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Busch, Andrew, James, Daniel

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EXTRACTION OF VIRTUAL ACCELERATION DATA FROM MOTION CAPTURE

Andrew Busch[1] and Daniel James[1,2]

[1] Centre for Wireless Monitoring and Applications, Griffith University, Australia
[2] Centre of Excellence for Applied Sport Science Research, Qld Acad. of Sport

Wearable inertial sensors, such as accelerometers, have recently proven to be very effective tools for studying the biomechanical performance of athletes in many sports, as they are lightweight, relatively unobtrusive, and in many cases can be worn outside the laboratory during both training and competitive conditions. In using such devices, it is important that the sensors are placed in the correct position to capture the desired data, and finding this position can involve considerable time and effort. By utilising 3-D imagery, an efficient method for calculating virtual acceleration data for multiple sensor positions is proposed, which will allow researchers to quickly obtain large amounts of data for testing without the need for extensive field trials. Verification undertaken using actual inertial sensors show the accuracy and usefulness of this approach.

KEY WORDS: inertial sensors, motion capture, Vicon

INTRODUCTION:

In recent years, the use of technology in sport has increased dramatically, with athletes and coaches utilising a variety of devices and techniques to improve skill acquisition and training effectiveness, provide a competitive advantage, and reduce the likelihood of injuries. One of the major areas of research in this field involves the monitoring of athletes during training and/or competition in order to extract performance related data, which can then be analysed to find weaknesses in an athlete's technique, extract information of interest such as scoring metrics, stroke rates, etc, to determine the legality of some aspect of the athlete's performance, or to assess the physiological impact of various activities (Ferdinands & Kersting, 2007; Reid, Elliot & Alderson, 2007; Lee, Mase & Kogure, 2005, Busch & James, 2007).

One of the most widely used systems for obtaining raw data for analysis of an athlete is 3-D motion capture, such as that provided by the Vicon MX system. By means of wearable reflective markers and multiple cameras, virtually every movement made by an athlete can be monitored and analysed, allowing for the calculation of a variety of metrics. Although extremely accurate, analysis of an athlete using such systems can be problematic, as the trials must be conducted in an artificial laboratory session, the athlete must wear a set of markers which can possibly affect performance and cause distraction, and the setup time required is quite large.

Recent advances in MEMS technology have allowed the creation of small, accurate, and low cost inertial sensors, capable of sensing the motion of an object to a very high degree of precision. Due to their small size and light weight, such devices have found increasing use in the field of sports monitoring, with accelerometers and rate gyroscopes used to measure activity levels and assess athletic performance in a number of sports. The primary advantage of these sensors over vision-based systems is their ability to be used in a wide range of situations. Due to their small size, they can be worn by the athlete with minimal discomfort, or placed on or even inside their equipment. Data can then be either sent via wireless transmission for immediate analysis, or stored within the device for later retrieval.

When extracting data from inertial sensors, their location on the athlete's body or equipment is of critical importance. To date, these locations have been determined by either a biomechanical study of the motion that is to be captured, or by a semi-random process of trial and error. In both cases, it usually necessary to modify this position a number of times before finding one which provides data that accurately and sufficiently describes the desired movements. Such repetitive trials are both time consuming and difficult to undertake, with no guarantee of a successful outcome. In order to save time effort, the virtual accelerometer proposed in this paper allows for extraction of simulated acceleration data from virtually any point on an athlete's body or equipment which is extremely similar to that captured by a real sensor. This means that a relatively low number of trials is sufficient to both determine the validity of using inertial sensors and to determine the optimum placement position. Results show that this technique is both accurate and able to be used for a wide range of motions.

METHOD:

Vicon Data Collection: Positional data is collected from the Vicon system via a set of reflective markers which are attached to the athlete's body, clothing, or equipment. For most applications, specific models are developed which enable the accurate extraction of the required biomechanical information. For example, studies into cricket bowling actions require accurate localisation of the shoulder, elbow and wrist positions, and as such a relatively high number of markers are placed around these locations. In order for the information to be accurate, the markers should be placed in areas which have little movement in the skin and underlying soft tissue, and in locations which provide a good approximation of the underlying skeletal or muscular regions of interest. Significant research has been carried out in this area, leading to the development of many marker models, however such an analysis is outside the scope of this paper.

In order to create the virtual sensor, both the position and orientation of the sensor must be able to be accurately determined with respect to the chosen markers. In order to ensure this is done, at least three markers must be used, with the relative positions of the markers remaining as fixed as possible throughout the action of interest. Although in theory any non-linear configuration of three markers is adequate, accuracy will be increased by arranging the markers such that two markers lie directly along one axis of the virtual accelerometer, and the third roughly perpendicular to this axis at a significant distance. Figure 1 shows one such possible configuration of markers which allows for accurate positioning of the virtual sensor at any location along the lower arm.

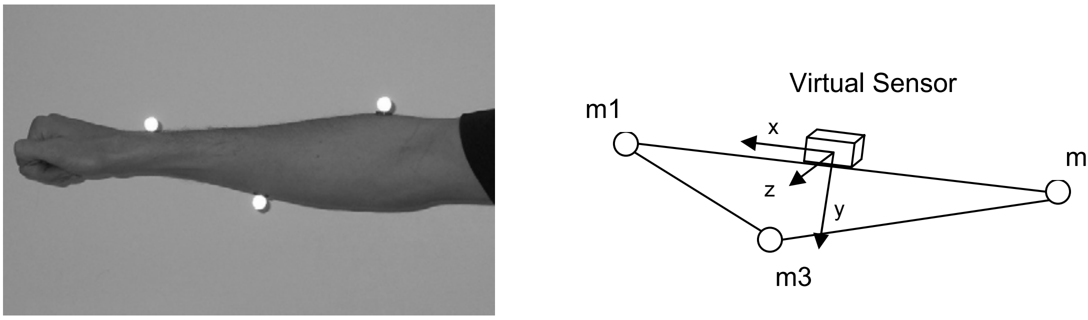

Figure 1: Sample positioning of markers on lower arm, and position of virtual sensor

Virtual Sensor: Acceleration forces on a physical object are caused by three major sources, the motion fo the object, the rotation of object, and the constant gravitational force. With the exception of gravity, these can all be measured using absolute positional data. The Vicon system provides absolute 3-D positioning data for each marker, in the form of $m_n(i,j,k)$ coordinates, where n is the marker number. In order to create the output of the virtual sensor, it is necessary to transform this data into acceleration coordinates along each axis of the device. To perform this operation, it is first necessary to accurately calculate the position and orientation of the sensor at each sample. This step is dependent upon the exact geometry of the markers in relation to the desired sensor position, and will vary depending on the desired application. As an example, for the marker configuration shown in figure 1, the sensor position $\mathbf{s}$ and orientation vectors $\hat{\mathbf{x}},\hat{\mathbf{y}},\hat{\mathbf{z}}$ can be calculated for each sample by:

$$\begin{aligned}
&\mathbf{s} = \alpha\mathbf{m_1} + (1-\alpha)\mathbf{m_2} \\
&\hat{\mathbf{x}} = \frac{\mathbf{m_2} - \mathbf{m_1}}{\|\mathbf{m_2} - \mathbf{m_1}\|} \\
&\hat{\mathbf{y}} = \frac{\mathbf{y}}{\|\mathbf{y}\|}, \text{ where } \mathbf{y} = \mathbf{m_3} - \mathbf{m_1} - (\mathbf{m_3} \bullet \hat{\mathbf{x}} - \mathbf{m_1} \bullet \hat{\mathbf{x}})\hat{\mathbf{x}} \\
&\hat{\mathbf{z}} = \hat{\mathbf{x}} \times \hat{\mathbf{y}}
\end{aligned} \qquad (1)$$

where α is the fractional position of the sensor between markers m_1 and m_2, and all variables are time dependent.

Once the absolute position and orientation of the sensor has been determined, the absolute acceleration a(t) of the sensor in free space can be calculated by finding the second derivative. In order to account for the gravitational force present when using a DC accelerometer, a steady 1-g acceleration along the vertical axis is also added at this stage.

$$\mathbf{a}(t) = \frac{d^2\mathbf{s}(t)}{dt^2} + \langle 0,0,1 \rangle \qquad (2)$$

As the data is in discrete form, a difference operator is used to approximate this function shown in (2). The final step of the procedure is to then project the absolute acceleration of the sensor onto the direction vectors of each axis, giving the final sensor output a*(x,y,z,t)* as

$$\mathbf{a}(x,y,z,t) = \langle \mathbf{a}(t) \bullet \hat{\mathbf{x}}, \mathbf{a}(t) \bullet \hat{\mathbf{y}}, \mathbf{a}(t) \bullet \hat{\mathbf{z}} \rangle \qquad (3)$$

Post-Processing of Data: The high precision of the Vicon system, in combination with the second derivative calculation, means that the output of the virtual sensor will often contain a significant amount of high-frequency noise. In order to remove as much of this noise as possible, whilst still retaining most of the data of interest, a low-pass filter is applied to each output channel of the sensor. A simple averaging filter was used for this purpose, with a cut-off frequency of 10Hz.

Experimental Setup: In order to verify the correct operation of the virtual sensor, trials were conducted in which an athlete was monitored with both the Vicon system and a 3-axis accelerometer simultaneously. The chosen location for these trials was the right forearm of the athlete, to which the accelerometer and three markers were attached as shown in figure 1, with the accelerometer placed approximately equidistant from markers 1 and 2 (α=0.5). During each trial, the athlete performed a number of simple tasks. In the first task, the arm was extended vertically upwards, then slowly moved to the horizontal position and finally vertically downwards, and repeated. This action tests the correct application of the gravitational force, as it moves from the x-axis, to the y-axis, and finally the negative x-axis, with minimal expected output on the z-axis. There will also be a small centrifugal acceleration along the x-axis which is proportional to the angular velocity of the arm. In the second trial, the athlete performed a more complex action, the simulated throwing of a ball.

RESULTS:

The results from the first trial are shown in figure 2, with the virtual sensor output (left) closely matching that of the actual device (right). The RMS errors of the virtual sensor for this trial are 0.0306g, 0.0384g, and 0.08g along the x, y and z axes respectively, with an average absolute error of 3.6%. The somewhat higher error in the z axis is most likely due to a small alignment error of the physical sensor combined with lateral motion of the sensor due to the flexibility of the skin. The second trial (throwing) contains motion involving significant acceleration along all axes of the sensor, as can be seen in the virtual and actual plots of figure 3. Of particular note is the centrifugal force along the x-axis (darkest plot), which is very accurately replicated by the virtual sensor. The RMS error for this trial is somewhat higher at 0.11g, 0.09g and 0.21g (average 4.8%), due to the higher accelerations involved and the more violent motion of the arm causing movement in the sensor. The applied smoothing function also tends to remove some information, so for higher speed applications it may be desirable to reduce the window size of this filter.

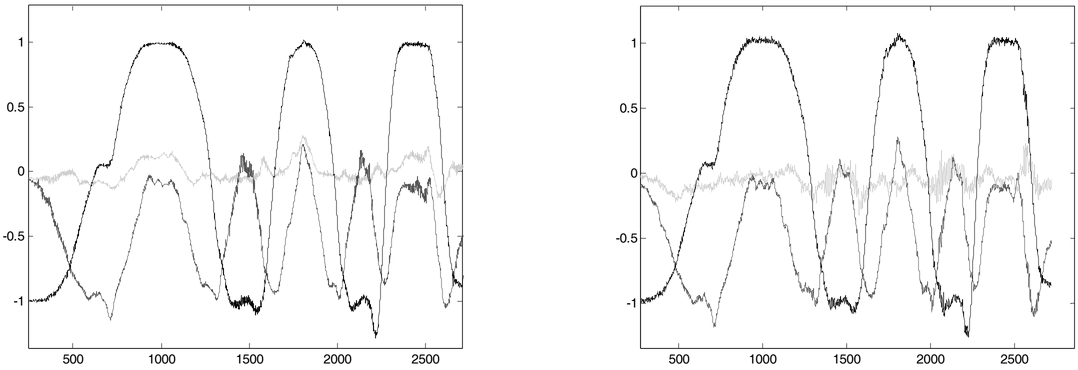

Figure 2: Acceleration plots for simple task showing virtual sensor output (left) and actual accelerometer output (right). Black represents the x-axis, grey the y-axis, light grey the z-axis.

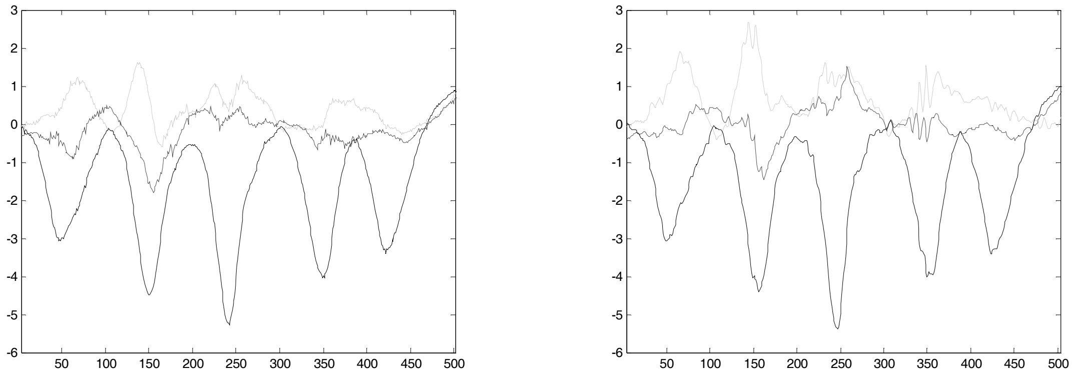

Figure 3: Acceleration plots for complex motion (throwing) showing virtual sensor output (left) and actual accelerometer output (right).

CONCLUSION:

The virtual accelerometer allows for a vast amount of accurate data to be extracted from a single Vicon trial, enabling researchers to quickly determine whether such sensors are useful for a given application, and where the most appropriate location to place them is. Using this technique can result in significant time savings in many areas of sports research, as well as improve the final results of accelerometer based analysis. Future work will include adding additional outputs to the sensor, such as angular velocity as would be obtained from a rate gyroscope, as well as the use of this technique to determine the feasibility of accelerometer analysis of particular sporting actions prior to the development of specialised hardware.

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