ENVELOPE CONTROL WITH AN OPTICAL KEYBOARD

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An optical keyboard will be employed as an input device for a real-time digital sound synthesis instrument that is under construction at Carnegie-Mellon University. The nature of this keyboard was described at the First International Conference on Computer Music. The present report will further specify certain functions and characteristics of the keyboard and will discuss some of the ways in which this device can be used for entering envelope data into a computer music system.

Human control of electronic sound is essential if the electronic media is to truly further the state of the art of music. The optical keyboard controls the amplitude, phase, and timbre of sounds being created in a straightforward manner. Of course, this device will be difficult for some users to employ because of the control that it requires from the user. Users will, no doubt, acquire the technique necessary to use it, to different degrees, just as other instrumentalists master their own instruments.

However, human inputs are time-varying and hard to duplicate. Understanding that parameters such as envelope might need to vary little with time to preserve timbre uniformity, we have provided two alternate types of, envelope control in the music system being built. An internal envelope parameters memory and an external PDP-11 can control envelope with precision while still permitting various degrees of human interaction.

The completed keyboard will consist of 512 key segments, organized as sixty-four keys ("voices") containing eight segments each (see Figure 1).

Figure 1. Keyboard Organization.
Each of the eight segments can be programmed to represent a separate pitch. However, every vertical group of eight segments is envisioned as representing eight harmonic or non-harmonic partials of some fundamental frequency conceptually represented by the key. Timbre variations on any key are made possible simply by varying the number of segments depressed and the amplitude of each.

When the keyboard is employed in this fashion, timbres are created by additive synthesis. Provision has been made for a maximum of thirty-two segments to be depressed and sounding simultaneously. The number of "voices" sounding depends upon the number of segments per voice. Four voices are possible if all eight segments are depressed on each of four keys. Eight voices are possible if four segments per key are used, and so forth.
For yet greater flexibility, one key is defined as an "FM key." Its output (from one to eight segments) frequency modulates from twenty-four to thirty-one other segments. This feature makes possible a large number of voices that possess complex timbres and timbre variations.

THE KEYBOARD CIRCUITRY

Two types of circuits operate in conjunction with the keyboard: the circuit that scans the keyboard and activates a particular key segment, and the circuit that generates the outputs that the key position indicates.

The keyboard is scanned from bottom to top and from left to right, activating one segment every 25 usec; thus the total keyboard is scanned in 12.8 msec. Each segment is activated by pulsing the two infrared light-emitting diodes (LED's) that it contains for 20 usec. As the key is depressed, one of the LED's moves toward an optical fiber, causing it to carry more light; as the key is tilted clockwise, the other LED moves toward the other optical fiber, causing it also to transmit more light. Thus, each segment generates both an amplitude output and a phase output. Light is transmitted down optical fibers from all key segments in a multiplexed fashion. The fibers terminate at a bank of photodiodes.

The 0-10 vdc output of the photodiode amplifiers can be digitized and used as either the value of amplitude and phase or as an address to a read-only memory (ROM) which can modify the response characteristics of the key in any linear or nonlinear fashion desired.

Table I specifies some of the keyboard's characteristics. Figure 2 shows the electrical response of a key and of the amplifier of the photodiode to which the signal is transmitted.
Figure 2. Key segment electrical response.

A. Amplifier input vs. output
B. Distance between LED and optical fiber vs. output

ENVELOPES OBTAINED UNDER HUMAN CONTROL
The following diagrams characterize the types of envelopes obtainable under human control.

1. Fast attack, variations in steady-state and decay.

Figure 3. 200ms/division
Figure 4. 500 ms/division
Figure 5. 500 ms/division
II. Slow attack, rapid release. Note the variation in release in Figure 7, and the staircase attack in Figure 8.

Figure 6. 500 ms/division
Figure 7. 200 ms/division
Figure 8. 500 ms/division
Figure 9. 200 ms/division

III. Multiple attacks, variations in steady state.

Figure 10. 500 ms/division
Figure 11. 200 ms/division
Figure 12. 200 ms/division
Figure 13. 200 ms/division
IV. Irregular growth and decay.

Figure 14. 200 ms/division
Figure 15. 200 ms/division

V. Impulse at beginning and at end of envelope.

Figure 16. 200 ms/division
Figure 17. 200 ms/division

VI. Maximum speed waveforms. Time axis is 50 ms/division in each.

Figure 18.
Figure 19.

Figure 20.
HUMAN INTERACTION WITH COMPUTER HARDWARE

A simple diagram of the entire music system under consideration will clarify the modes of control and interaction discussed below.


The parameters memory in the preprocessor can be loaded with parameters for eight different envelopes. When used, these envelopes are always assigned to key segments in the same vertical position. That is, the lowest segment on the leftmost key and the lowest segment on the rightmost key have the same envelope. Likewise, the highest segment on the leftmost key and the highest segment on the rightmost key have the same envelope. However, unless the parameters are defined identically for the highest and lowest segments, these highest and lowest segments will have different envelopes, as shown in Figure 1.

A mode bit in the preprocessor controls the usage of key and envelope information from the keyboard, from the preprocessor's own parameters memory, and from the PDP-11. In addition, the preprocessor has function switches which specify the types of data that the PDP-11 controls at any time.

The PDP-11 is considered to have its own parameters memory, which differs from the internal parameters memory in that it can be respecified dynamically. The parameters memory internal to the system can only be specified during system setup, but not while the instrument generates sound. In all other ways, the PDP-11 and the preprocessor's memory function in the same manner.

The modes of human interaction with the internal or PDP-11 envelope parameters are the following:
1. Key-segment amplitude is scaled by output of envelope generator.
   A. Output of Envelope generator goes to zero before amplitude of key-segment. (Eg. percussive effect)

   ![Amplitude of Key-Segment](image)

   ![Envelope Generator Output](image)

   ![Resulting Envelope](image)

   B. Precision attack control with variable amplitude with time.

   ![Amplitude of Key-Segment](image)

   ![Envelope Generator Output](image)

   ![Resulting Envelope](image)

   C. Total control by Key-segment amplitude.
II. Key-segment amplitude controls length of sustained steady-state value.
Key-segment amplitude triggers events. Key-segment amplitude is not multiplied by Envelope Generator Output. Output of Envelope Generator is the Resulting Envelope.

Mode I is designed primarily for human control with computer modification of parameters that are difficult to control. In Mode II, a threshold value of amplitude must be crossed to trigger the onset and end of a tone. This allows a user with very limited finger technique to control a precisely-shaped sound.

Figure 22 Envelope Parameters:

The envelope parameters employed in this system are: (see Figure 22):

1. Delay. The digital hardware allocates space for a tone only when its amplitude is greater than zero. To permit percussive attacks while using a scaling procedure for the creation of envelopes, a delay is programmed. In other words, for up to 1.6 sec. after key depression, the key output is scaled against zero from parameters memory and no sound is heard. After this time interval, the attack may begin, and the rise time may be faster than is possible with the key depression alone.
3. Peak level. The peak of the attack.
4. Initial decay. Traditional.
5. Sustain level. Traditional, except that when scaling against the key is done, interesting variations may take place during this interval.
7. Threshold. The value which triggers the envelope in Mode II.

CONCLUDING REMARKS

The present design takes into account the needs of the performer, composer, and psychoacoustician who might use this device. The keyboard alone can generate a large number of possible envelopes under the control of the user. When the keyboard’s output is modified by the parameters memory, the unskilled keyboard player can still generate envelopes with a consistent character and quality. Control from a PDP-11 makes yet more precise control of envelope possible. Future plans include enabling the PDP-11 to "remember" human envelopes which otherwise would be difficult to reproduce.

Since each of the eight segments per key is assigned its own envelope, it is possible for each partial of a complex tone to attack independently. This, of course, resembles the response of non-electronic instruments and should provide many interesting results in timbre manipulation.

This project is being funded by the Carnegie Corporation and by the Department of Electrical Engineering at Carnegie-Mellon University.