THE STUDY OF APPLICATION OF UN-SYNCHRONIZED VIDEO CAMERAS FOR 3-D MOTION ANALYSIS

Xiaogang Wang[1] and Wei Xie[2,1]
[1]School of Physical Education, Shanxi University, Taiyuan, China
[2]Sports Medicine and Research Center, Singapore Sports Council, Singapore

The aim of this paper is to study the error induced by the time difference of the unsynchronized (no genlock connection) video cameras while they are applied to capture video for three-dimensional motion analysis, such as in competition arena. Three synchronized video cameras were used to capture data for this study at the rate of 200fields/second in laboratory and competition field of discus events. The motion of free fall is used to analyze the error of vertical position and velocity of the object. Finally the data of discus throw is discussed at different time-delay of the cameras.

KEY WORDS: error, unsynchronized, camera, motion, analysis

INTRODUCTION: The three-dimensional motion analysis has been widely using in the research work of sports biomechanics. For three-dimensional computing of Direct Linear Translation (DLT), two or more than two cameras are applied to capture the image of subjects. Generally all used cameras must be synchronized to assure that there is no time difference among the recorded images, because the time difference induces measurement error while the DLT is applied to translate the two-dimensional coordinates from multi cameras into three-dimensional coordinate. But synchronizing cameras needs many long cables to connect the cameras, sometimes it is inconvenient in the competition arena especially if the cables need to cross runway. Similarly it is also not easy if you are going to change the location of the cameras. Now unsynchronized cameras are also used to capture image for three-dimensional motion analysis by DLT. Using camcorder doesn't need extra monitor, VCR, power and cables, and it is easily carrying and moving anywhere. In this way, the users may save much time, equipment and be more easily and efficiently to set up the cameras for data acquisition. But unsynchronized image will bring error into the data and there are some ways to reduce time difference such as extra light synchronizer, interpolate data and match them with series synchronous events. But some existing motion analysis systems in market don't allow user to process data before DLT for reduction of the time difference.

The aim of this paper is experimentally analyze the error of three-dimensional measurement, which is caused by time-difference between the video images in computing of DLT without data process of reducing the time difference. The error of coordinates and velocities are discussed for the measurement of free-fall and discus throw by using Peak Motion Analysis System. Firstly the free fall is an example of the cameras' axes being perpendicular to the direction of motion. Then the data of discus throw is discussed as the example in practice.

METHODS: In this study, the speed difference among all video cameras is supposed to be equal or so small during the video capture that it may be neglected, thus the time difference among the images of the cameras is constant.

Firstly the video images recorded by three synchronized cameras are digitized and then the raw two-dimensional coordinates from one or two cameras are shifted leading or lagging in time domain, to simulate the time difference of the images among the cameras. After computing the shifted two-dimensional data by DLT and Butterworth filter, the three-dimensional data is obtained. Finally the error is estimated by comparing the time-shifted data with the original.

Three synchronized Peak HSC-200 (200/50 fields/second) video cameras were applied to capture video at 200 fields/second in both free-fall and discus throw tests. The collected video was processed, manually digitized and computed by Peak Motus V 4.3 Motion Analysis System. Figure 1 and 2 show the placement of the cameras and the coordinates system in the arena of data acquisition.

In the free-fall test, the object was 2 kg white colored iron ball, falling from the height about 3 meters. The three cameras were located in a horizontal plane and about 120 degrees apart in between (Figure 1). The data of discus event of the 19th South East Asian Games (SEA Games) was also used for the analysis. There were also three video cameras located in a horizontal plane in the competition field of discus final event of the SEA Games (Figure 2). Camera 1 was located for right-hand view (facing throwing direction), camera 2 was back view and camera 3 was left-front view. The angle between the optical axes of camera 3 and camera 1, same as that of camera 3 and camera 2, was about 135 degrees.

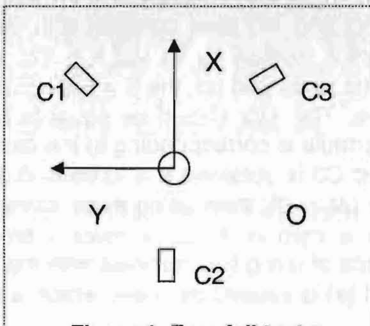

Figure 1 Free-fall test.

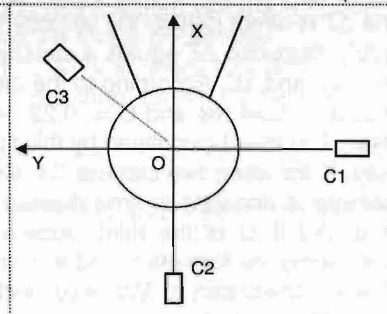

Figure 2 Discus throwing event.

To reduce the influence of the error caused by calibration, manual digitization, data conditioning and other factors, same group of digitized raw data was used to produce the data of different time-shift. The raw data from one or two cameras was shifted to cause the man-made time-difference just before the compute of DLT, to simulate the unsynchronized data at different time-difference at 5 ms, 10 ms, 15 ms and 20 ms as ¼, ½, ¾ and 1 field difference of the normal PAL video camera. The coordinates and velocities are calculated, and filtered by Butterworth filter at cutoff frequency 8 Hz. Finally the data is compared at different time-shift and the error caused by these time shift is discussed.

RESULTS AND DISCUSSION: Figure 3 and 4 show the results of the free fall and discus throw, where (Δt_1,Δt_2,Δt_3) indicates the shifted time of C1, C2 and C3 respectively, the unit is millisecond (ms), and the minus (-) means shifting time to leading. ΔX, ΔY, ΔZ, ΔV and ΔVz indicates the difference between the time-shifted and original data of vertical coordinate and velocity.

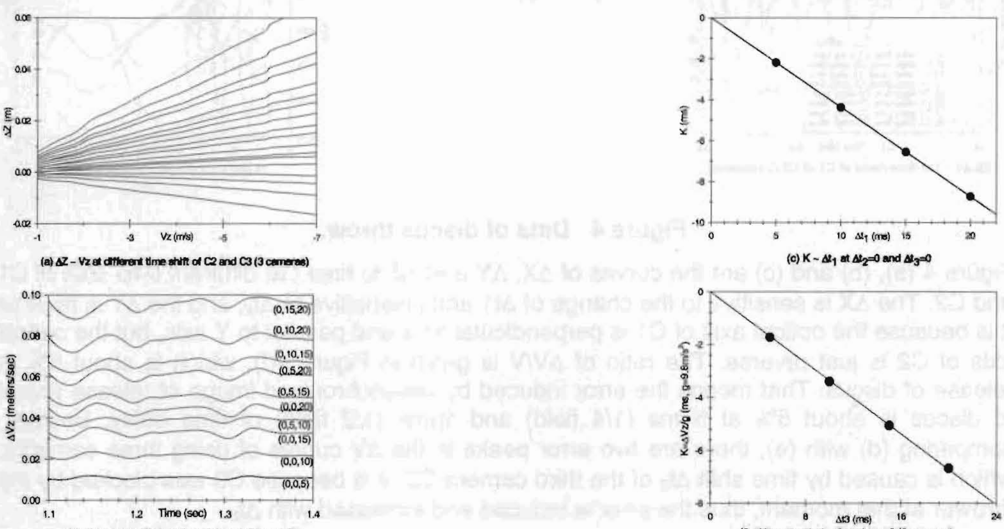

Figure 3 Data of free-fall test.

Free-fall test: Only the vertical coordinate Z and velocity Vz are discussed here. The data in Figure 3 (a) and (d) illustrates that the time difference Δt causes the coordinates and velocity deviating from the original value. The departure rises with the increase of Δt. If Δt is constant, the ΔZ is direct ratio to the velocity Vz and ΔVz likes constant with fixed acceleration (g = 9.8 m/s^2). Suppose ΔZ equals a constant K multiply by Vz (ΔZ = K Vz), where K is a function of Δt_1, Δt_2, and Δt_3. According to the data in (b) and (c), the $K = A\Delta t_1 + B\Delta t_2 + C\Delta t_3$, where A =-0.44 ms, B = -0.34 ms and C = -0.22 ms. The ΔVz should be equal to K multiplying by g = 9.8 m/s^2. The result calculated by this formula is corresponding to the data in Figure 3(f). In same way, K for using two camera C1 and C3 is obtained $K = -0.65\Delta t_1 - 0.34\Delta t_3$. Suppose that one camera is accurate in time domain ($\Delta t_1 = 0$), then using three cameras may reduce the ΔZ and ΔVz if Δt of the third camera is zero or it has a reverse time shift. It is proved by comparing the formula K and test data of using two cameras with that of using three cameras. The nonlinear part of ΔVz in (d) and (e) is caused by noise, which is also amplified by bigger time difference Δt.

Discus: Only the coordinates and velocities of the discus are discussed here since it was the fastest among the measured objects. It will have bigger time-shift induced error in measurement comparing with other measured points according to above analysis. Figure 4 gives the data of discus throw, where (a), (b), (c), (d) and (f) are the data of using two cameras (C1 and C2), (e) is that of using three cameras.

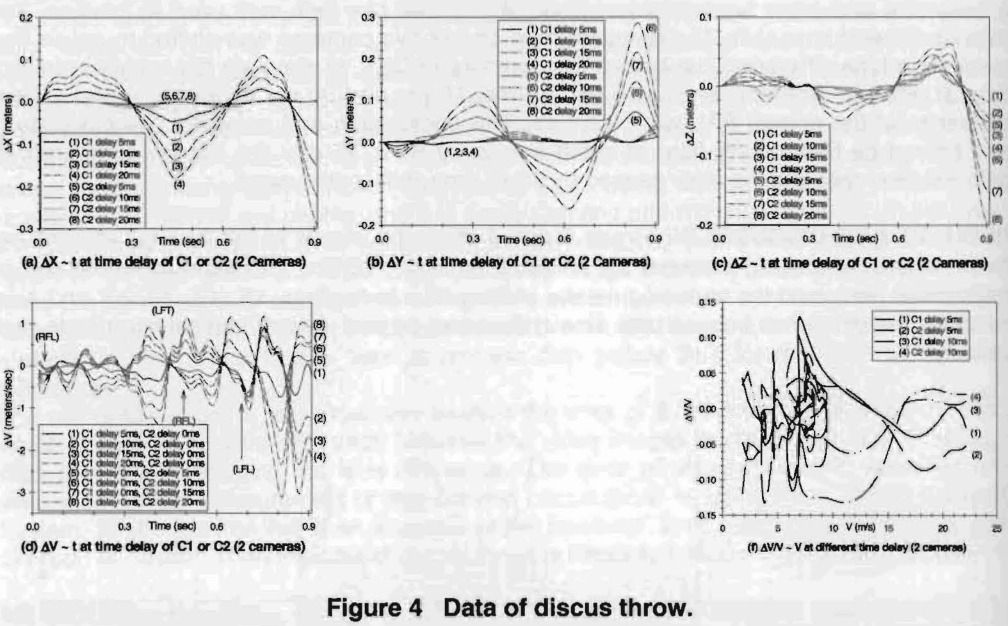

Figure 4 Data of discus throw.

Figure 4 (a), (b) and (c) are the curves of ΔX, ΔY and ΔZ to time t at different time shift of C1 and C2. The ΔX is sensitive to the change of Δt1 and insensitive to Δt_2, and the ΔY is reverse. It is because the optical axis of C1 is perpendicular to X and parallel to Y axis, but the optical axis of C2 is just reverse. The ratio of ΔV/V is given in Figure 4(f), which is about 5% at release of discus. That means the error induced by unsynchronized image of release speed of discus is about 5% at 5 ms (1/4 field) and 10ms (1/2 field) of time delay. Besides, comparing (d) with (e), there are two error peaks in the ΔV curves of using three cameras, which is caused by time shift Δt_3 of the third camera C3. It is because C3 was blocked by the thrower at that moment, thus the error is induced and increased with Δt_3.

CONCLUSION: The application of unsynchronized cameras can give user such convenience that they are applied in three-dimensional motion analysis, although they may bring measurement error. The error may not only be estimated by using motion analysis system (such as Peak Motus) to simulating the time difference before data acquisition, but also could controlled according to what to be measured by following way: (1) minimize the time error of the cameras that is perpendicular to measured velocity, (2) use the third camera, (3) select the synchronous event to control the time difference among the image of cameras.

As discussed above, the ΔX, ΔY and ΔZ are less than 0.1 m, $\Delta V/V$ is about 10% and error of release speed of discus is about 5% at $\Delta t1$ or $\Delta t2$ not more than 10ms (1/2 field of PAL video). The error is acceptable for technique analysis.

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