A VIDEO-SYNCHRONIZED HIGH-SPEED-EMG AND METABOLIC DATA ACQUISITION SYSTEM

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A video-synchronized electromyography (EMG) and metabolic data acquisition system is being developed to monitor human response to workplace conditions. This high-speed EMG data rate (1000 Samples/second/channel for 16 channels) plus metabolic data acquisition (20 seconds of refresh interval) is suitable for the combination of frequency-domain muscle fatigue and time-domain human stress studies associated with human activities. The system is composed of a video camera/recorder to record human activity images, and a personal computer to simultaneously acquire the EMG and the metabolic data (including oxygen consumption, carbon dioxide generation and heart rate) along with the video time-codes from the video recorder. The computer uses the time-codes recorded both on the video tape and in the data file to synchronize each video frame with the corresponding segment of the physiological data sequence. With the recorded time-codes, the computer is able to search a physiological data segment correspondent to any recorded video frame, and vice versa.

INTRODUCTION

To analyze a worker's stress in various workplace conditions, the researchers need to collect multi-channel EMG data and variety of metabolic data in various body postures. This body-movement related data analysis requires a video-synchronized multi-channel data acquisition system, sometimes, with a high frequency data bandwidth if the frequency-domain EMG analysis is needed. Some schemes have been published to achieve video-synchronized data acquisition (Gaskill, *et al.*, 1992; Vannier, *et al.*, 1992; Gacía, *et al.*, 1995; Yen and Radwin, 1995; Engström and Medbo, 1997; Zeng, *et al.*, 1999 and 2000). But no published method has been found to conduct synchronized data acquisition for three types of signals: video images, high-speed-EMG data and metabolic data.

This literature introduces a computerized data acquisition system which records the human motions on a video tape and acquires high-speed- EMG and metabolic data on a computer hard disk. The system utilizes a data interface board to line up the video time codes with the EMG data and metabolic data, and further synchronizes the video frames on the video tape with the EMG-metabolic data on the hard disk by a time-code-bridge-file. With handling only the video time codes in the system computer instead of large-sized video signals, this system not only effectively synchronizes the video frames with the EMG/metabolic data, but also boosts the total data acquisition speed, and enables long recording duration.

METHOD

System Hardware

Fig. 1 shows the system setup of this computerized video-synchronized data acquisition. The system consists of a video camera to output NTSC color video signals, a digital video tape recorder (VTR) with a Society of Motion Picture & Television Engineers (SMPTE) longitudinal time code (LTC) output, a TV monitor to display video frames, a multi-channel EMG device with parallel digital output, a metabolic data device with a serial RS232 data output, a signal-interface board to line up and condition the LTC, EMG and metabolic data streams, and a 266-MHz Pentium II microprocessor-based system computer with a 32-bit digital I/O board for data acquisition and signal processing.

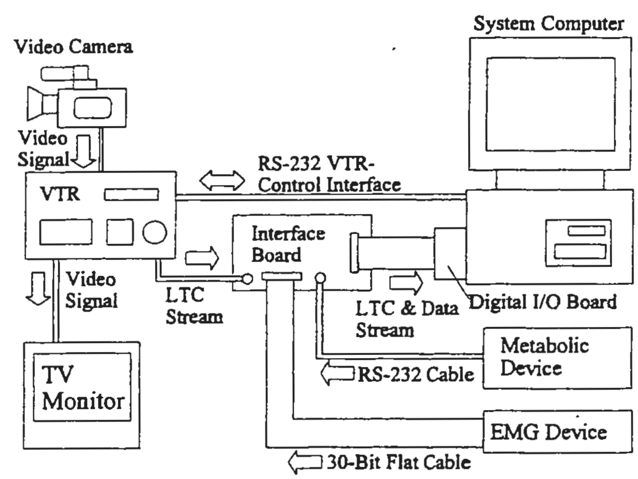


Fig. 1 System setup of the video-synchronized high-speed-EMG and metabolic data acquisition.

During data acquisition, the human motion video signals are recorded by the VTR onto a digital video tape, and monitored by the TV monitor. Meanwhile, the VTR, the EMG device and the metabolic device output the LTC, the multi-channel EMG data and various metabolic data to the interface board, respectively. The interface board receives all three types of signals simultaneously, and forms a combined 32-bit integer stream. The simultaneous input of these signals ensures that the LTC, EMG and metabolic signals in each 32-bit integer are temporally synchronized. For every integer sent from the interface board to the digital I/O board, the I/O board scans the integer, and in turn outputs the scanned integer to the system computer buffer for further data processing.

Input Data Mapping and Scanning

Fig. 2 shows the data mapping of the system. The total number of combined LTC, EMG and metabolic data bits equals the number of I/O board input bits. The binary LTC stream occupies one bit of I/O input. Since the dual eight-channel EMG device needs more frequency bandwidth for each EMG channel (≥500 Hz/channel), it occupies a total of 30 bits of the I/O input. Each of the eight-channel EMG device has a 12-bit parallel data output and a 4-bit channel-synchronization output. At each clock cycle, each of the eight-channel EMG device outputs one of eight channels of EMG data in sequence, and outputs the corresponding channel number for channel identification. In order to fit the 30-bit allocation for the dual EMG device, the least significant data bit of each EMG data was truncated, with 11 bits of EMG data resolution left. The metabolic data device has a low data rate of 2400 bits/second, so it has a serial output, and occupies one bit of the I/O input. The interface board lines up the combined 32-bit data stream, conditions the binary signals, converts the voltage level of the LTC and metabolic signals to 0-5 V, and outputs the integers to the I/O board for scanning.

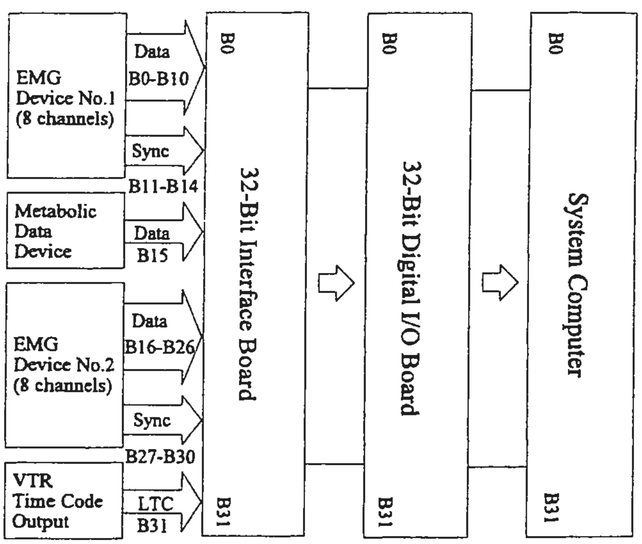


Fig. 2 Input data mapping of the 32-bit data acquisition system.

The scanning frequency of the I/O board was determined by the frequency bandwidth of the three incoming signals. The data frequency of the bi-phase modulated LTC stream is no more than 2400 Hz. The dual EMG device has a 500 Hz/channel frequency bandwidth for 16 EMG data channels, and has a 16 kbits/second data rate for the channel-synchronization signals. The metabolic device outputs a data packet for every 20 seconds containing oxygen consumption, carbon dioxide generation and heart rate/breath rate data with a total data rate of 2400 bits/second. Among these data rates/bandwidths, the EMG synchronization signals have the highest data rate, and therefore the minimum scanning frequency for sampling these three data streams should be no less than 16 ksamples/second. In practice, the scanning frequency of this digital I/O board should be selected to a higher frequency, to provide more scans for each data bit to avoid decoding errors during data processing.

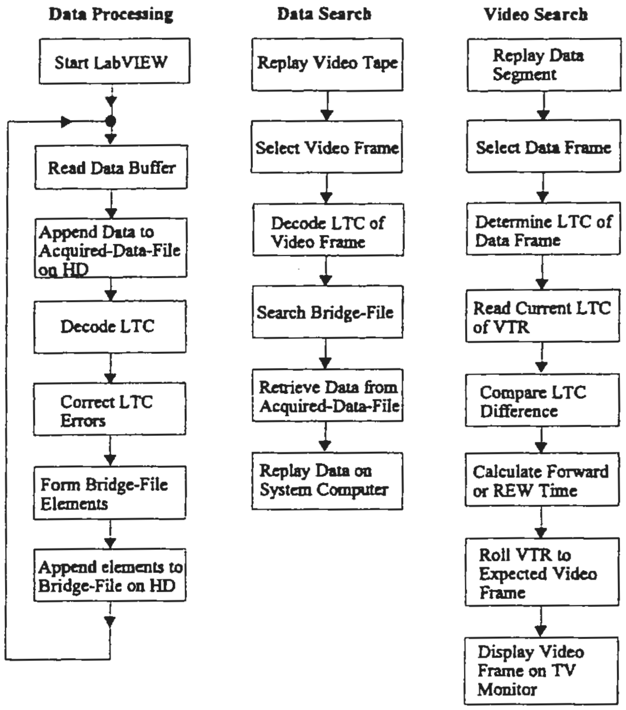
System Computer Program

LabVIEW graphical programming software (National Instruments, Austin, TX) was used to program the data acquisition, processing, storage and replay, and VTR control. The computer program consists of three sub-programs: the data processing, data search and video search sub-programs. The task of the data processing sub-program is to decode the SMPTE LTC from the VTR, and to build an acquired-data-file and a time-code-bridge-file. The task of the data search sub-program is to search the data segment correspondent to a given video frame, by retrieving the timing information from the time-code-bridge-file. The task of the video search sub-program is to do the reverse search for the video frame correspondent to a given data segment, also by retrieving the timing information from the time-code-bridge-file, but in reverse direction.

Data processing sub-program. The data processing sub-program flow chart is shown in Fig. 3 (a). During video-synchronized data acquisition, the sub-program monitors the incoming 32-bit data integers to the computer buffer. Whenever the buffer is half full, the program retrieves all the integers from the buffer, and appends them to the acquired-data-file on the hard disk. The acquired-data-file is an integer array consisting of all 32-bit integers acquired during data acquisition [Fig. 4 (a)]. This array contains the binary LTC stream, EMG data and sync signal stream and metabolic data stream.

In the meantime, the sub-program retrieves the LTC bit stream from Bit 31 of the retrieved integer sequence, and sends the LTC stream to the decoding subroutine for LTC decoding. During decoding, the subroutine determines the index number of the acquired-data-file at each video frame-start, and translates each LTC into a unique 8-digit frame number integer [Fig. 4 (b)]. After each decoding, the sub-program scrutinizes decoded time code to determine whether the decoded frame-start is within a predicted tolerance range (1/80 of a video frame, set by this program) and whether the decoded time code integer matches the predicted number. If it is not, the sub-program automatically discards this erroneous LTC and later interpolates this time code between two correctly decoded time codes.

After the decoding, the sub-program forms a time-code-bridge-file with a two-column array. The time-code-bridge-file is a cross reference file that links the timing of the video frames with the timing of the EMG and metabolic data. As shown in Fig. 4 (b), the LTC column of the array contains the 8-digit frame-number integers of all recorded video frames, and the data-file-index column contains the corresponding index numbers of the acquired-data-file at frame-starts. In this way, each row of the array represents a unique video frame and its corresponding acquired-data-file index number at the frame-start. With this time-code-bridge-file, the computer is able to search for any data segment correspondent to a given video frame, or search for any video frame correspondent to a given data segment.



(a) (b) (c)

Fig. 3 Flow charts of the system computer sub-programs.

EMG/Metabolic data searching sub-program. The flow chart of the sub-program for EMG/metabolic data searching is shown in Fig. 3 (b). During video frame replay, the VTR outputs the video frame-by-frame to the TV monitor, and outputs the LTC to the computer via the interface board and digital I/O board. When an interesting video frame is determined on the TV monitor and is frozen by the VTR, the sub-program acquires and decodes the frozen LTC from the VTR through the RS232 VTR-control interface. With the decoded time code of the frozen video frame, the sub-program searches for the identical time code on the LTC column of the time-code-bridge-file, and in turn determines the corresponding frame-start index number of the acquired-data-file on the data-file-index column. Obtaining the expected corresponding index number, the sub-program retrieves the expected data segment from the acquired-data-file. The sub-program converts B0-B10 and B16-B26 of the 32-bit integer array into dual eight-channel EMG signals, and converts B15 of the array into the metabolic data containing the values of oxygen consumption, carbon dioxide generation, expire volume, heart rate and respiratory rate. The sub-program displays EMG/metabolic signals on the computer monitor.

Video-frame searching sub-program. As shown in the video-search flow chart in Fig. 3 (c), the sub-program uses the time-code-bridge-files to retrieve a desired length of data from the acquired-data-file, replays the data frame-by-frame on the system computer monitor, and tracks the frame-start index number of the replayed data on the data-file-index column of the time-code-bridge-file. When an interesting frame of replayed data is determined and frozen on the computer monitor, the sub-program retrieves the corresponding LTC from the LTC column of the time-code-bridge-file. The sub-program reads the LTC of the current video-tape position from the VTR through the RS232 VTR-control interface, and determines the difference between the current video-tape LTC and the frozen-data LTC. Then, the sub-program calculates the "Forward" or "Rewind" running time from the current video-tape position to the expected frame. The sub-program finally controls the VTR through the RS232 VTR-control interface to forward or rewind the video tape to the expected frame, and display this video frame on the TV monitor.

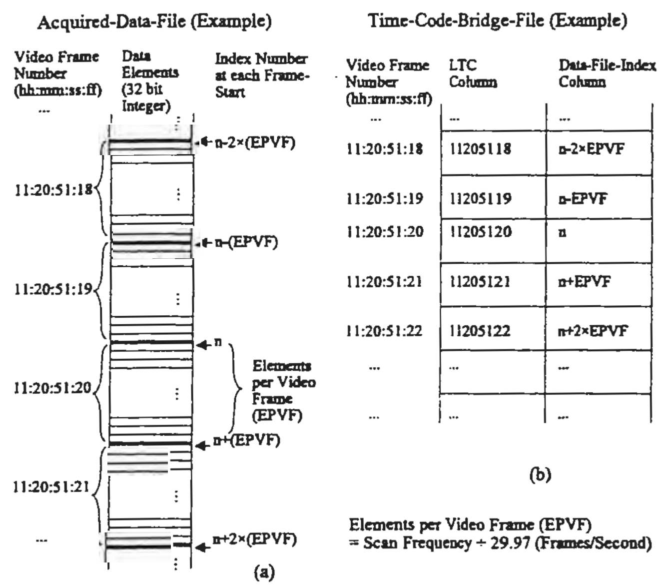


Fig. 4 Structure of acquired-data-file and time-code-bridge-file.

RESULTS AND DISCUSSION

System Capacity

The proper input-data bit mapping enables this data acquisition system to synchronize the video frames with both 16-channel high-speed-EMG data and metabolic data. The separated storage of video signals from the LTC/EMG/metabolic data, and the usage of the time-code-bridge-file further enables real time data synchronization, boosts the data acquisition scanning frequency, and extends the acquisition duration. Currently, the maximum scanning frequency for realtime video-synchronized 32-bit data acquisition achieves 72 kHz without system corruption. With this maximum scanning frequency, the system reliably scans the incoming high-speed EMG data (500 Hz/channel for 16 channels) and metabolic data. At this scanning frequency, the maximum data acquisition duration without data overflow is 30 minutes, which records 506.70 Mbytes of information onto the hard disk: 506.25 Mbytes for the acquired-data-file, and 421.5 kbytes for the time-code-bridge-file. The program effectively decoded the LTC stream in realtime and automatically corrects all decoding errors. The maximum bandwidth of the EMG signals is 500 Hz/channel which is limited by the maximum bandwidth of the EMG device integrated in this system. Without EMG device bandwidth limitation, the maximum frequency bandwidth of this data acquisition system with the same EMG data structure could achieve 2000 Hz/channel at a 72 kHz scanning frequency. The data refresh interval of the metabolic data is 20 seconds which is also limited by the data refresh rate of the metabolic data device integrated in the system. Without data refresh rate limitation, under the current RS232 data packet transmission protocol (60 ASCII characters/packet), the maximum data refresh interval of the metabolic data could achieve 0.25 second at 2400 baud.

Synchronization Accuracy

In the timing accuracy test, 1800 seconds of video signals and corresponding simulated-biomedical signals were acquired at a scanning frequency of 72 kHz. The mean synchronization error between the video frames and simulated-biomedical signals was 0.219 mS and the maximum synchronization error was 1.052 mS (for test setup see Zeng, *et al.*, 2000). To estimate the synchronization accuracy between the video frames and the EMG signals, the intrinsic channel lineup latency of the EMG device should be counted in. For the EMG device used in this system, the intrinsic channel lineup latency is 8 mS. Thus, the estimated mean video/EMG signal synchronization error is 8.219 mS and estimated maximum synchronization error is 9.052 mS. To estimate the synchronization accuracy between the video frames and the metabolic signals, the intrinsic metabolic-data-packet lineup latency of 250 mS should be counted in. The estimated mean video/metabolic signal synchronization error is 250.219 mS and estimated maximum synchronization error is 251.052 mS.

Status of the System Development

The system hardware and software have been developed and tested. The system integration is underway.

CONCLUSIONS

This system accurately synchronizes the acquired 16-channel EMG data and metabolic data recorded on a computer hard disk with the corresponding human activity images recorded on a video tape in realtime. With 500 Hz/channel EMG signal bandwidth and 20 seconds of metabolic data refresh interval, this data acquisition system is adequate for workers' stress monitoring in various work place conditions.

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