Computer generated optical sound tracks

by E. K. TUCKER, L. H. BAKER and D. C. BUCKNER

University of California
Los Alamos, New Mexico

INTRODUCTION

For several years various groups at the Los Alamos Scientific Laboratory have been using computer generated motion pictures as an output medium for large simulation and analysis codes. Typically, the numerical output from one simulation run is so large that conventional output media are ineffective. The time-variable medium of motion picture film is required to organize the results into a form that can be readily interpreted. But even this medium cannot always convey all of the information needed. Only a limited number of variables can be distinctly represented before the various representations begin to obscure or obliterate each other. Furthermore, the data presented usually must include a significant amount of explanatory material such as scaling factors, representation keys, and other interpretive aids. If a film is to have long-term usefulness to a number of people, this information must either be included on the film or in a separate writeup that accompanies the film.

In an effort to increase the effective information density of these films, a study was undertaken to determine the feasibility of producing optical sound tracks as well as pictorial images with a microfilm plotter. Some exploratory work done at the Sandia Laboratories, Albuquerque, New Mexico, suggested that this might provide a good solution to the problem. It has been demonstrated many times that a sound track facilitates the interpretation of visual presentations. However, from our standpoint, the addition of another channel for data presentation was as important as facilitating interpretation. Not only could a sound track present explanatory and narrative material efficiently and appealingly, it could also be used to represent additional data that might otherwise be lost. For example, it is always difficult to clearly represent the movement of many particles within a bounded three-dimensional space. If, however, the collisions of particles—either with each other or with the boundaries of the space—were represented by sounds, interpretation of results would be greatly facilitated. This is feasible only if the sound track is computer produced, not “dubbed in” after the fact. It should be made clear at this point that it was not an objective of this project to have the computer create all of the waveforms represented on the sound track. What was required was that the computer be able to reproduce on an optical sound track any recorded audible sound, including voices or music. The waveforms that the computer would actually have to create could be limited to some of the sounds we wanted to use as data representations.

OPTICAL SOUND TRACKS

Sound is generated by a vibrating body which produces a series of alternating compressions and rarefactions of some medium, i.e., a wave. As this series is propagated through the medium, particles of the medium are temporarily displaced by varying amounts. We shall speak of the magnitude and direction of this displacement as the instantaneous amplitude of the wave. If the variation of this amplitude can be described as a function of time, a complete description or encoding of the wave is obtained. Thus, a sound wave can be “stored” in various representations, as long as the representation fully describes the variation of amplitude with respect to time.

An optical sound track is one way of representing a sound. It consists of a photographic image which determines the amount of light that can pass through the track area of the film at a given point. As the film is pulled past the reader head, varying amounts of light pass through the film to strike a photocell, producing a proportionally varying electrical signal. A given change in signal amplitude can be produced at the photocell by varying either the area or the intensity of exposure of the sound track image.

Conventional sound tracks are produced by either of two methods. The variable area type of track is pro-
duced by having a beam of light of constant intensity pass through a slit of variable length to expose the film. In the variable intensity recording method, either the light’s intensity or the slit width can be varied with the slit length held constant. Commercial sound tracks are produced by both methods. In both cases, the sound track image is produced on a special film that is moved past the stationary light source. Separate films of sound track and pictures are then reprinted onto a single film.

Sixteen-millimeter movies with sound have sprocket holes on only one edge. The sound track is located along the other edge of the film (see Figure 1). Such sound tracks are normally limited to reproducing sound with an upper frequency of 5000-6000 Hz. This limitation is imposed by the resolution that can be obtained with relatively inexpensive lens systems, film and processing and by the sound reproduction system of most 16 mm projectors.6

INPUT SIGNALS

In order not to be limited to the use of computer created sounds alone, it was necessary to be able to store
other complex audio signals, such as voices, in a form that could be manipulated by a digital computer. As discussed above, any audio signal can be completely described by noting the variation of the signal's amplitude as a function of time. Therefore, the data for a digital approximation of an audio signal can be obtained by periodically sampling the signal's amplitude (see Figure 2). The primary restriction associated with this approach requires that the sampling rate be at least twice the highest frequency contained in the signal. In effect, samples obtained at a relatively low sampling rate $S$ from a wave containing relatively high frequencies $f$ will create a spurious “foldover” wave of frequency $S-f$.

The input for our experimental film was recorded on standard 3/4-inch magnetic tape at a speed of 7 1/4 IPS. Frequencies greater than 8000 Hz were filtered out, and the resulting signal was digitized at a sampling rate of 25,000 samples/second. The digitizing was performed on an Astrodada 3906 analog-to-digital converter by the Data Engineering and Processing Division of Sandia Laboratories, Albuquerque. The digital output of this process was on standard 1/2-inch 7-track digital magnetic tape in a format compatible with a CDC 6600 computer. This digital information served as the audio input for the sound track plotting routine.

PLOTTER MODIFICATIONS

All of our early experimental films were produced on an SD 4020 microfilm printer/plotter. Three modifications had to be made to the 16 mm camera of this machine in order to make these films. These modifications do not affect any of the camera's normal functions.

In the first modification, the Vought 16 mm camera had to be altered to accommodate single sprocketed 16 mm movie film. For this it was necessary to provide a single sprocketed pull-down assembly. This was accomplished by removing the sprocket teeth on one side of the existing double sprocket pull-down assembly. Next, it was necessary to replace the existing lens with a lens of the proper focal length to enable the camera to plot the sound track at the unsprocketed edge of the film.

The lens used was a spare 50 mm lens which had previously been used on the 35 mm camera. With the existing physical mountings in the 4020, this 50 mm lens presents, at the film plane, an image size of approximately 17.5 X 17.5 mm. Thus, with proper raster addressing, a suitable 16 mm image and sound track may be plotted on film. (Increasing the image size in this fashion produces a loss of some effective resolution in the pictorial portion of the frame while the 50 mm lens is in use. This loss of resolution in the picture portion is not particularly penalizing in most applications.) Finally, it was necessary to expand the aperture both horizontally and vertically to allow proper positioning and abutment of the sound track on the film.

By interchanging the new lens with the original lens, normal production can be resumed with no degradation caused by the enlarged aperture and single sprocketed pull-down. No other modifications were required on the SD 4020 in order to implement the sound track option.

The primary difficulty we encountered using the SD 4020 was that we could not get consistently accurate butting of consecutive frames. Therefore, the later films were plotted on an III FR-80, which has pin registered film movement. In order to use this machine, the film transport had to be altered to accommodate single sprocketed film, and the aperture had to be enlarged. A software system tape was produced to allow the sound track image to be plotted at the unsprocketed edge of the film, with the pictorial images still plotted in the normal image space. The FR-80 also provides higher resolution capabilities, so that no loss of effective resolution is incurred when pictorial images and the sound track are plotted in one pass through the machine.

As was discussed earlier, optical sound tracks are usually limited to reproducing sound with an upper frequency of 5000-6000 Hz. Since motion picture film is projected at a rate of 24 frames/second, a minimum of
410 lines per frame are needed to represent such frequencies in the sound track. While we have made no quantitative tests to demonstrate the production of such frequencies, we would expect efficient resolution to produce frequencies in or near this range with either of the plotters. Our applications so far have not needed the reproduction of sounds in this frequency range.

THE TRACK PLOTTING ROUTINE

The present sound track plotting routine was written with three primary objectives in mind. First, it was felt that it would be advantageous to be able to produce both pictorial imagery and the sound track in one pass through the plotter, with the synchronization of pictures and sound completely under software control. Second, the routine was written to allow the user maximum flexibility and control over his sound track “data files”. Finally, the routine was designed to produce film that could be projected with any standard 16 mm projector.

One-pass synchronization

The sound track plotting routine is written to produce one frame's sound track at a time, under the control of any calling program. However, in a projector, the reader head for the sound track is not at the film gate; it is farther along the threading path. The film gate and the reader head are separated by 25 frames of film. Therefore, to synchronize picture and sound, a frame of sound track must lead its corresponding picture frame by this amount so that as a given frame of sound track arrives at the reader head, its corresponding pictorial frame is just reaching the film gate. In order to be able to generate both picture and sound in one pass through the plotter, it was necessary to build a buffer into the sound track plotting routine. This buffer contains the plotting commands for 26 consecutive frames of film. In this way, a program plotting a pictorial frame still has access to the frame that should contain the sound track for the corresponding picture.

The simultaneous treatment of pictorial plot commands puts the synchronization of pictures and sound completely under software control. Furthermore, this can be either the synchronization of sound with picture or the synchronization of picture with sound. This is an important distinction in some applications; the current picture being drawn can determine which sound is to be produced, or a given picture can be produced in response to the behavior of a given sound track wave.

Flexibility

The present routine will read from any number of different digital input files and can handle several files simultaneously. Thus, for example, if one wishes to have a background sound, such as music, from one file behind a narrative taken from another file, the routine will combine the two files into a single sound track. The calling routine can also control the relative amplitudes of the sounds. In this way, one input signal can be made louder or softer than another, or one signal can be faded out as another one fades in. Any input file can be started, stopped, restarted or rewound under the control of the calling program.

DEMONSTRATION FILMS

Several films with sound have been produced using the sound track plotting routine. Most of the visual portions were created with very simple animation techniques in order to emphasize the information content added by the sound track. The films review the techniques employed for the generation of a sound track. No attempts have been made to rigorously quantify the quality of the sounds produced since no particular criterion of fidelity was set as an objective of the project. Furthermore, the sound systems of portable 16 mm projectors are not designed to produce high fidelity sound reproduction, since the audio portion will always be overlaid by the noise of the projector itself. For our purposes it was enough to make purely subjective judgments on the general quality of the sounds produced.

SUMMARY

The ability to produce optical sound tracks, as well as pictorial imagery, on a microfilm plotter can add a tremendous potential to computer generated movies. The sound medium can serve to enhance the visual presentation and can give another dimension of information content to the film. This potential cannot be fully exploited unless the sound track and the pictures can be plotted by the computer simultaneously. Under this condition, the input for the sound track can be treated by the computer as simply one more type of data in the plotting process.

The input for the sound track plotting routine discussed in this report is obtained by digitizing any audio signal at a suitable sampling rate. This digital information can then be plotted on the film like any other data. Very few hardware modifications were made to the
plotter in order to produce sound tracks. The modifications that were made did not affect the plotter's other functions.

The routine is written to give the user as much flexibility and control as possible in handling his sound track data files. Multiple files can be combined, and synchronization is under the control of the user's program.

It now appears that the production of computer generated optical sound tracks will prove to be cost effective as well as feasible. If so, this process could conveniently be used to add sound to any computer generated film.

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