A WIRELESS BODY-WEARABLE SENSOR SYSTEM FOR DESIGNING PHYSICALLY INTERACTIVE VIDEO GAMES

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Keywords: eHealth, Exercise, Obesity, Wireless Systems, Games for health.

Abstract: This paper presents a novel wireless body-wearable sensor system to control video games, making the user more active while gaming. Our system uses data gathered from accelerometers and pressure sensors worn by the player, to detect specific movements, which are used as in-game motion controls. Our system is designed to detect different types of motions, and with proper integration into any game, will ensure that the player will constantly remain active. To demonstrate, our system was adapted to a popular soccer game that uses the player's various leg motions as replacements for keyboard strokes. The result is a higher heart rate and calorie burn for the user, making the overall experience significantly healthier and more active than analogous sedentary video games.

1 INTRODUCTION

Video games continue to be an ever-growing and tremendous source of revenue for companies, and entertainment for people. In the past year alone, millions of games have been sold and millions of hours of time have been spent playing them. In January 2010, Activision Blizzard Inc. reported that Call of Duty: Modern Warfare 2 had earned more than $1 billion in worldwide sales since its release that previous November, and earning more than half of that in only its first five days of availability (Activision Blizzard Inc., 2010). Likewise, Electronic Arts Inc.'s FIFA Soccer 10 had already sold over 4.5 million units, making it the fastest selling sports video game in the world; also averaging three million games played online per day(Electronic Arts Inc., 2009).

With a multitude of hours spent playing video games and watching television, questions have emerged with respect to the obesity level in the country, specifically children, and the contribution that sedentary activities have. This obesity level in the United States manifests itself in many ways, including the increase in adult waist size from 1998 to 2004 by 40.5% (Li et al., 2007). Projections of the year 2030 places approximately 90% of all American adults as overweight or obese, of which at least half of those would be classified as obese (Wang et al., 2008). This trend is not limited, however, to adults; children are increasingly becoming overweight and obese as a result of further increased sedentary behavior associated with television watching and video game playing (Robinson, 1999)(Stettler et al., 2004)(Rey-Lopez et al., 2008). Specifically with regards to video game use, the prevalence of obesity increased from around 5% in children spending no time playing video games to over 20% when playing three hours per day (Stettler et al., 2004).

The potential to target video game use and develop active and healthy video games is a field with great potential. The use of sensor networks worn on the body as input devices has achieved success even in simple pose-based game control systems (Whitehead et al., 2007). The Nintendo Wii's hand-held accelerometer-based motion controller has led to 70.9 million units in lifetime sales(Nintendo Co. Ltd., 2010). Wii Fit, a game that comes with a balance board and various games and exercises targeted at improving fitness, has sold 21.82 million units since its release(Nintendo Co. Ltd., 2009). This result illustrates the growing popularity and potential for healthy video games, especially those that can induce exercise activity (Brown, 2006). However, the Wii remote is limited to only hand-held activity, and the balance board can only sense weight. In fact, activity on the Wii can be generated with little to no movement if desired. Most games, including those on the Wii, use gesture based movements, stance based movements and a few use continuous activity monitoring (Stach et al., 2009).

Mortazavi B., Hagopian H., Wodbridge J., Yadegar B. and Sarrafzadeh M..
A WIRELESS BODY-WEARABLE SENSOR SYSTEM FOR DESIGNING PHYSICALLY INTERACTIVE VIDEO GAMES.
DOI: 10.5220/0003159100620069
In *Proceedings of the International Conference on Biomedical Electronics and Devices* (BIODEVICES-2011), pages 62-69
ISBN: 978-989-8425-37-9

In this paper, we will show that the use of a body-wearable sensor network can help achieve video game control to promote actual exercise activity. Using sensors to capture gestures(Jung and Cha, 2010) or pose-based movements (Whitehead et al., 2007) have shown that monitoring of basic controls can be performed. Our system, however, will take this a step further and monitor not only continuous active controls but the strength of these movements as well. Sports games, in particular, are a well-suited target for such a system, with previous work in sports games (Mueller et al., 2007) and general activity recognition for such sports applications (Avci et al., 2010) having been done. Such exercise games are not only limited in scope, but restricted by the platform and peripherals needed to play. For example, some systems require an exercise bike (Mokka et al., 2003), while others require using a soccer ball and camera to capture only the ball movement and not the player movement (Mueller et al., 2007). Indeed, the number of continuous activity monitoring systems applicable to a wide range of games is quite limited (Stach et al., 2009) and our system targets this area. The system we have designed allows for the body to become an active and continuous motion controller and we show how such a controller can be adapted to games, particularly sports games; such a system can actually promote physical health through exercise.

The rest of the paper is organized as follows. Section 2 gives a brief description of related work in terms of body-wearable sensor networks and the potential health benefits of targeting television and video gaming. Section 3 contains our system design along with its use as a motion controller for a popular soccer game. Section 4 summarizess the health benefits of our system. Section 5 discusses future work and Section 6 concludes our study.

2 RELATED WORK

Several research projects extend beyond the limitations of gesture or stance based body control for games and extend to body-sensor networks for health promotion. Each project takes a unique approach to help target a specific health goal while our system extends beyond a single goal and can work for a multitude of situations.

2.1 No Pain no Game

No Pain No Game is a home automation system developed to monitor the physical activity of children throughout the day in order to regulate the time spent watching television or playing electronic games (Hsiao et al., 2010). The system uses an accelerometer-based pedometer to calculate the Metabolic Equivalent of Task (MET) in order to measure activity. It then uses this data to control power outlets and manage electronic activities such as television viewing or video gaming. No Pain No Game attempts to address and limit the time spent playing video games, while our work makes that spent time healthier.

2.2 Games for Stroke Rehabilitation

A collaboration between Washington University in St. Louis and University of California, San Diego produced a game customized to help stroke rehabilitation through the use of a tracking web-camera and on-body accelerometers built into Wii remotes (Alankus et al., 2010). This is a prime example of a class of games targeted to a specific subset of controls. Multiple sensors were used in this project to monitor single or multiple muscles for associated movements specifically related to stroke therapy exercises. By placing the Wii-mote in specific areas around the arm, they are able to monitor shoulder, elbow, or wrist movements and exercise, and use these inputs for games targeted to stroke rehabilitation exercises. Our system improves on this idea and extends the control from a subset of exercises to a range of motions for various activities.

2.3 Health Games

Research by Thompson et. al. shows a different direction in the healthy video game domain by targeting the game design instead of the game control, in making a game specifically built to address Type 2 Diabetes (Thompson et al., 2008). Their goal was to build a fun game whose content addressed dietary issues and diabetes understanding. Their game is played with a standard keyboard and their work focuses on the story and game content. The game is intended to educate the user, but the user remains sedentary while playing.

2.4 Dance Dance Revolution

The best example of a popular video game being used for physical activity is Dance Dance Revolution (DDR), the popular dancing game by Konami. The game requires the use of a dance pad to sense pressure in specific directions and can double the heart rate of the user to exercise levels (Brown, 2006). Further studies on DDR have shown that promoting

DDR leads to an increase in vigorous physical activity (Maloney et al., 2008), which further indicates the ability to promote video games that induce physical activity without having to specially tailor the game. Again, DDR along with Wii Fit are limited in scope due to their need of a physical pad as the control mechanism.

3 SYSTEM DESCRIPTION

Our body-wearable video game controller allows for, and in fact enforces, physical activity at exercise levels that can be adaptable to a wide range of video games. While sedentary activities, such as video games, have previously been linked to the cause of obesity amongst children and adults, this system will actually turn such activities into entertaining exercise, promoting the health benefits of such games by using the human body as an active controller. Our system incorporates tri-axial accelerometers attached to the hands and feet to monitor movement, pressure sensors to detect standing and running, and software algorithms to further classify and interface with any PC-based game. In this paper, the system has been adapted to the FIFA Soccer 10 PC game.

3.1 Hardware

With the use of low-cost commodity hardware, we are able to enact the desired controls necessary for the soccer game. We use two Analog Devices 3-Axis Accelerometers (ADXL335) (Analog Devices, 2010) attached to an Texas Instruments' MSP430 (Texas Instruments, 2010) development board shown in Figure 1. The MSP430 Development board allows us to communicate the accelerometer data wirelessly to the PC. Also, attached to the MSP430 is a square-shaped force sensitive resistor for pressure sensing. Each of these sensors is strapped to a foot, allowing for two footed control of the players within the game. Three actions are detected for the primary foot. The first is a forward shooting motion in the y-axis direction of the accelerometer. The second, primarily in the x-axis direction, is the passing motion, while the z-axis helps determine strength and detect running. The accelerometer on the secondary foot can determine crossing, through passing, and running. All of these actions map directly to the actions defined by FIFA Soccer 10. A Nintendo Wii-Remote is used as a wireless direction pad for easy turning of players.

The Wii-Remote is used only to indicate the direction of the running movement generated by the accelerometers and pressure sensors, and can easily be replaced by a gyroscope in future designs.

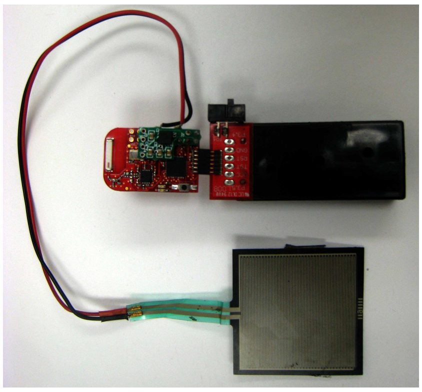

Figure 1: Accelerometer + Pressure Sensor Hardware Unit.

3.2 Software

The software algorithm, written in the C# language, developed in Microsoft Visual Studio, helps further classify the continuous actions and consists of four primary components. A flowchart of the algorithm is shown in Figure 3. This algorithm detects the trained movements and constantly calculates health information based upon sensor readings and consists of five primary pieces: calibration, segmentation, support vector machine classification, movement decision, and calculation of health statistics.

3.2.1 Calibration Phase

The top of a foot is not generally flat and the angle of the y-axis, the rotation around the x-axis (pitch), and the rotation around the y-axis (roll) varies from person to person and must be accounted for. Since we use a strap, visible in Figure 2 to place the device firmly on top of the foot, rotation around the z-axis (yaw), is not considered a factor in affecting motion analysis, but can be accommodated in a similar fashion as the other two angles of rotation. Figure 2 shows the orientation of the sensor and the desired flat directions that the readings will be adjusted to. Since we know the standard flat position of the accelerometer, we can obtain a reading and normalize its values to that of 0 acceleration in the y-direction and 0 acceleration in the x-direction with an acceleration in the z-direction counteracting gravity. Using this as an initial vector, our algorithm can begin by taking an initial set of readings, while asking the user to remain still briefly, to determine the acceleration readings due to the position of the sensor on the foot and associated force of gravity.

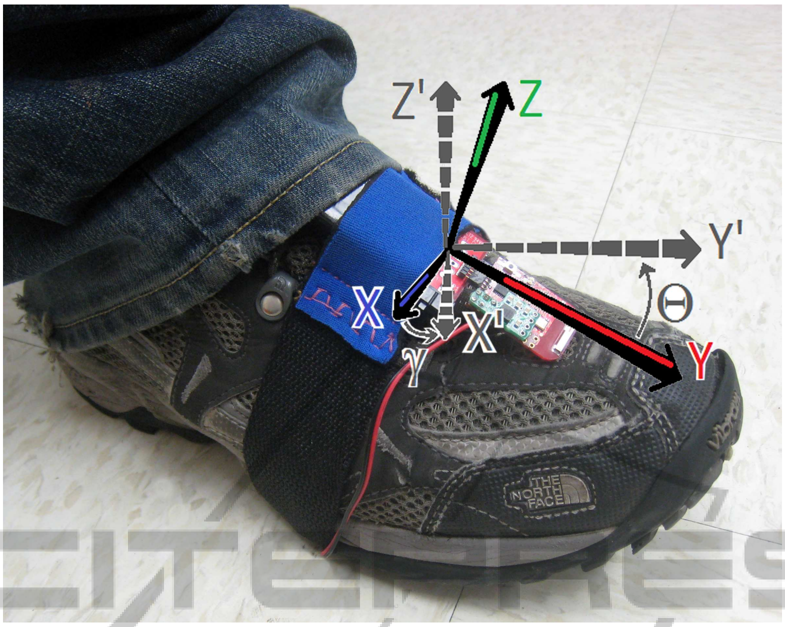

Figure 2: Hardware unit attached to foot. Bold lines are the sensor's coordinate frame of reference. Dashed Lines show the calibrated and rotate frame of reference. Angle θ is the pitch, or rotation around the x-axis, and Angle γ is the roll, or rotation around the y-axis.

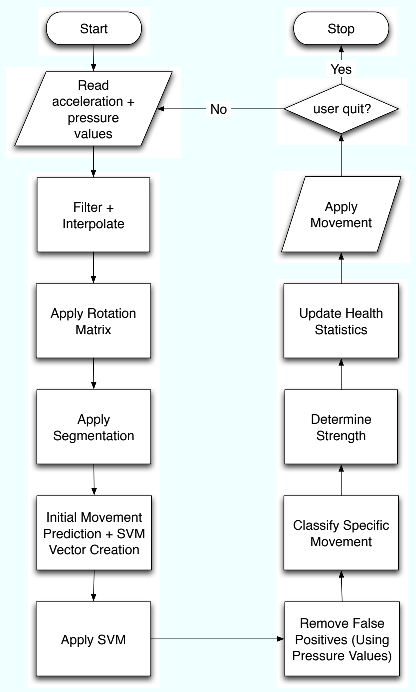

Figure 3: Flowchart of our Algorithm.

$$\cos(\theta) = \frac{\vec{v1} \cdot \vec{v1}}{\|\vec{v1}\| \|\vec{v2}\|} \tag{1}$$

Equation 1 is a well-known equation for finding the angle between two vectors $\vec{v1}$ and $\vec{v2}$, where $\vec{v1} \cdot \vec{v2}$ is the dot product of the two vectors and $\|\vec{v1}\|$ is the magnitude of a vector.

$$\theta = \arccos \frac{0 * y + g * z}{\sqrt{0^2 + g^2}\sqrt{y^2 + z^2}} \tag{2}$$

$$\gamma = \arccos \frac{0 * x + g * z}{\sqrt{0^2 + g^2}\sqrt{x^2 + z^2}} \tag{3}$$

Given we have normalized our standard coordinates in the flat direction, namely 0 in the y direction, 0 in the x direction, and g, the effect of gravity, in the z direction, we can find the pitch angle and the roll angle by equations 2 and 3, respectively. Please note in 2 and 3 that x y and z refer to the x, y, and z components of the angled vector, while our base vector is of the form $< 0, 0, g >$. We then use a simple rotation matrix from linear algebra to convert every 3-point $< x, y, z >$ vector back into our normalized space $< x', y', z' >$ to classify a set of movements with better accuracy by no longer being dependent on the person and the exact position of the accelerometers. The rotation of the coordinate system can be solved via equations 4 and 5, where 4 allows us to calculate rotation in the opposite direction, as was deemed simpler in this case:

$$\hat{\theta} = 2\pi - \theta \quad , \quad \hat{\gamma} = 2\pi - \gamma \tag{4}$$

$$A = \begin{pmatrix} \cos(\hat{\gamma}) & 0 & -\sin(\hat{\gamma}) \\ -\sin(\hat{\theta})\sin(\hat{\gamma}) & \cos(\hat{\theta}) & -\sin(\hat{\theta})\cos(\hat{\gamma}) \\ \sin(\hat{\gamma}) & \cos(\hat{\theta})\sin(\hat{\gamma}) & \cos(\hat{\theta})\cos(\hat{\gamma}) \end{pmatrix}$$

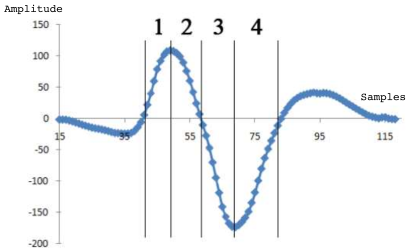

Figure 4: Y-Acceleration Samples plotted against normalized amplitude of 8-bit ADC Channel. 1, 2, 3, and 4 correspond to the segments created by the segment state machine.

$$A \cdot \begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} \tag{5}$$

Once all points are rotated back into the standard plain, the algorithm can begin its initial movement classification.

3.2.2 Segmentation + SVM

A segment state machine is built to identify changes in slope of the acceleration values. These segments help identify the potential for the standard kick, pass, cross, through pass, and running movements. Each movement corresponds with a standard slope pattern in the acceleration curve. The movements segment into four specific sectors of a sinusoid similar to that in Figure 4. The sensors broadcast at 100 Hz and adjust the slope according to a sliding window of twenty (20) $< x, y, z, pressure >$ samples read. This allows for some history to indicate a trend, but is not prohibitively large enough to introduce a delay in the actions of the user. This segmentation, adapted from an initial segmenting system presented in (Hagopian, 2010), can accurately determine the slopes of acceleration curves and the associated state machine can predict potential movements based on a pattern of acceleration and deceleration. Figure 4 shows a kick and the state machine's corresponding segmentation. The state machine itself can classify a large set of actions but for movements that are not entirely dominant in any particular direction, a more precise pattern-matcher can be used for the boundary cases, like a support vector machine.

A support vector machine (SVM), such as the open source libsvm (Chang and Lin, 2001) that we used, allows for multi-class classification based on extracted features from the segment state machine. The SVM, of course, is trained with the movements in a prior phase, but the calibration reduces the need to retrain the segment state machine or the SVM for each user. The test vectors used for the SVM in our algorithm consists of fifty (50) points, each containing four values: x, y, z, and pressure.

3.2.3 Movement Decision and Health Features

Once the classification is accomplished, a final filter is run based upon the pressure profiles and health statistics are updated along with the movement being generated and delivered to the game. The health features are based upon the idea of the Metabolic Equivalent of Task (MET), in order to determine the activity level of the user. Different sports have different MET numbers resulting in different calorie burning. MET is expressed versus the cost of resting metabolic rates; therefore, it measures specifically based upon the increase in activity, where 1 METs is considered being at rest (sedentary), while 3 METs is walking and above 6 is more vigorous activity (Ainsworth et al., 1993). Based upon the mass the user must input to start the system, and the level of activity of the accelerometer+pedometer, equation 6(Hsiao et al., 2010) helps calculate the specific number of calories burned by the user.

$$Calories = \frac{MET * 3.5 * m}{200} * t \tag{6}$$

In equation 6, m is the mass in kilograms and t is the total duration in minutes. This calorie information, along with the pedometer information based upon the pressure sensor, give a basic set of health information to the user as he/she is using our system. While those health statistics are updated, the movements are decided. The strength of these movements can be calculated by various heuristics. In this case, the heuristic is the magnitude of the absolute sum of activity according to:

$$\|\vec{move}\| = \sum_{i=0}^{l} |move_i| \tag{7}$$

, where $\vec{move}$ is the movement vector, l is the length of $\vec{move}$, and $move_i$ is the i^{th} value of the vector. FIFA Soccer 10 allows a wide range of strengths for kicks, crosses, and a differentiation between standard running and sprinting. No movement of the player will occur if the user is not at least stepping in place. All movements are based upon actual human movements. For example, running in place faster will allow the player to sprint, soft swings of the leg will generate soft kicks while stronger swings generate harder shots, and wild kicks by the user cause the player in FIFA Soccer 10 to lose control of the ball by overpowering the shot. Our system is able to continuously monitor not only the movements generated by the body but the strength of those movements in order to more properly determine the activity level MET and the actions within an associated game.

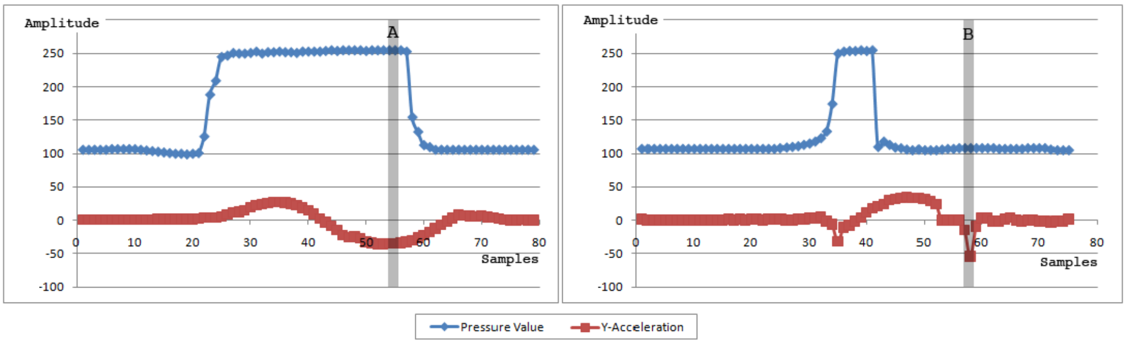

Figure 5: Pressure value and Y-acceleration samples plotted against normalized amplitude of 8-Bit ADC Channel. Points A and B correspond to the decision point of the system on an action.

3.3 Accelerometer Vibration Issues and Enforcing Activity

Running in place is of particular concern as it can cause sensor vibration, which even the pattern-matching algorithms like an SVM can mistake for movement. As a result, the pressure profile of the user becomes a significant portion of the decision making process for movements in order to eliminate false positives as a result of acceleration vibration. The pressure profile must work in association with the accelerometers in order to more accurately detect movement as shown in Figure 5. In Figure 5, the left graph at point A detects a proper kick. When pressure is lifted, the sensor peaks to its maximum amplitude, showing the foot is in the air while the kick occurs. The right graph, at point B, shows a step misrepresented as a kick. With the addition of the pressure sensor, however, the system can now determine that at the classification point, the foot is pressed on the ground, and thus, appropriately designates this only as a step and not as a kick. This sensor fusion is a quick and effective way of dealing with a significant problem with accelerometers when strapped to the body. Our system, with the addition of the pressure sensors under the feet, is able to eliminate what might otherwise be mistaken as movements in simple accelerometer-only based systems.

The important contribution to this system is the ability to control video games with the body in an active and continuous fashion in order to promote healthier game play. As a result, a primary component to our system is, in fact, to enforce that the user be actively playing the game. As the algorithm runs, if at any point the pressure profile decreases from what is expected as a standing person, it will pause and alert the user that he/she is no longer standing and actively playing. The algorithm allows for the pressure to be lifted but these intervals of reduced pressure are monitored in order to guarantee actions are occurring and the user is not, instead, attempting to circumvent the necessary activity levels of the system. As a result, we have a simple but effective manner to ensure the user is not sedentary and is instead up and about actively moving and, hence, exercising.

4 HEALTH BENEFITS

FIFA Soccer 10 was a suitable choice for our system because it allows for varying speeds of running and different leg movements for different actions; it has supported over 113 million total online games played (Electronic Arts Inc., 2009) and serves as a good example of a popular game that can be made active and healthy with our system. Our FIFA Soccer 10 system allows the user to run, sprint, kick and pass with one foot, and cross and through pass with the other. One can use this system to control any action in the game and can even take it online to challenge others. Table 1, which shows the average of five (5) users playing with our system over a fifteen (15) minute period, compares the level of exercise of various activities. Heart rate is based on the specific user, calorie burn is based on equation 6 for a 160 lb individual, MET for walking and soccer is a known value (Ainsworth et al., 1993), and MET for FIFA Soccer 10 PC and our system is based on activity level based on system equation 7. As indicated in the table, FIFA Soccer 10 as played with a standard keyboard is completely sedentary, whereas our system performs on par with moderate exercise. As a point of reference, actual soccer is also listed.

Table 1: Table showing approximate calorie burn and heart rate (beats per minute) associated with 5 users playing FIFA Soccer 10 on PC with keyboard, with our system, and a comparison to walking 4.5 miles per hour and playing casual soccer (Ainsworth et al., 1993) over a 15 minute period.

Activity	Heart Rate	MET	Calories
FIFA 10 (PC)	73 bpm	1.0	19
Walking	–	4.5	85.7
FIFA 10 (Active)	144 bpm	4.5	85.7
Soccer	–	7.0	133.3

5 FUTURE DIRECTIONS AND DISCUSSION

In the current form of our controller system, we can monitor movements and enforce physical activity and adapt it to a wide range of games. Although we have shown how, with the devices strapped to the user's feet, one can play a popular and widely available soccer game, our system is not solely limited to these actions. One can attach the devices to other parts of the body, such as the hands, and generate movements from there as well. The general structure of the system remains the same with a re-training of the classification portion of the algorithm and an adjustment to the calibration phase being the only pieces that require attention. Indeed, our system is adaptable and flexible to many different end applications and lends itself to further user studies on human activity monitoring.

Additional sensors can be added to make the system more flexible if needed. As we further monitor the health status of users with this system, it becomes apparent that the addition of human vital signs, such as heart rate and respiration are features that can be added not only to monitor health but to affect future games. For example, one may become fatigued in real life, and by monitoring this, our system can tell the game to make their characters also show fatigue. Vibration and sounds may be added to enhance feedback to the body to allow for better control. More complex movements, such as rotations measured by a gyroscope, can also be monitored by the addition of hardware into our system. In fact, with the announcement of Microsoft Corporation's Kinect (Microsoft, 2010) camera-based movement system, these additions would keep our system at the forefront of body-controlled games. In cases where camera systems may only visualize moves and approximate health information, our system will be able to continue gaining accurate results and provide feedback to the user for more realistic behavior and feel.

6 CONCLUSIONS

The obese and overweight population of the United States, and most of the industrialized nations, is increasing. As the population grows and the costs become more prohibitive to health-care, new and alternative ways to attack sedentary behavior must be developed. Television viewing and video game playing are time-consuming processes in which users are relatively, if not completely, inactive. Research projects have attempted to address this inactivity by limiting the television time, or by restricting movements to a small subset, but we have developed a system with which players of video games may use their bodies as input devices to the games they are already playing. This system will ensure that the video game player will no longer be in a prolonged sedentary state, but instead, has to exercise to a point where the game becomes beneficial. Through the use of accelerometers and pressure sensors, we can enable active and continuous motion control and activity level monitoring. With a clever classification algorithm we can mimic the input behaviors necessary to perform realistic actions as a body-controller for a video game, and at the same time, measure and monitor activity to ensure a physically motivated game playing experience in which calories are burned and the heart rate climbs. This system is adaptable to current state-of-the-art games by simply replacing any of the given inputs and can be used to keep users entertained while making them active.

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