SYNCHRONIZATION OF VIDEO KINEMATIC AND ANALOG BIOMECHANICAL DATA USING THE MOTION ANALYSIS SYSTEM

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INTRODUCTION

A significant advantage of using integrated biomechanical data collection systems to study human movement is the simultaneous storage in a single computer of video-derived kinematic data and digitized records of analog data such as force plate and electromyographic signals. However care must be taken to assure that these records are properly synchronized by the respective data-logging parts of the hardware and software. This is particularly important when both types of data are combined to calculate dynamic values such as net joint moments, and when very small time shifts are significant, as is often true with electromyographic data. In fact, for some studies the primary variable of interest is the time between a force change or EMG burst and a kinematic change, thus requiring very precise synchronization of the two data sets. The issue is often complicated by the use of different sampling rates for the video and analog data. We have studied data synchronization using the Motion Analysis Corporation's ExpertVision 60 Hz video system (with a VP320 video processor) and have identified three important issues: 1) data sampling initiation; 2) video/analog sampling initiation synchronization; and 3) sampling rate accuracy. This report describes the errors found related to each of these issues and suggests procedures suitable to correct or control potential synchronization errors.

METHODOLOGY

We examined the three main issues identified above with a two-camera 3-D video kinematic system (ExpertVision, Motion Analysis Corp.) and the analog-to-digital (A/D) system (Data Translation) supplied by Motion Analysis. The ExpertVision system was run on a Sun Sparc workstation linked via thick-cable Ethernet with a Gateway 2000 386 PC in which the A/D system was installed. Outputs of a Bertec force plate were connected to the A/D system inputs. A Motion Analysis-supplied optical trigger switch was wired to initiate data sampling when a light beam was interrupted.

We used two experiments to study data collection synchronization issues. In order to examine the temporal relationship between collected data and events used to trigger or initiate sampling, the sweep of a storage oscilloscope (Tektronix) was triggered by the output of the optical triggering device, which was also connected to the video processor. The electrical signal from the video processor which triggered the A/D sampling was viewed on the oscilloscope. The delay between external triggering event (breaking the light beam) and triggering A/D sampling could be read from the oscilloscope screen with an accuracy of 1 ms. In this experiment we sampled 78 triggered sweeps.

In order to examine the temporal synchronization of the analog and video data, kinematic (vertical position) and analog (vertical reaction force) data were simultaneously collected during five ten-second epochs of repeated ball drops onto the force plate. The ball was a retroreflective marker sphere (2 cm dia.). Two 60 Hz (NEC, TI-

23A, CCD) cameras were oriented at about 100° and focused on the drop area. Three-dimensional spatial calibration was obtained using sixteen markers, four along each vertical edge of a cube with 2 m sides. Seven drops were performed from a height of about 0.8 m in each 10 s epoch, providing a total of 35 events.

The analog data were examined for the first indication of the reaction force corresponding with each ball impact, and the time of onset relative to sampling onset was noted to the nearest millisecond. The vertical kinematic record of the ball was likewise examined to determine the time of impact. Since the video sampling rate was 60 Hz, a graphical interpolation strategy was devised to estimate the exact time of impact. The time history of the ball vertical position was plotted for ten pre-impact and ten post-impact flight frames, ignoring frames immediately adjacent to the impact. A curve was fitted to these two data sets for each impact, and the curves were extended to intersect. This intersection occurred at true impact and allowed estimation of the onset of impact within 4 ms (this level of uncertainty was primarily related to digitization error, represented by deviations of the data from the fitted line). In order to estimate the initial analog to video synchronization error and the continuous synchronization throughout the ten-second epoch, a linear regression was performed on the paired estimates of impact onset from analog and video data.

RESULTS and DISCUSSION

The results of these two experiments were used to address three major issues in data synchronization. The first issue is how data sampling initiation is related to the onset of the triggering event. The data collected from 78 triggered sweeps showed a delay from trigger onset to analog sampling onset which ranged randomly from 17-34 ms (Figure 1). These times correspond to a delay of from one to two video frames (at 60 Hz). Motion Analysis documentation describes the cause of this variable delay (Motion Analysis, 1990). The external trigger signal is led to the video processor, which waits for one 60 Hz clock pulse then initiates the analog sampling on the second subsequent pulse. Thus the delay consists of the combination of a variable wait for the first pulse (0-17 ms) and an additional 17 ms calibrating wait for the second pulse. (This same process occurs in the initiation of analog data sampling, but when sampling at 1000 Hz this only introduces a delay of about 1.5 ms, not significant in light of the 16.7 ms video sampling interval.)

This arrangement is predicated on the assumption that data sampling will not be initiated precisely with a (temporally) significant event. Accurate synchronization of data with real-time events can only occur if the data collection has already been initiated and a marker of the event is stored with the data. One way to accomplish this is by sending an event-marking signal to an analog data channel. Another way is to store an auditory "mark" or tone on one of the video system's two audio channels. Data analysis software then allows identification of the first video frame to include the tone. Both of these methods offer temporal precision equal to the respective analog or video sampling rate. One technique for matching video and analog records involves interpolating data values between the measured points (Motion Analysis, 1986). (ExpertVision uses the "stretch operator" to perform a spline interpolation.) However this technique cannot help increase precision in identifying a step change in a kinematic trace or a marker signal because the interpolation will smooth the change out over the entire interframe interval.

The second issue is closely related to the first and addresses the simultaneity of sampling initiation for both the video and analog data. We calculated ball impacts in both the video and analog records and then subtracted the video onsets from the respective analog onsets to determine the analog-video delay. Since this value appeared to be somewhat dependent on when in the epoch it occurred, we calculated a linear regression of the A-V delay on the analog time of onset (Figure 2). The resulting equation was $Y=11.5 + .003X$, in which the y-intercept indicates the predicted delay. A positive 11.5 indicates that the video estimate of impact onset precedes the analog estimate by 11.5 ms. This estimate must be further corrected by the 1.5 ms initiation delay for analog sampling (see above) so the full estimate of synchronization error was 13 ms. Since the video estimate of onset included some error, this y-intercept is best understood as a single video frame offset (17 ms).

The explanation of this observation appears to be that the video analysis system expects the video signal to be buffered in the camera, so that each image sampled actually occurred during the preceding frame interval. Some video cameras do this, others do not. Our cameras apparently were not buffering, so the automatic video delay in sampling introduced an additional one-frame synchronization error. (It is important to keep in mind that delaying the onset of video sampling relative to analog sampling makes each event, such as a ball impact, appear to occur earlier in the video record, or at fewer elapsed frames, than it should.) The correction for this problem is almost always in the software, either before or after data collection. It may be possible to reset the sampling algorithm so that it doesn't wait a frame before starting to sample. It is certainly possible to alter the frame count in the collected data sets before further post-processing. Other methods to assist in precise initiation synchronization include collecting the video synch pulse (or an elongated derivative) on an unused analog channel or including at sample onset simultaneous light and electrical pulses on the video and analog data respectively.

The third issue, maintaining synchronized analog and video sampling throughout the sample period, arises since each data collection process assigns time values throughout based on a nominal sampling rate. Errors in this assumed rate will cause increasing cumulative synchronization error throughout the sampling interval unless appropriate corrections are applied. We have found the analog data collection rates to be very accurate (within the 100-2000 Hz range). However the video sampling rate deviates from the nominal 60 Hz. Our regression equation has a coefficient of .003, indicating a 0.3% error in sampling rate. The slope is positive, indicating that the video clock is actually sampling at about 59.82 Hz. The A-V error thus increases over sample time by about 3 ms for each second of sampling or about 30 ms after 10 s. This error requires a software adjustment to the packaged calculation of video frame times. If uncorrected, the error will add to the one-frame A-V delay for a total delay of about 47 ms after 10 s. (Note: the 59.82 Hz clock is an improvement by hardware substitution over the 59 Hz clock originally supplied with our system.)

One way to approach this problem of a variable synchronization between video and analog data is to synchronize the two sampling clocks. The Motion Analysis system supports this option, providing a video clock pulse which could be used to drive the A/D board at its inherent rate (60 Hz) or any multiple of that rate (Motion Analysis, 1989). While this would keep the A-V delay from increasing throughout the sample, the problem of the "slow" video clock would remain. Thus a software adjustment would still be required to obtain true times for the data.

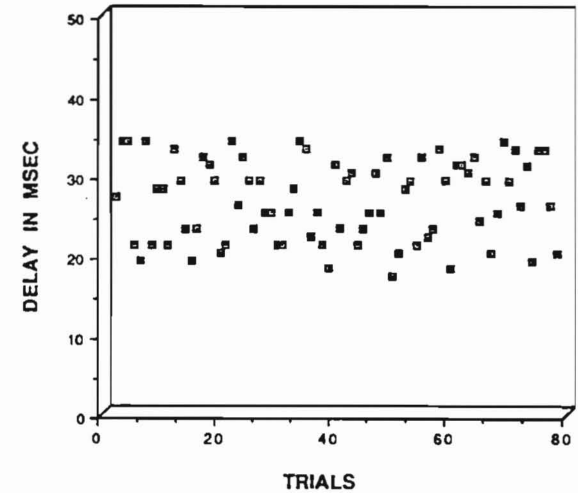

Figure 1. Delay values from external trigger to analog sample initiation trigger for 78 trials showing a 1 to 2 frame delay.

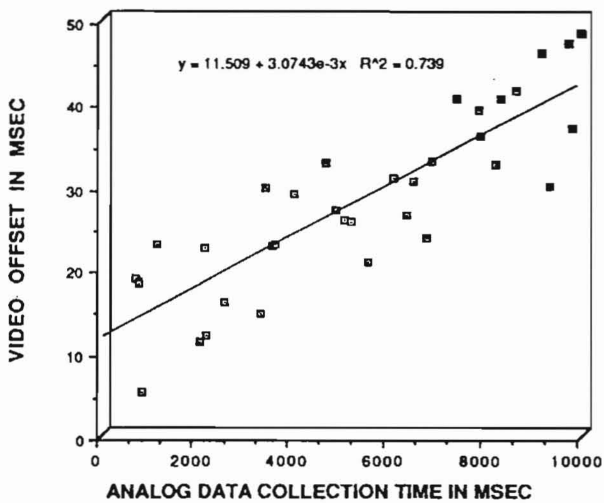

Figure 2. Analog-video delay values plotted as a function of time of occurrence during a 10-second sample. The regression line reveals a progressive increase in delay over time. The y-intercept indicates an initial delay of one video frame; the slope indicates a 0.3% error in the video clock.

CONCLUSIONS

Synchronization errors are system-specific, and may be constant or variable. Such errors may reflect discrepancies between real-time events and sampled records, or between video and analog data records. The significance of these errors depends on the level of precision demanded by each application. Collection of accurately synchronized video kinematic and analog data is possible but requires careful attention and post-processing to control these sources of potential error.

REFERENCES

Motion Analysis Corporation. (1989). ExpertVision User's Manual.

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