of complex interactive devices, ranging from vibrating controllers [22] to fully tactile haptic feedback [23].

However, video games require more than representational graphics and tactility to be engagingly realistic. Video game environments also require greater humanlike emotive attributes or interactions between players and video game characters. Artificial intelligence (AI) attempts to bring the individuality of emotive human characteristics to human computer interactions (HCI). It has long been asserted that emotions are an important part of the human psyche and play a vital role in human communications [6]. The field Affective Computing (AC) has seen a dramatic rise in popularity over the past decade [24] [4] [25] permeating various disciplines such as computer science, electronic engineering and psychology. Growing on this trend, Affective Gaming (AG) is receiving significant consideration from academic and industrial fields [20] [3] [2] [12]. However, there is still no consensus on the best modalities and methods to use to collect emotional data. Many modes have been considered for use in gaming environments, see table I.

Table I
AFFECTIVE GAMING MODALITIES AND THE CURRENT CONTRIBUTORS.

	Reference	Modalities	Game
[2]	Ambinder	HR, eye movement, EDA, EEG, pupil dilation, EOG, posture, gesture, voice, face expression, respiration	Left4Dead2 Portal2
[3]	Bonarini	EDA, HR, pressure, temperature, gyroscope	Racing game
[5]	Chanel	HR, EOG, GSR, EEG, respiration, temperature	Tetris
[7]	Drachen	EDA, HR	Prey, Doom3, Bioshock
[9]	Gilleade	HR	Action based
[10]	Hoogen	Control tilt, pressure	Racing game
[11]	Jannett	Time, eye movement	HalfLife
[12]	Jones	Vocal cue/pitch/intonation, speech rate/volume	HalfLife Mod
[16]	McQuiggan	HR, EDA	Treasure Hunt (Source)
[21]	Nacke	EDA, EMG	HalfLife2 Mod
[26]	Rani	HR, EDA	Pong
[27]	Saari	User control knobs	Generic
[29]	Sykes	Game pad pressure	Space Invaders
[30]	Tijs	HR, EDA, respiration	Pacman
[31]	Tognetti	EDA	Racing game

Abbreviated terms: Heart Rate (HR), Electrodermal Activity (EDA), Electrooculography (EOG), Electroencephalography (EEG), Electromyography (EMG).

Emotions can be detected using a myriad of sensors. These sensors can be broadly divided into two distinct groups: behavioural and physiological, see figure 1. Behavioural recognition systems typically use cameras, microphones, Human Computer Interaction (HCI), and re-

ISBN: 978-1-61208-250-9

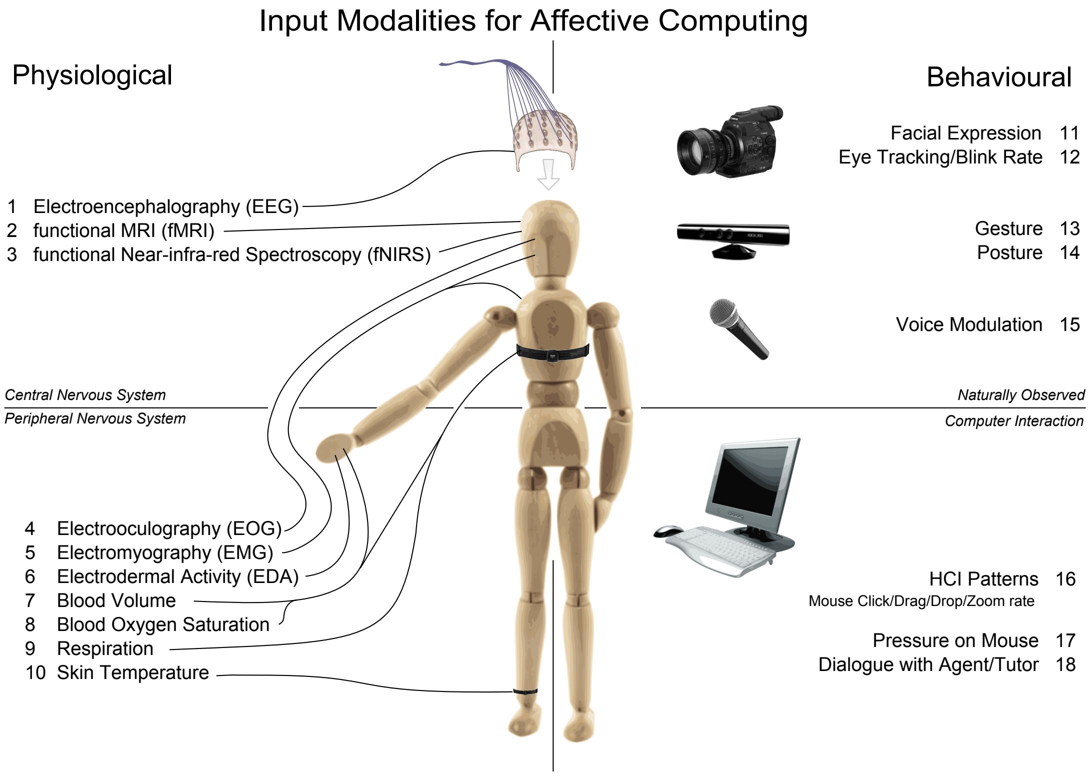

Figure 1. An illustration of the modalities for measuring emotion.

cently 3D depth sensors (Microsoft Kinect). Behavioural-based emotion recognition systems are generally unobtrusive; however, various facets of emotion are not always accurately displayed externally, particularly noted across different cultures [17]. Physiological patterns of emotion are less susceptible to cognitive artefacts; therefore give a truer representation of experienced emotion state [13]. Physiological recognition systems use various electrodes or sensors to detect changes in the body's peripheral nervous system [13]. However, physiological systems require sensors that are in direct contact with the user's skin or are attached to the user. This raises the questions of wearablity and comfort [3], particularly when introducing such a system or device to a gaming environment. Principally, video game input-devices are expected to add to the player's experience and not detract from the player's enjoyment [2].

For an affective interaction device to be adopted, it should be unobtrusive. The device should not hinder the player's enjoyment and should not handicap the player or the type of game that can be played. It should be intuitive to use. A player should not have to guess what the device should do. In addition, the set-up procedure, if any, should be short and straightforward. The player may get irritated by a delayed start of the game or by having to strap a device to their wrist, finger, chest of head.

One particular problem is the need to keep the physiological sensors still when in use, due to the high levels of amplification often needed to pick up signals from the body. Chanel et al [5] chose Tetris as a game that requires only one hand to play, so that the signals can be measured from the resting hand. Similarly, McQuiggan et al [16] relied on a static hand while the subject played Treasure Hunt, a bespoke HalfLife2-Source-engine driven game. However, having one hand tied in sensors and having to keep it still throughout the game may spoil the experience.

Many systems use sensors placed away from their respective amplifiers and analogue to digital converters; thus the signals are then carried through long (12"+) wires to be processed. Therefore, artefacts introduced due to cables-noise are amplified. To overcome this limitation, it would be advantageous to integrate the sensors and the amplifiers within a device already being utilised to control the game. Special care has to be taken when designing such a device, to ensure that the movements of the hand controlling the device are not affecting the sensor outputs.

During the 2011 Game Developers Conference, Mike Ambinder [2] highlighted the difficulty of obtaining a reliable pulse signal when actively playing a computer game. Obtaining a robust heart rate signal by using a photoplethysmograph (PPG) is challenging as it is highly sensitive to movement artefacts. For this reason, to apply a PPG to a game controller, a mechanism is required to hold the sensor/finger still during use.

Research carried out by Bonarini et al [3] on a novel device attached to the player's head revealed several additional problems. Participants reported that the device stimulated excessive sweat, took too long to attach and was not very intuitive to use.

Taking all into account, we believe that there is a niche for a simple and unobtrusive device which can deliver some of the most important physiological modalities for emotion recognition in real time. This paper proposes such a device in the form of a computer mouse. Our device attempts to include pulse rate through a "shark fin" hub implemented as a small alteration of a standard computer mouse, an electrodermal activity (EDA) sensor and a infrared temperature sensor.

The remainder of this paper describes the basic AMBER Shark-fin Mouse set-up, together with the individual signals used. We review how each signal was tested for accuracy, both individually and as a complete system. The experimental set-up and video-game is discussed, followed by the results and finally our conclusion.

II. THE SHARK-FIN MOUSE

The humble mouse was first introduced as a prototype as early as 1963, by Douglas Engelbart and Bill English of the Stanford Research Institute. Since its inception it has formed the backbone of all HCI. The concept of an emotional mouse has been explored before [14]. However, limitations of the designs discussed in the Introduction hampered successful adoption of such devices.

The Advanced Multi-modal Biometric Emotion Recognition (A.M.B.E.R.) project was developed to create a low-cost, unobtrusive, physiology sensitive system, incorporating a minimal set of physiological sensors with a high potential for affect detection. The AMBER system also incorporates EEG and combines both hardware and software algorithms that support affect detection. The AMBER Shark-Fin biometric mouse, being part of the AMBER project, is a fully functional computer mouse which can output three physiological signals in real time. It allows biometric data to be collected as the player naturally participates in a video game. This allows the device to seamlessly blend into the PC gaming environment.

The AMBER prototype produces two digital data-streams. The first is the mouse position data and the second is the physiological affective data. Both mouse and data signals can be read by a single computer or split into two separate computer systems, for research purposes. For this paper, one computer was used. To enable a mouse-driven emotion interaction device to be functional, a novel hardware approach and design was needed. Preliminary testing demonstrated that the middle finger was the optimum choice for a strong blood flow volume needed by the photoplethysmograph (PPG) heart rate sensor. We observed that resting the wrist on a desk while holding the mouse decreases the blood flow in the middle finger. It was observed that the amplitude of the peaks in the pulse signal fell to a quarter of their initial values. To overcome this issue, the mouse was designed so as to provide support for the wrist (figure 2).

To maintain the mouse's full functionality, the scroll-wheel was moved from the centre finger (now being used for a pulse) to the right or left side (depending on preference), to be operated by the thumb, as shown in figure 2. To assist in the stabilisation of the middle finger, and to house both active component of the PPG, an arched housing was designed in the centre of the mouse, in place of a standard scroll-wheel. This also created a dark chamber to comply with the PPG's optical requirements.

The EDA sensors required the player to place a continuous pressure on the electrodes in order to prevent artefacts. Typical EDA devices place the electrodes between two fingers of the hand. Since the fingers move during clicking the mouse, the sensors were designed to connect with the palm where the least amount of movement was likely. Two 1cm x 1cm square electrodes were situated 1cm apart on the back of the mouse casing (figure 2).

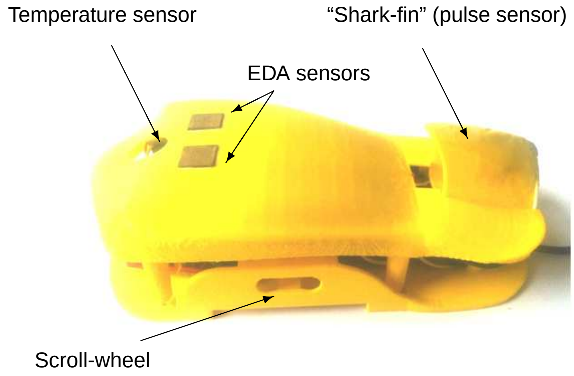

Figure 2. AMBER Shark-fin Mouse

To take account of any heat build-up invoked by thermal contact, a contactless IR thermometer was used. The temperature sensor was situated where it would receive a continuous and steady air convection from the hand. To assist further in heat build-up removal, the mouse casing was designed to be open, allowing air to circulate the circuitry, and the heat to dissipate naturally.

A. Signals

Many studies confirm the importance of combining the use of several physiological sensors to detect affect in video games, as seen in table I.

The variation in heart rate is a good indicator of stress and anxiety [13]. Using optical volumetric sensors known as a photoplethysmograph, the waveform of the heart's pulse can be detected through a thin part of the body, typically the finger or ear. The received signal produces a sharp peak in the waveform for every beat of the heart. Shelley and Shelley [28] demonstrate the wealth of information available through a photoplethysmograph sensor.

Electrodermal Activity (EDA), also referred to as Galvanic Skin Response (GSR), Skin Conductance Response (SCR) or Psycho Galvanic Reflex (PGR), measures the variance in electrical conductivity through the surface of the skin. EDA readings are effected through the sympathetic nervous system, making it a good indicator of stress and anxiety. EDA suffers with latency, with a delay of approximately one second for a response to be evoked, followed by approximately three seconds for the effect to dissipate. It is among the most basic and low cost physiological modalities available, and is widely used in physiological emotion recognition, including video games (table I).

Body temperature is affected by emotion, specifically joy, anger and sadness [18][19], and has been used for emotion recognition in video games. Temperature sensors fall into two general types: contact and non contact. Both types are sensitive to movement, which can introduce inaccuracies in the data collected. Movement is an important issue in the process of an active game play; hence, the positions of the sensors have to be chosen carefully.

Temperature is measured in Fahrenheit. Other units of measure are 3.3 volts used for both EDA and pulse data, capped by rapid-prototyping board FEZ-mini; measuring 1000 units per volt. Thus the minimum value will always be a positive integer or zero and the maximum value cannot exceed the integer value of 3,300. We avoid the typical contamination and artefacts through using capacitors in a smoothing circuit, as well as short cables and on-board computation.

III. EVALUATION

Prior to running experiments, each component was individually evaluated to measure its performance against the expected output values. Each component was tested for minimum and maximum range and temporal responsiveness.

1) *Temperature:*

The temperature sensor was expected to accurately respond to variances in the temperature of the skin. To test the range of the sensor, three objects with extreme variations in temperature where presented to the IR thermometer's 90° field-of-view (FOV), at an approximate distance of 5.5mm. The objects used were ice, a hot coffee pot and a human hand. The ice was taken from the freezer drawer of a fridge. Due to the reflective properties of ice, the ice-block was masked with a thin layer of paper. This had the expected effect of marginally raising the surface temperature. The same approach was used on the coffee-pot, again slightly altering the temperature. However, these alterations did not detract from the aim of the test, which was to measure the response of the thermometer to temperature changes. The objects where presented one after the other to the IR-thermometers FOV. The system collected the temperature data for 10 seconds and then paused for a key press; while the next object was selected. The pause was introduced to eliminate any danger when moving the hot-coffee-pot, while maintaining a 30 second data window. During this pause, the next object was presented, then the data recording resumed with key press.

After all three objects had their temperature read, the data was analysed, for range accuracy. Figure 3 shows the temperature range over the 30 second interval. The expected temperatures of all three objects can be seen in table II.

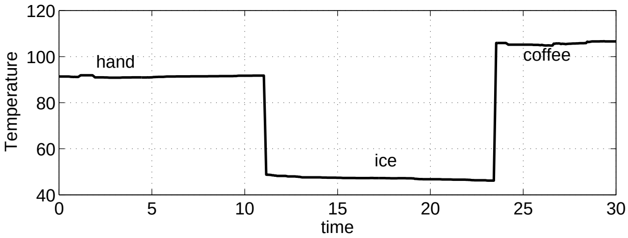

Figure 3. IR-Temperature 10s hand, 10s ice, 10s coffee

Table II
TEMPERATURE RANGE (°F)

Object	Minimum	Maximum	Mean observed
Hand	55	99	91.5
Ice (surface)	-30	50	48.7
Coffee	68	170	105.5

2) *Photoplethysmograph:*

The photoplethysmograph sensor comprises of a 3mm infrared (IR) light emitting diode (LED) and a 3mm phototransistor. The sensor is required to optically detect blood volume, entering and leaving the middle finger. To test the functioning range of the sensor, a dense light blocking/absorbing card was used to completely block the light emanating from the IR-LED. When in situ, no light was able to enter the phototransistor and therefore no current should flow through the phototransistor. When the card was removed, the full range of light was passed to the phototransistor and the maximum current should be produced. The minimum and maximum voltage levels are 0-volts and 3.3-volts, respectively. The 3.3-volt is governed by the 3.3-volt analogue input cap of the devices circuitry. The card was placed in front of the sensor for approximately 5 seconds then removed for 5 seconds repeatedly, for a total duration of 30 seconds. Figure 4 depicts the recorded data.

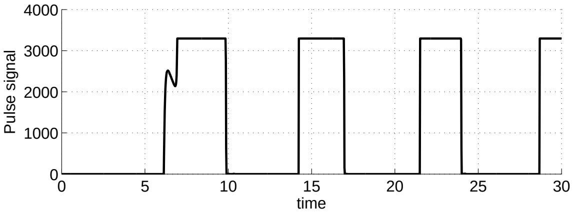

Figure 4. Heart Rate, 30 sec with 5sec covered 5sec uncovered repeatedly

3) Electrodermal Activity (EDA): To assess the function of the EDA sensors, a simple hand test was conducted. The palm of the right hand was placed on and off the device making contact with the two sensors, at intervals of approximately five seconds. The test began with the sensor untouched. This procedure was repeated for 30 seconds. Figure 5 demonstrates the unloaded (untouched) and loaded (touched) EDA circuit and the maximum and minimum range; 2552 and 196 respectively. This demonstrated the system's ability to respond during natural use.

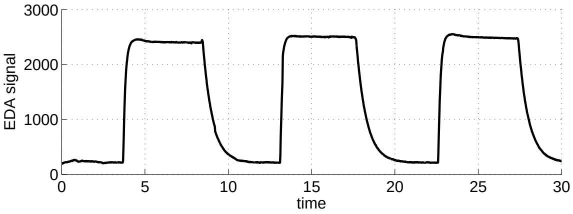

Figure 5. Electro-dermal activity, 30 sec with 5sec off 5sec on repeatedly

4) Complete system test: After ascertaining the minimum and maximum ranges, a trial was made to determine the ability of the sensors at detecting all signals together when applying the hand onto the device. For this test, all three sensors were recorded without any contact for approximately 10 seconds. After that, the right hand was placed on the mouse, covering both EDA and temperature sensors with the palm of the hand, and the middle finger was placed inside the photoplethysmograph cover. Figure 6 demonstrates the system's ability to pick up all three signals simultaneously. As expected the heart signal takes several seconds for the capacitors driving the amplification to find the pulse. After that, the pulse is cleanly detected. The EDA responded as expected with a small rise in current as soon as the sensors made contact with the skin. Similarly, the temperature sensor detected the change in temperature, from room temperature to skin temperature, almost immediately.

IV. EXPERIMENTAL VIDEO-GAME

After completing the individual sensor function tests, a simple video game was created to test the device's ability to detect basic affect in a gaming environment. The game involved moving the mouse over a randomly appearing white

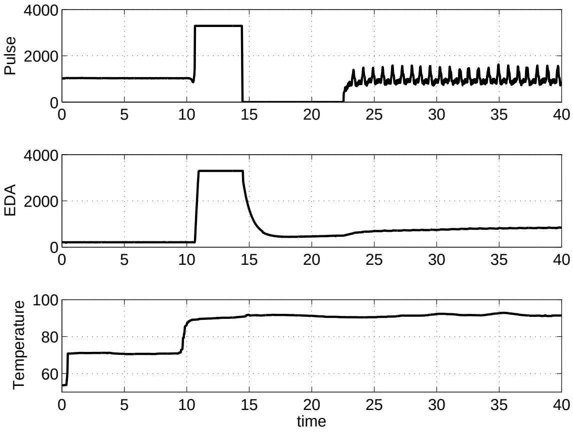

Figure 6. Heart rate (top), EDA (middle), Temperature (Bottom)

square, while avoiding a black square appearing in a straight path to the white square. The game set-up and the layout of the screen are shown in Figures 7 and 8, respectively. The game was specifically developed to invoke mild levels of stress. This was done by limiting the player's ability to freely move the mouse, while at the same time maintaining a need to move the mouse as quick as possible to gain a higher score within the countdown period. To achieve this, a mouse speedometer was created that limited the player's ability to score. If the mouse was moved at normal speeds, the scoring potential was reduced. If the players move the mouse quickly the energy level was reduced. If the energy bar became depleted, one of three lives was lost (Figure 8). The game ended after the counter reached zero or all three lives were lost.

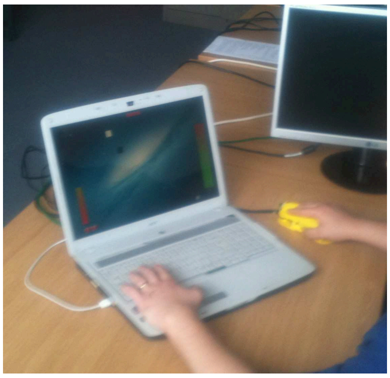

Figure 7. Experimental video-game layout

The data was recorded using two files. The first stored the computer game event data. The second recorded the biometric sensor data. For each file an epoch time-stamp was stored along with each iterative data point to enable temporal comparisons of the game-play and biometric data. To begin the experiment, the player placed their hand on the mouse and were given the rules of the game. The game commenced

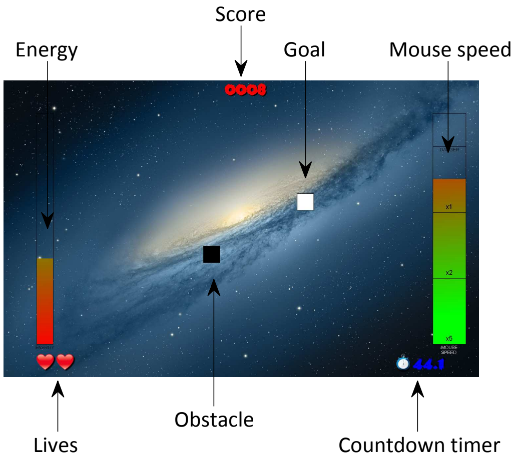

Figure 8. A screen shot of the experimental video-game.

and ran for a total of 90 seconds. During game-play, the state-of-play and game triggered-events were recoded to a text file, approximately every tenth of a second. Similarly the raw signals from the biometric sensors were collected through MATLAB along with the epoch time stamp, at approximately two tenths of a millisecond.

V. RESULTS

The results of the trial highlight the effectiveness of the device at measuring clean physiological signals from a fully functional mouse, while playing a video-game. Figure 9 demonstrates the quality of the signals achieved during a live game trial. To test the potential of the proposed device at emotion recognition, we carried out off-line analyses of the data. The data consisted of the three variables (Pulse rate, GSR and skin temperature) measured along the whole approximately 90-second long game run. Each value in the sequence was the average of the previous 3 seconds of the signal. The pulse signal was transformed into pulse rate by the following steps:

1) The raw curve was smoothed with a window of 1/2 a second and then with a window of 1 second.
2) The locations of the peaks in the signal were identified.
3) The intervals between the subsequent peak locations was used to approximate the heart rate.
4) A linear interpolation was used to set the heart rate values between the peaks.

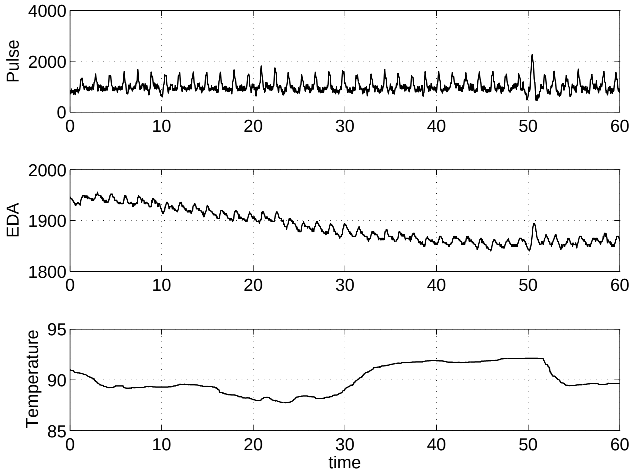

Figure 9. Typical physiological data output

Two categories were formed. Assuming that the player is in state ‘Calm’ during most of the game run, we hypothesised that certain situations would provoke a negative state which we labelled ‘Agitated’. In this experiment, a state was labelled as ‘Agitated’ if all of the following held:

- The speed of the mouse exceeds a threshold of 200.
- The countdown clock indicates less than 25 seconds left.
- The player has lost at least one life thus far.

For example, game #3 produced 4129 data points, 56 of which were labelled ‘Agitated’ (3.78%), while the remaining points were labelled ‘Calm’. After removing the outliers (GSR signal less than 500 and temperature signal less than 50), and concatenating all 20 games, we obtained a labelled data set with 60,684 data points with 5332 data points (8.79%) in class ‘Agitated’. The task of developing a proper real-time classifier for such an imbalanced data set is one of our future lines of research. Here we are interested to find whether there are differences between the distributions of the two classes. A histogram was calculated for each of the three features and each class. The polygons of these histograms are shown in Figures 10, 11, and 12.

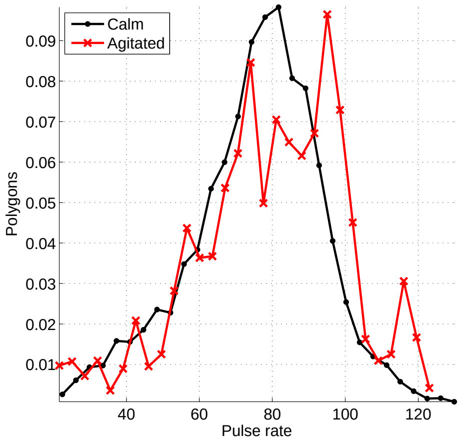

Figure 10. Polygons for classes ‘Calm’ and ‘Agitated’ for the Pulse Rate.

The polygon for class ‘Agitated’ has a more jagged appearance than the one for class ‘Calm’ because it was calculated from much fewer data points. More importantly, however, all distributions for class ‘Agitated’ are slightly

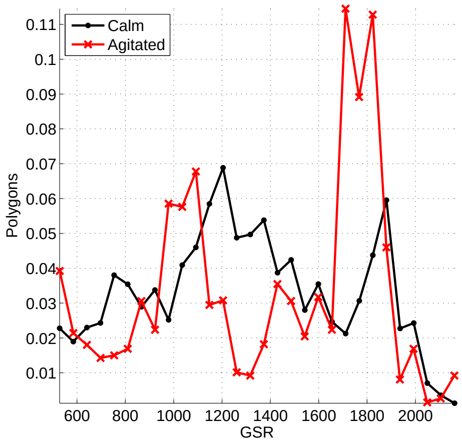

Figure 11. Polygons for classes ‘Calm’ and ‘Agitated’ for the GSR.

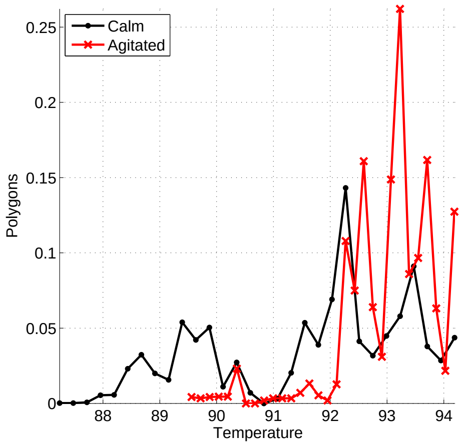

Figure 12. Polygons for classes ‘Calm’ and ‘Agitated’ for the Skin Temperature.

shifted to the right, indicating increased Pulse Rate, GSR and Skin Temperature. These findings are consistent with increased level of anxiety [13], which demonstrates the ability of the proposed device to output genuine and useful signals.

VI. CONCLUSION

In this study, we identified the need for a simple input device capable of streaming real-time physiological data. We proposed a novel solution, named the “Shark-fin Mouse” (due to the shape of the hub housing the plethysmograph). The mouse outputs three signals: pulse, electrodermal activity (EDA, often termed Galvanic Skin Response or GSR) and the skin temperature. Compared to the existing devices, the Shark-fin Mouse has the advantage of producing clean and reliable signals in real time in a subtle way. The Shark-fin mouse retains full functionality as a mouse, while hosting sensors positioned so as to ensure maximum robustness of the signals. Our tests and experiments demonstrated that the Shark-fin Mouse is capable of streaming the three physiological signals during a real game play.

The proposed device opens up interesting future research avenues. First, the Shark-fin Mouse was intended as a part of the A.M.B.E.R. project. The system will include additional affective modalities such as EEG and facial expression recognition. Second, we aimed at designing a device with a wide range of applications, including psychology, medicine, business, and entertainment industry. Data can be collected in different experimental environments. Due to the ability of the device to stream data in real time, experiments with emotional feedback can be carried out. The device can be turned into a useful gaming accessory because of its low cost and simplicity of concept and operation. It has to be mentioned that the Shark-fin Mouse is only a prototype at this stage. However, with the rise of the interest in affective computing we are planning to work towards wider academic and commercial deployment of the Shark-fin mouse.

ACKNOWLEDGMENT

This project has been supported by the Coleg Cymraeg Cenedlaethol www.colegcymraeg.ac.uk.

REFERENCES

[1] M. Ambinder. Biofeedback in gameplay: How valve measures physiology to enhance gaming experience. Internet, 2011. Last access 24 Dec 2012.

[2] M. Ambinder. Biofeedback in gameplay: How valve measures physiology to enhance gaming experience. Game Developers Conference, 2011. Last access 24 Dec 2012.

[3] A. Bonarini, F. Costa, and M. Garbarino. Affective videogames: the problem of wearability and comfort. *SpringerLink: Human-Computer Interaction. Users and Applications*, 6764:649–658, 2011.

[4] R.A. Calvo and S. DMello. Affect detection: An interdisciplinary review of models, methods, and their applications. *IEEE Transactions on Affective Computing*, 1(1):18–37, 2010.

[5] G. Chanel, C. Rebetez, M. Bétrancourt, and T. Pun. Boredom, engagement and anxiety as indicators for adaptation to difficulty in games. In *Proceedings of the 12th international conference on Entertainment and media in the ubiquitous era*, pages 13–17. ACM, 2008.

[6] Charles Darwin. *The Expression of the Emotions in Man and Animals*. Murray, J., 1872.

[7] A. Drachen and A.L. Pedersen. Correlation between Heart Rate , Electrodermal activity and player experience in first-person shooter games. *Heart*, pages 49–54, 2009.

[8] Entertainment Software Association (ESA). Essantial facts about the computer and video game industry 2011. ESA E3 2011, 2011.

[9] K.M. Gilleade and J. Allanson. A Toolkit for exploring affective interface adaptation in videogames developing an affective videogame. *Proceedings of HCI International*, 2:370–374, 2003.

[10] V.D. Wouter M Hoogen, A.I Wijnand, and Y.A.W. de Kort. Effects of sensory immersion on behavioural indicators of player experience: movement synchrony and controller pressure. *digraorg*, 2009.

[11] C Jennett, A.L. Cox, P. Cairns, S. Dhoparee, A. Epps, T. Tijs, and A. Walton. Measuring and defining the experience of immersion in games. *International Journal of Human-Computer Studies*, 66(9):641–661, 2008.

[12] C. Jones and J. Sutherland. Acoustic emotion recognition for affective computer gaming. *Affect and emotion in human-computer interaction: from theory to applications*, 4868:209, 2008.

[13] S. Kreibig. Autonomic nervois system activity in emotion: a review. *Biological psychology*, 84:394–421, 2010.

[14] Wenhui Liao, Weihong Zhang, Zhiwei Zhu, and Qiang Ji. A Decision Theoretic Model for Stress Recognition and User Assistance. *Systems Engineering*, pages 529–534, 2004.

[15] I. Livingstone. 'seismic shift' in computer education. BBC News, November 2011. Last access 24 Dec 2012.

[16] S.W. McQuiggan, S. Lee, and Lester J.C. Predicting user physiological response for interactive environments: An inductive approach. In *Proceedings of the 2nd Artificial Intelligence for Interactive Digital Entertainment Conference*, 2006.

[17] B. Mesquita, N.H. Frijda, and K.R. Scherer. Culture and emotion. *Handbook of cross-cultural psychology*, 2:255–297, 1997.

[18] H.G. Mittelmann, B. Wolff. Effective states and skin temperature: experimental study of subjects with ”cold hands” and raynaud's syndrome. *Psychosomatic Medicine*, 1:271–292, 1939.

[19] H.G. Mittelmann, B. Wolff. Emotions and skin temperature; observations os patients during psychotherapeutic (psychoanalytic) interviews. *Psychosomatic Medicine*, 5(3):211–231, 1943.

[20] L E Nacke, S Stellmach, and C A Lindley. Electroencephalographic Assessment of Player Experience: A Pilot Study in Affective Ludology. *Simulation & Gaming*, 41(41):1–24, 2010.

[21] L.E Nacke and C.A. Lindley. Affective .ludology, flow and immersion in a first-person shooter: measurement of player experience. *Loading...: The Journal of the Canadian Game Studies Association.*, 3 (5)(5):21, 2009.

[22] Nintendo. Rumble pak. www.nintendo.co.uk, 2012. Last access 24 Dec 2012.

[23] Inc Novint Technologies. Novint falcon. www.novint.com, 2012. Last access 24 Dec 2012

[24] R.W. Picard. *Affective computing*. The MIT press, 2000. Last access 24 Dec 2012

[25] R.W. Picard. Affective computing : from laughter to IEEE. *Affective Computing, IEEE Transactions on*, 1(1):11–17, 2010.

[26] P. Rani. Maintaining optimal challenge in computer games through real-time physiological feedback mechanical engineering. *Pulse*, 2005.

[27] T. Saari, N. Ravaja, J. Laarni, and M. Turpeinen. Towards emotionally adapted games based on user controlled emotion knobs. *Human Factors*, 2005.

[28] K Shelley and S Shelley. Pulse oximeter waveform: photoelectric plethysmography. *Monitoring: Practical Applications for Anesthesia*, pages 420–428, 2001.

[29] J. Sykes and S. Brown. Affective gaming. *CHI 03 extended abstracts on Human factors in computing systems CHI 03*, page 732, 2003.

[30] T Tijs, D. Brokken, and W. Ijsselsteijn. Dynamic game balancing by recognizing affect. In *Proceedings of the 2nd International Confer- ence on Fun and Games.*, 2008.

[31] S. Tognetti, M. Garbarino, A. Bonarini, and M. Matteucci. Modeling enjoyment preference from physiological responses in a car racing game. *Computational Intelligence and Games (CIG)*, pages 321–328, 2010.