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On the Correlation Between Motion Data Captured from Low-Cost Gaming Controllers and High Precision Encoders

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***Abstract*— Gaming controllers are attractive devices for research due to their onboard sensing capabilities and low-cost. However, a proper quantitative analysis regarding their suitability for use in motion capture, rehabilitation and as input devices for teleoperation and gesture recognition has yet to be conducted. In this paper, a detailed analysis of the sensors of two of these controllers, the Nintendo Wiimote and the Sony Playstation 3 Sixaxis, is presented. The acceleration and angular velocity data from the sensors of these controllers were compared and correlated with computed acceleration and angular velocity data derived from a high resolution encoder. The results show high correlation between the sensor data from the controllers and the computed data derived from the position data of the encoder. From these results, it can be inferred that the Wiimote is more consistent and better suited for motion capture applications and as an input device than the Sixaxis. The applications of the findings are discussed with respect to potential research ventures.**

I. Introduction

Video game controllers such as Nintendo's Wiimote remote enabled with the Motion Plus and Sony's Playstation Sixaxis controllers have revolutionized how we interact with games by enabling intuitive motion sensing and interpretation rather than relying on keyboard, mouse, or button clicks. Recent developments in the field of Micro Electro Mechanical Systems (MEMS) have made it possible to develop high precision and high performance sensors for a nominal cost [1]. The availability of such sensors within these gaming controllers, and the wide range of tools available for open-source development with these devices, makes devices such as the Wiimote and Sixaxis potential platforms for low-cost motion capture, gesture recognition, rehabilitation and low-cost input devices mainly in the field of telerobotics.

A number of studies have reported on the use of low-cost devices for motion capture, including comparisons of low-cost devices [2]; tracking reliability [3], [4], [5]; and use of accelerations from low-cost devices for teleoperation [1]. Uniformly, however, and despite their broad appeal, the utility of low-cost input devices is potentially limited due to a lack of published data regarding the accuracy, resolution, sensitivity or reliability of the sensors.

Therefore, we analyze two of these low-cost gaming devices, the Nintendo Wiimote with the Motion Plus and the Sony Playstation 3 (Sixaxis), in terms of their accuracy, resolution, reliability and performance. This work is a continuation of our earlier work [6] where we compared only the accelerometers of the Wiimote and the accelerometer for measurements along the X axis of the Sixaxis. In this paper we give a more detailed and complete analysis of all the sensors (both the gyros and all the accelerometers) in the Wiimote and the Sixaxis. We compare recorded accelerations and angular velocities in a variety of controlled conditions to computed accelerations and angular velocities from a high resolution encoder. Finally, we discuss the comparative performance of the gaming controllers, and the viability of these devices for both motion capture and as input devices especially in the fields of robotics, rehabilitation and related areas.

II. Methods

A. Nintendo Wiimote controller

The Wiimote with the Motion Plus has six sensing elements: a 3-axis linear accelerometer, an infrared digital camera and a two axis gyro for pitch and roll along with a single axis gyro for yaw. We previously reported the specifications of the Wiimote's accelerometers in [6]. Since the accelerometers onboard the Wiimote are sensitive to the direction of gravity, the addition of the gyros in the Motion Plus helps in distinguishing between a change in orientation and a change in linear acceleration. The combination of gyros and accelerometers enable six degrees of freedom of motion data to be sensed.

B. Sony Sixaxis controller

The Sixaxis controller is able to sense linear accelerations with a 3-axis accelerometer (HDK 3-axis) [7]. In addition to the accelerometers, the Sixaxis has a gyro for measuring yaw (Murata ENC-03R gyro chip) [7]. Unlike the Wiimote, the accelerometers in the Sixaxis are piezoresistive type [8]. The details of the accelerometer can be found in [9].

The Sixaxis has a piezoelectric or vibrating structure gyro, with details found in [10]. The Sixaxis communicates with its console through a Bluetooth link or USB cable. Unlike the Wiimote, the Sixaxis is capable of measuring four degrees of freedom with four sensors. However, a combination of data from the four sensors can be used to control six degrees of freedom of motion.

C. Mechatronic Test Bed

To test the gyros of each gaming controller, each device was first mounted on a moving one degree of freedom mechatronic test bed and then coupled directly to the motor shaft of the test bed for two separate experiments as shown in Figure 1. The details of the test bed and mounting of the controllers for testing the accelerometers can be found in [6].

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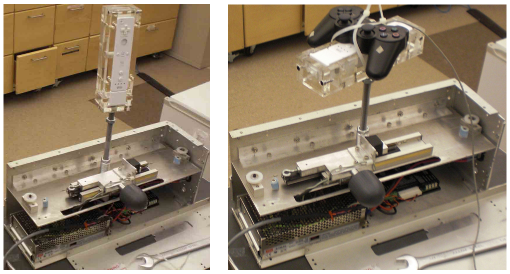

(a) (b)

Fig. 1. One degree of freedom mechatronic test bed with (a) Wiimote and (b) coupled Wiimote and Sixaxis mounted on the testbed for angular velocity measurements

D. Experiments and Data Acquisition for the Gyros

To test the gyros, the controllers were directly coupled to the motor shaft of the mechatronic test bed in different orientations and the motor of the mechatronic test bed was commanded to track sinusoidal inputs of varying frequencies and amplitudes as shown in Table II. The amplitudes and frequencies for the experiment were selected such that they encompassed the range of motion for activities of daily living (ADL) [11], [12]. The data from the Wiimote Motion Plus and the linear encoder connected to the test bed were collected using QuaRC [13] at a sampling rate of 1000 Hz. However, for the Sixaxis, the data was collected using GlovePIE [14] at 70 Hz which was then converted to a virtual joystick input using PPJoy [15] and read by the QuaRC gaming controller block into Simulink at 1000 Hz. The data were acquired from the two controllers in different ways in order to take advantage of existing data acquisition blocks available in QuaRC.

The measurements were then compared and correlated with those obtained from the test bed's sensor. The computed angular velocity was determined by differentiating the ratio of the encoder reading (the arc length) to the product of the sensor gains and the radius of the motor shaft. The details of the experiments and data acquisition for the accelerometers along with the post processing techniques used for filtering the high frequency white Gaussian noise produced by the accelerometers and the gyros are reported in [6].

III. Results and Discussion

Table I shows the correlations of the acceleration data from the Wiimote and the Sixaxis controllers with the computed accelerations from the position data of the high resolution encoder. Figures 2 and 3 show the angular velocities measured from the roll and the pitch gyros of the Wiimote Motion Plus while Figure 4 shows the angular velocity data from the Wiimote Motion Plus and the Sixaxis controller's yaw gyro. The data sets represented by thick grey dotted lines indicate computed angular velocities, thin light grey continuous lines indicate raw unfiltered gyro data from the controllers, and thick black continuous lines indicate filtered angular velocity data from the controllers. Representative plots of the acceleration from both the Wiimote and the Sixaxis controllers are reported in [6].

In Figures 2-4 and Table II, the performance of the gyros are reported at three different frequencies and amplitudes. The amplitudes pertain to small and large movements of the wrist during pitching and yawing motion and the arm during rolling motion. The dashes in Table II indicate that respective arm and/or wrist motions were not tested at those frequencies and amplitudes. The frequencies corresponding to the different amplitudes were decided based on the maximum frequency range of human wrist and arm movements at those amplitudes. It should be further noted that for clarity Figures 3a and 3b have the low and ADL amplitudes shown and Figure 4b has the ADL and the high amplitudes shown.

Analysis of the correlations between the gaming controller data and the computed accelerations and the angular velocities shows that the acceleration data from the Sixaxis controller has a higher correlation with the computed acceleration while the angular velocity data from the Wiimote has a higher correlation with the computed angular velocity at the various test frequencies and amplitudes. The high correlation coefficients suggest that the sensors in both gaming controllers are well suited to operate in this range as motion tracking and input devices. This can be further verified from Figures 2-4 and [6], where the data sets in thick black are seen to track the data sets in thick dotted grey with high accuracy. The phase lag is likely due to delay in transmission of the data from the sensors of the controllers to the console.

When compared with each other, the accelerometers of the Sixaxis are more consistent and show less variation in sensitivity than those of the Wiimote across the tested range [6]. At frequencies around 1 Hz, the accelerometers of the Wiimote are less accurate at detecting small accelerations, thus resulting in smaller correlation coefficients. Increasing the amplitude increases the correlation coefficients. The reason for the better results of the Wiimote at low frequencies and higher amplitudes may be because of the stiffness of the spring mass system of the accelerometers. As a result of the higher spring stiffness, the deflection of the spring may not be high enough at low frequencies and amplitudes to cause a deflection in the capacitive plate the spring is attached to, resulting in an insignificant voltage change and faulty output. On the other hand, the reason for the high and consistent performance of the Sixaxis over the test range can be attributed to the fact that the springs in the accelerometers of the Sixaxis are attached to a highly sensitive piezoelectric material, thus resulting in a noticeable voltage fluctuation irrespective of the magnitude of the spring deflection. One other reason may be the lower spring stiffness and thus greater spring deflection for the same amount of force for the springs in the accelerometers of the Sixaxis. The accelerometers in the Sixaxis controller are thus more sensitive and have better resolution than the accelerometers in the Wiimote. Therefore, for very slow motions which include abrupt changes in direction, the Sixaxis controller would be a better choice. For motions with higher frequencies and amplitudes, both controllers perform well. In addition, at higher frequencies and amplitudes, both devices exhibit

TABLE I

CORRELATION BETWEEN THE ACCELERATION FROM THE WIIMOTE AND THE SIXAXIS WITH THE COMPUTED ACCELERATION.

		Correlation Coefficients of Controllers					
Frequency	**Amplitude**	**Wiimote**			**Sixaxis**		
Hz	cm	X	Y	Z	X	Y	Z
1	0.7	0.90	0.81	0.97	0.94	0.94	0.92
4	0.7	0.97	0.96	0.97	0.98	0.99	0.99
1	4.9	0.98	0.98	0.99	0.97	0.98	0.96
4	4.9	0.98	0.98	0.99	0.98	0.98	0.97

TABLE II

CORRELATION BETWEEN THE ANGULAR VELOCITIES FROM THE CONTROLLERS AND THE COMPUTED ANGULAR VELOCITIES.

		Correlation Coefficients of Controllers			
Frequency	**Amplitude**	**Wiimote**			**Sixaxis**
Hz	degrees	roll	pitch	yaw	yaw
0.4	30	0.99	0.93	0.99	0.98
0.7	30	0.98	0.96	0.99	0.97
1	30	0.98	0.95	0.99	0.97
0.4	60	-	-	0.99	0.99
0.7	60	-	-	0.99	0.97
0.4	110	-	0.99	-	-
0.7	110	-	0.94	-	-
0.4	160	0.99	-	-	-
0.7	160	0.99	-	-	-
0.4	180	-	0.98	-	-
0.7	180	-	0.99	-	-
0.4	200	0.99	-	0.99	0.98
0.7	200	0.99	-	0.99	0.98

low noise in the sensor data. When used for slow and low amplitude applications, adequate noise filtering is required.

When comparing angular velocity measurements, the gyros on the Wiimote Motion Plus have a higher fidelity and are marginally more sensitive than the yaw gyro on the Sixaxis. However, one major drawback of the gyros is measuring angular position from angular velocities which result in subsequent integration drift in a very short time, thus preventing accurate angular computations over large time intervals.

IV. CONCLUSIONS

The use of low-cost gaming controllers is attracting attention in research domains where human-scale motions are of interest. This paper has presented a detailed comparison of dynamic sensor data of the Wiimote and Sixaxis controllers. The Wiimote and the Sixaxis are both suited for applications with fewer jerks and fast sweeping motions. However, the Sixaxis is better than the Wiimote for slow motions across short distances. The gyros of the Wiimote Motion Plus are marginally superior to the gyro in the Sixaxis. Additionally the Wiimote with the Motion Plus allows a full six degrees of freedom of sensing. Therefore, the Wiimote with the Motion Plus is a more suitable controller for motion capture and as an input device for experiments. The overall performance of these gaming controllers was comparable to the computed acceleration and angular velocity data, therefore these low-cost controllers should provide reliable data for gross human motion capture at a fraction of the cost of camera based systems and could also replace sophisticated joysticks used as input devices for various experiments in fields of rehabilitation, gesture recognition and teleoperation. As shown in the paper, however, for optimal performance, the acceleration data from the controllers should be filtered, as the data is noisy.

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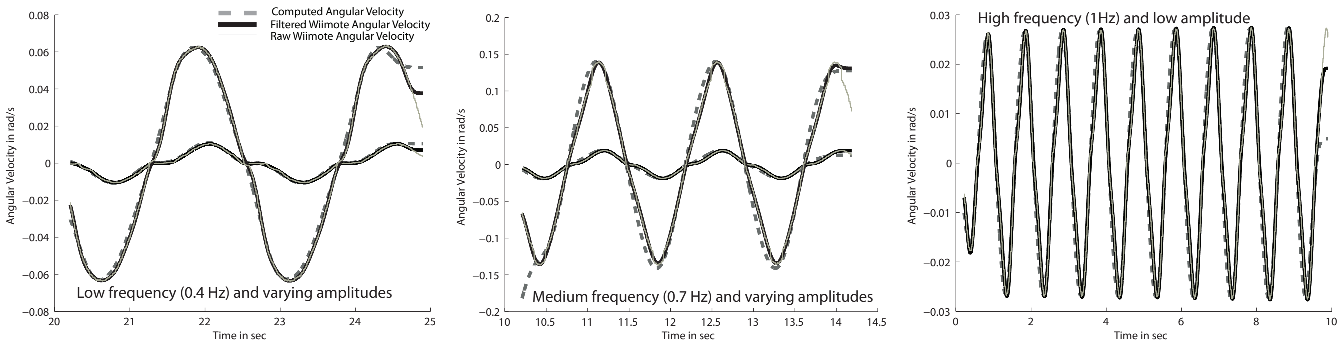
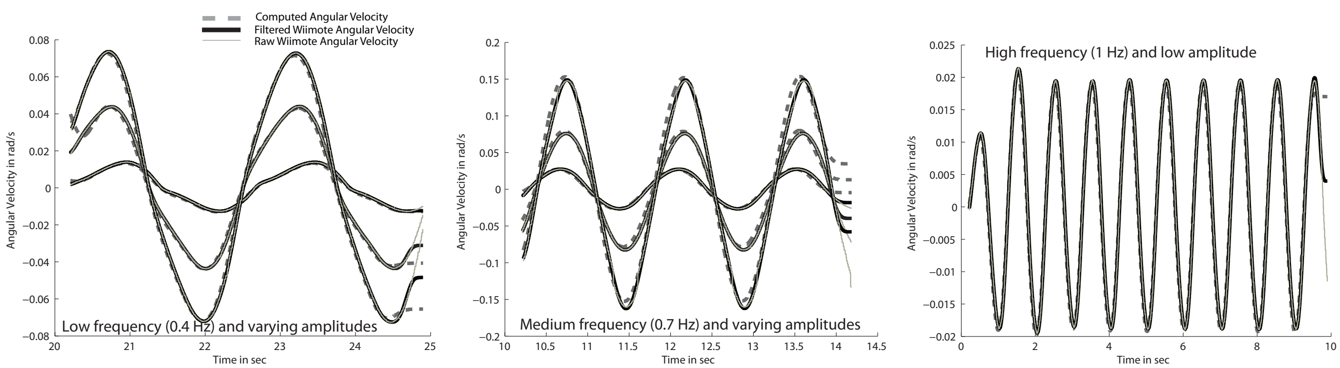


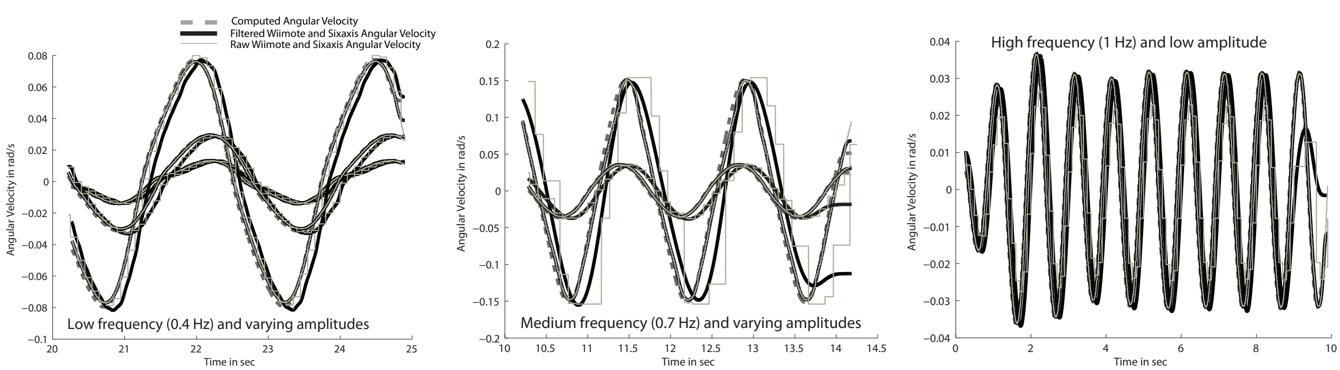
(a) (b) (c)

Fig. 2. Performance of the Wiimote Motion Plus controller's roll gyro at different frequencies and amplitudes, (a) 30°and 160°at 0.4 Hz, (b) 30°and 160°at 0.7 Hz (c) 30°at 1 Hz



(a) (b) (c)

Fig. 3. Performance of the Wiimote Motion Plus controller's pitch gyro at different frequencies and amplitudes, (a) 30°, 110°and 180°at 0.4 Hz, (b) 30°, 110°and 180°at 0.7 Hz (c) 30°at 1 Hz



(a) (b) (c)

Fig. 4. Performance of the Wiimote Motion Plus and the Sixaxis controller's yaw gyro at different frequencies and amplitudes, (a) 30°, 60°and 200°at 0.4 Hz, (b) 30°, 60°and 200°at 0.7 Hz (c) 30°at 1 Hz

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