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An Acceleration-based Control Framework for Interactive Gaming

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Abstract—**In this paper we presented a 3-D acceleration-based interactive framework using Body Sensor Networks (BSN) for real-time game controls. The framework consists of three modules: a wireless signal acquisition module that senses the accelerations of body movements, a signal processing module that uses the Kalman filter to rectify the contaminated acceleration data, and a control module that makes interactive gaming strategies. Our framework enables a wearable gaming control solution that differs from the conventional methods using joysticks, key boards or mice. The framework was implemented on a racing-type game. The results suggested that our framework was fully functioning. It was capable of combining moderate physical exercises with the computer game, at the meantime brought in more funs and motivations to exercises.**

Keywords—**interactive gaming control; pervasive computing; accelerometer sensor; Kalman filter**

I. INTRODUCTION

One of the primary goals for the wireless body sensor network (BSN) is to establish a home-based pervasive system for healthcare and sports applications [1]. Instead of physiological monitoring the signal from the BSN node could also be used as a human-computer interaction, where real-time heart rate information was used to control an interactive skiing and shooting game [2]. To use heart rate as an interaction method was another example of unconventional human-computer interface (UHCI). There are different UHCI examples [3] and one of the noticeable trends is the combination between computer games and physical exercises. Game-related exercise has been reported to increase presence and to motivate to exercise [4]. Representative systems included the games played by pedaling an exercise bike [5, 6] and the games played by gestures using computer vision technologies [7].

Differing from the aforementioned interactive game control methods, we presented a pervasive control framework that utilized a low-cost BSN platform. The primary motivation was to create a wearable solution that uses body movement signals acquired from different body parts to control various computer games.

One possible application of the interactive game-related exercise is the field of rehabilitation for persons with disabilities [8]. Studies have showed that the activities of daily living performed by persons during recoveries were not enough to provide their needs for rehabilitation [9, 10]. By introducing an interactive physical gaming into their daily exercise, a subject may be motivated to conduct more activities. Meanwhile our exercise platform could monitor patients' physiological states such as the physical energy expenditures during the exercise, which could further be used to regulate the subject's daily exercise level.

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II. METHOD

The 3-D acceleration-based control framework consists of three modules: a wireless BSN node that acquires on-body 3-D acceleration signals, a signal processing module and a control module that makes interactive gaming strategies. Fig. 1 illustrates the three modules. In the signal filtering module a Kalman filter was employed. The output was utilized as the game control parameters. The control module implemented a keyboard emulator to emulate different key pressings.

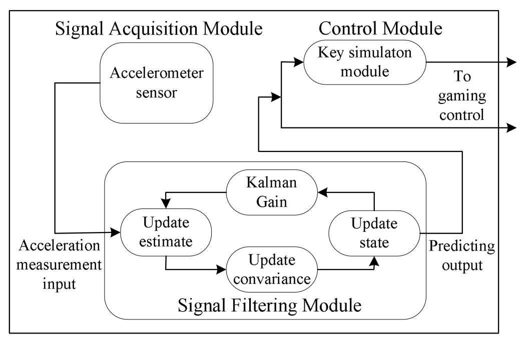

Fig. 1. Acceleration-based control framework

A. Wireless Signal Acquisition

The hardware configuration of our control framework included a BSN node board that built in a 3-D accelerometer sensor (SCA3000 from VTI), a battery board with a charger IC that provided power supply for the BSN node board, and a base station board that connected with a PC [11].

The accelerometer sensor we used incorporates a 3-D MEMS sensing element and a signal conditioning ASIC packaged into a plastic molded interconnection device package [12]. This approach makes the BSN node more compact and immune to the noises induced by cables and connectors.

The 3-D accelerometer, a low-power microprocessor, a memory IC, a radio transceiver and a 20-pin expansion port were integrated on the BSN node board. The basic structure was depicted in Fig. 2. The BSN node board and the battery board were designed to be at a unified form factor of 23 millimeters in diameter, therefore could be easily worn on body.

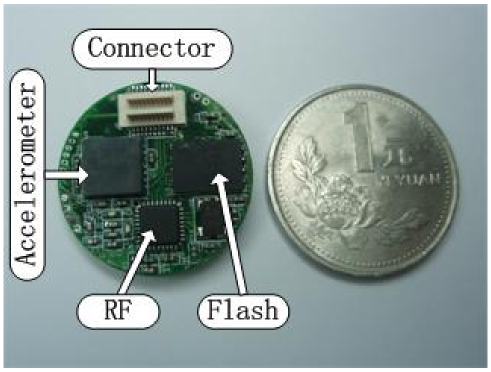

Fig. 2. Photo of a BSN node board

For real-time wireless communications there was a RF transceiver (nRF905 from Nordic) in the BSN node board and the base station board, respectively. The output from the base station board was connected with the PC through a RS232 port.

B. *Initial Calibration*

Because of the low power consumption and the compact form factor, the BSN node could be conveniently worn on any part of the body, such as head, wrist, or ankle (Fig. 3). However, since the initial coordinates of the 3-D accelerometer were at an uncontrolled state, it was essential to calibrate the initial state at the beginning of a game. This calibration procedure was unique to our framework to the best of the authors' knowledge. As showed later in the result section (the BSN node was placed within a cap), the x-, y- and z-axis of the accelerometer were aligned with the moving axes of the head, respectively. At the beginning of the game, the player was asked to be still, and the first dataset was recorded as the reference values. The calibration procedure was repeated for each round of the game in order to improve the control accuracy against body posture changes.

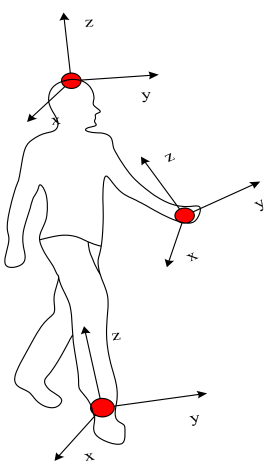

Fig. 3. Different sensing coordinates for different position of the node.

C. *Kalman Filtering*

The accelerometer outputs 3-D data representing the x-, y- and z-axis acceleration, respectively. A typical 3-D acceleration data episode was illustrated in Fig. 4. The raw acceleration data was primarily contaminated because of the relative displacement of the accelerometer sensor device and the body during gaming. A Kalman filter was used to rectify the raw signal.

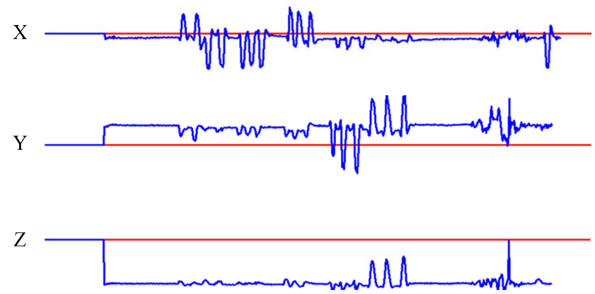

Fig. 4. The three axis noisy signal from 3D accelerometer sensor

Kalman filter is a set of mathematical equations that use an underlying process model to make an estimation of the current state of a system and then corrects the estimation using any available sensor measurements [13, 14]. The filtering algorithm was described below.

First, the acceleration / velocity model was defined by

$$a = dv / dt \tag{1}$$

Where a is the acceleration, v is the velocity. To calculate the velocity from the acceleration, Equation (1) could be approximated with a one-order Taylor series, as illustrated in Equation (2).

$$v' = v + a \cdot \Delta t \tag{2}$$

In the Kalman filter the state vector at time k is defined by

$$\bar{\mathbf{x}}_k = [a, v]^T \tag{3}$$

Where T represent the transpose of vector or matrix here and in the following equations. Given the state vector at step k-1, a prediction step is demonstrated as:

$$\begin{cases} \bar{\mathbf{x}}'_k = \mathbf{A}\bar{\mathbf{x}}_k \\ \mathbf{P}'_k = \mathbf{A}_k \mathbf{P}_{k-1} \mathbf{A}_k^T + \mathbf{Q}_k \end{cases} \tag{4}$$

Where $\mathbf{Q}_k$ is the noise covariance, $\mathbf{P}_{k-1}$ is the *a posteriori* estimate of the error covariance, and $\mathbf{A}_k$ is the state transition matrix:

$$\begin{bmatrix} 1 & 0 \\ \Delta t & 1 \end{bmatrix} \tag{5}$$

Where Δt is the sampling interval.

After the prediction step, the correction step is performed using Equation (6):

$$\begin{cases} \mathbf{K}_k = \mathbf{P}'_k \mathbf{H}_k \left(\mathbf{H} \mathbf{P}'_k \mathbf{H}_k^T + \mathbf{R} \right)^{-1} \\ \bar{\mathbf{x}}_k = \bar{\mathbf{x}}'_k + \mathbf{K}_k \left(\bar{\mathbf{z}}_k - \mathbf{H}_k \bar{\mathbf{x}}'_k \right) \\ \mathbf{P}_k = \left(\mathbf{I} - \mathbf{K}_k \mathbf{H}_k \right) \mathbf{P}'_k \end{cases} \tag{6}$$

Where $\mathbf{I}$ is the identity matrix, $\mathbf{K}_k$ is the Kalman gain, $\mathbf{R}$ is the measurement noise covariance, $\mathbf{H}_k$ is the measurement matrix for the noiseless connection between the state vector and the measurement vector, $\bar{\mathbf{z}}_k$ is the measurement vector, which is the acceleration data a obtained from the accelerometer.

D. Keyboard emulation

A key emulation strategy was implemented in the control module. Fig. 5 illustrates a filtered acceleration data episode when the subject kept swaying his head. For interactive game control purpose, the upward and downward impulse signals from x-axis could be treated as the left and right arrow keys, respectively; consequently the impulse signals from y-axis were treated as the up and down arrow keys, respectively; and the impulse signals from z-axis were treated as speed-up and speed-down signals, respectively.

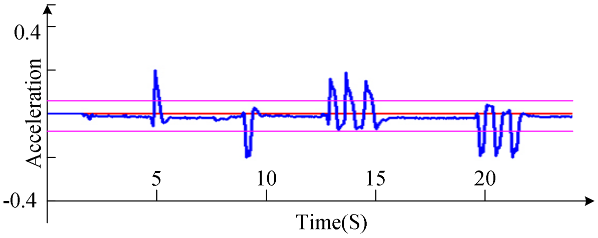

Fig. 5. An acceleration signal episode while the subject kept swaying his head. The signal was normalized to be in the range of -1 to +1.

Both amplitude and rhythm information are important in assessment of postal sway and body movements [15]. The amplitude and rhythm vary in different body sites and during different activities such as standing, walking and running [16, 17]. Therefore a customized emulation model must be associated with a specific game and at a specific body site for interactive gaming controls. As shown later in the result session, the BSN node was worn on the head (within a cap), so it was primarily the neck vertebra movements that 'emulate' the different key-presses. After intensive test runs a simple yet effective multiple-threshold emulation strategy was employed. The amplitude threshold was set to be $\pm$ 0.0625 (the straight lines in Fig. 5). Once it exceeds this threshold value in either way the key-press event(s) was provoked.

The maximal repetition rate of the normal neck vertebra movements is approximately 1Hz (if too fast a subject would feel discomfort during an extended gaming time period), which is significantly slower than the maximal repetition rate when a finger performs key-presses continuously. Therefore, a temporal threshold scheme was elaborated so that one neck movement would emulate 1, 3, 5 or even more key presses, depending on the duration of the acceleration signal being exceeded on the amplitude threshold. A longer duration emulated more key-presses. This way a game player using our control framework was capable of 'catching up' the racing computer game in a real-time manner.

III. RESULTS

The BSN node was found to be comfortable to wear for all game participants. The wireless link between BSN node and the base station was highly reliable and there was no noticeable communication latency during most of the gaming periods.

Fig. 6 compared the original acceleration data with the data after processing. It is envisaged that the rectified data was more reliable for the subsequent key-press emulations.

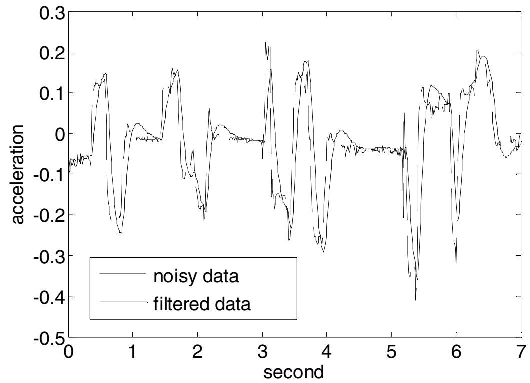

Fig. 6. Noisy raw acceleration data vs. Kalman filter processed data.

in-situ verification of the complete control framework was carried out using an open source racing-type game [18] illustrated in Fig. 7. Two types of interactive game controls were selected: one was the conventional keyboard-based solution; another one was using our control framework while the BSN node was attached on the top of a cap and the cap was worn on the subject head. More than twenty subjects were randomly assigned to play the computer game using either of the two control solutions. A comparison of the 'play-ability' was evaluated by scoring from 0 (extreme boring) to 5 (extreme exciting) after playing the game. Most of the subjects played the game many times.

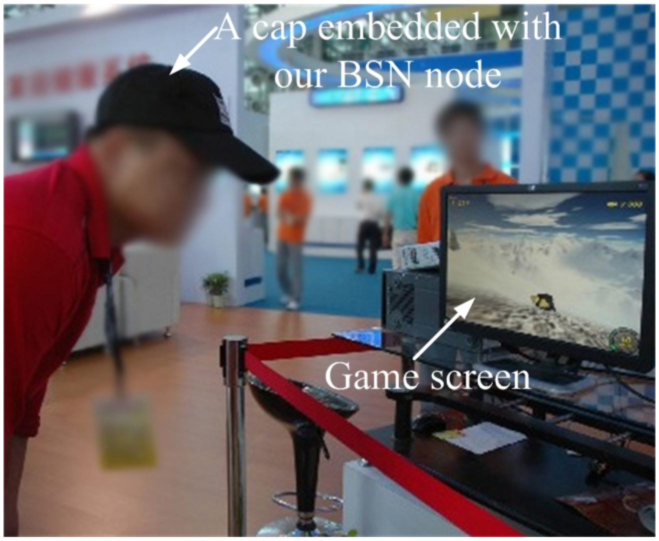

Fig. 7. Photo of our system setup

By averaging the scores after the first-time plays of the game, it indicated that both control solutions achieved similar scores (approximately 4.2), which suggested that our control framework was comparable with the conventional control solution in terms of the maneuverability. However, most of the subjects (90%) were clearly in favor of our control framework after playing the same game several times, suggested that our control framework outperformed the conventional solution in terms of the 'play-ability' and the motivation to exercise.

IV. Conclusion

In this paper a novel framework for interactive game controls was presented. A wireless BSN was used as hardware platform. The *in-situ* experiment result verifies that our decision making strategy for key emulation is suitable for real-time gaming control by our head-worn cap. The system could be worn literally any part of the body, make it a good candidate for various movements.

In the future we will explore more sports gaming applications. We are also looking at rehabilitation of chronic diseases and people who work in front of a computer for long times due to inactivity by motivating them for physical exercises.

References

[1] G.Z. Yang, *Body Sensor Networks*, Springer-Verlag London, 2006.

[2] S. Jose, “Using heart rate to control an interactive game,” ACM Conference on Human Factors in Computing Systems, 2007.

[3] S. Beckhaus, and E. Kruijff, “Unconventional human computer interfaces,” In Proceedings of the Conference on SIGGRAPH 2004 Course Notes Los Angeles, CA, August 08 - 12, 2004.

[4] S. Mokka, A. Vaatanen and J. Heinila et al., “Fitness computer game with a bodily user interface,” In Proceedings of the Second international Conference on Entertainment Computing (Pittsburgh, Pennsylvania, May 08-10, 2003). ACM International Conference Proceeding Series, vol.38. Carnegie Mellon University, Pittsburgh,PA,1-3.

[5] Cat Eye Fitness Game Bike. http://www.cateyefitness.com/GameBike.

[6] RacerMate CompuTrainer. http://www.racermateinc.com.

[7] J. Hoysniemi, A. Aula and P. Auvinen, et al., “Shadow boxer: a physically interactive fitness game,” NordiCHI’04: Proceedings of the third Nordic conference on Human-computer interaction, ACM Press (2004), 389-392.

[8] S. F. Guo, G. G. Grindle, and E. L. Authier et al., “Development and Qualitative Assessment of the GAME^{Cycle} Exercise System,” IEEE Transactions on Neural System and Rehabilitation Engineering, Vol. 14, No. 1, March 2006.

[9] R. A. Washburn and S. F. Figoni, “High density lipoprotein cholesterol in individuals with spinal cord injury: The potential role of physical activity,” *Spinal Cord*, vol. 37, pp. 685–695, 1999.

[10] T.W. J. Janssen, C. A. J. M. Van Oers, and L. H. V. van derWoude et al, “Physical strain in daily life of wheelchair users with spinal cord injuries,” *Med. Sci. Sports Exerc.*, vol. 26, no. 6, pp. 661–670, 1994.

[11] S. J. Lin, B. Y. Huang and B. Wang, et al., ”Towards A Ubiquitous Head-worn Physiological Measurement Device for Sports and Gaming Applications,” 5th International Conference on Ubiquitous Healthcare 2008,October 29 - 31, 2008, Busan, Korea.

[12] SCA3000-D01: 3-Axis Low Power Accelerometer with Digital SPI Interface. VTI Technology, http://www.vti.fi/en/.

[13] Welch, Greg and B. Gary, *An Introduction to the Kalman Filter*, Technical Report TR 95-041, Department of Computer Science, University of North Carolina at Chapel Hill, 1995.

[14] J. Joseph, Jr. LaViola, “A Comparison of Unscented and Extended Kalman Filtering for Estimating Quaternion Motion,” American Control Conference, 2003, vol.3, pp.2435-2440.

[15] M. J. Mathie, A. C. F. Coster and N. H. Lovell et al. “Accelerometer: providing an integrated, practical method for long-term, ambulatory monitoring of human movement,” Physiological Measurement, 25(2), 1-20, 2004.

[16] M. Sun and J. O. Hill, “A method for measuring mechanical work and work efficiency during human activity,” J. Biomech., 26, 356-69, 1993.

[17] Cappozzo, “Low frequency self-generated vibration during ambulation in normal men,” J. Biomech. 15, 599-609, 1982.

[18] http://tuxracer.sourceforge.net/.