A Modular Feedback Keyboard Design

Claude Cadoz, Leszek Lisowski, and Jean-Loup Florens
Association pour la Création et la Recherche
sur les Outils d'Expression (ACROE)
INPG, 46 Avenue Felix Viallet
38000 Grenoble, France

The modular feedback keyboard (MFK) design that we describe in this article was conceived and constructed at ACROE. It was first presented to the public on 17 October, 1989 in Grenoble at the opening celebration of our center's new studio. The system we present is the prototype of a more general device, and its construction is the result of research into the relationship between instrument and performer within the framework of a system for real-time sound synthesis and computer-assisted musical creation.

The first feature of this device is that it is a gestural control system with feedback for the tactile senses—it enables actual fingering of a physical instrument to be simulated. The second important feature is that this is a modular system: the piano- or organ-type keyboard is its nominal form, but its mechanical morphology can be modified and easily configured for other applications or types of performance interfaces.

Retroactivity in the Design of MFK

In this section, we would like to address the issues of touch synthesis, instrument simulation, and the instrument-performer relationship. In 1978, ACROE introduced the *tactile feedback* principle by building a novel experimental device that could produce a mechanical feedback force to a manipulated object (e.g., a joystick or a key) on the same level as the force of the manipulation organ (e.g., the manipulator's hand and arm) (Cadoz and Florens 1978; Florens 1978). By doing so, this device enabled the implementation of touch synthesis. The resulting force could be made to be simultaneous to and coherent with the sound and, if required, with a visual display of the instruments that were being simulated. We call this concept *gestural force-feedback transducer.* We were not simply aiming at improved ergonomics of gestural control in sound synthesis, but rather at a fundamentally new insight into musical synthesis itself. Our approach focused on the importance of the instrument-performer relationship in both the learning and the intrinsic process of musical creation. We therefore were led to propose not only a synthesis of the sound but also of the instrument. The latter term generalizes the concept of the traditional instrument by incorporating an implicit reference to the ease of experimentation, to the rich variety of instrumental play, and to the specific relation that any instrument establishes between a given gestural space and a sound area.

The standard gestural instrument-performer relationship is bidirectional. This indicates both a transmission (i.e., our gestures inform the instrument) and a reception: at the very moment of the instrumental gesture, a tactilo-proprio-kinesthetic perception takes place. This in turn informs us of the nature of the object we are manipulating and how it behaves. It also provides us with manipulation possibilities and even signals the nature of the sound phenomenon itself. In many cases, the instrumental gesture is the best way to communicate sound control information. In addition, as in a natural instrumental situation, we can only attain very fine and accurate control during performance by intervening in the sensory control loop via the performer's physical perception.

In computer synthesis, the device that transduces the relationship between gestural and digital phenomena is the gestural transducer. Hence, it has a very special role for several reasons. The instrumental gesture must be made in a genuine manner; by definition the instrumental gesture is applied to a physical object that has typical and well-known

Computer Music Journal, Vol. 14, No. 2, Summer 1990,
© 1990 Massachusetts Institute of Technology.

(to the performer) deformation and movement behavior. The transducer must sense the characteristic information of the gesture without loss of information. Finally, it has to provide the instrumentalist with a mechanical resistance in some realtionship to the nature of the simulated generator process. This third function is what we shall refer to here as *feedback*. It is fundamental to achieving control finesse. It therefore follows that our device for genuine instrumental play—in addition to the usual control actions, be they in real- or non-real-time—must include some kind of motors that are in fact the transmitters of the physical phenomenon (the force), which is responsible for the tactile perception.

It goes without saying that such motors must be special. Their performance entails ultrarapid, accurate response. In some cases, the bandwidth of the mechanical phenomena we are concerned with can go as high as 700 or 800 Hz. Pulses of up to several tenths of KgF of force are needed to simulate very rigid objects, and they must be able to be packed in a very confined space—e.g., side-by-side within a keyboard. Classical electric motors cannot offer these three characteristics simultaneously; this is why we have designed a special motor that can provide sufficient power and is about the width of a standard piano key.

The Modularity of the Feedback Keyboard

Given the current state of the art, it is not possible in the foreseeable future to have a transducer for the gestural channel that is as general as a loudspeaker is for the acoustic channel. The current instrumental interface can only be presented as a system of different and complementary devices because the technical difficulties are of a different type and because these difficulties are increased by the bidirectionality of the gestural interface.

The keyboard will be the predominant element within this system because it responds to a highly pertinent ergonomic situation. Another reason is that the keyboard, which has existed in roughly the same form for centuries, is a basic link with our instrumental heritage. This link should thus be guaranteed, but it is nonetheless important to open up the range of possibilities to other categories of instrumental gestures and to enable experimentation with new ones.

The above considerations lead us to investigate the kinds of devices that would guarantee us a relatively wide variety of instrumental situations and yet would still conform to the basic keyboard interface style according to its traditional characteristics. These were the conclusions we drew from the second experimental system we constructed (in 1981)—shown in Fig. 1—which led us to the modular feedback keyboard.

The modularity of the new system involves two aspects: it allows for freedom of choice as to the

Fig. 1. A photograph of the single key or paddle designed in 1981 and described in Cadoz, Florens, and Luciani (1984).

Fig. 2. Basic structure of the Sliced Motor configuration.

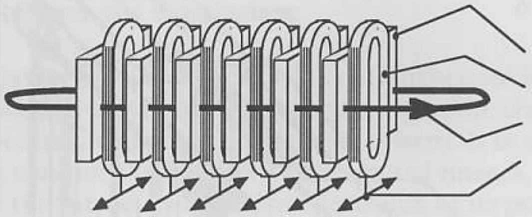
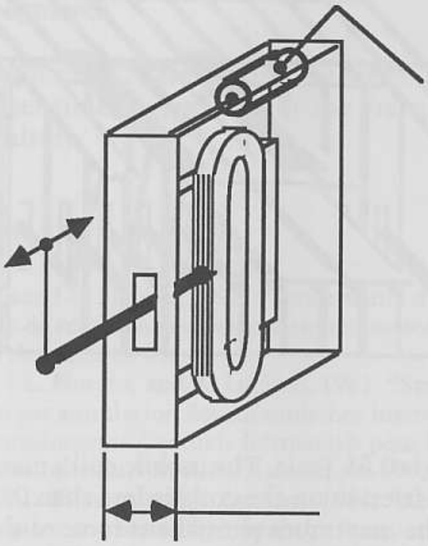


Fig. 3. A single sensor-motor module showing the sliced motor and the displacement sensor.



number of keys (and, in fact, to the number of degrees of freedom of the keys) and it offers a choice of morphology of the keys. By *morphology* we mean everything that characterizes the outside shape, the trajectories, and the geometric and spatial constraints of the manipulated physical device. This also determines the types of manipulation of, and contact with, the device, as well as the possible types of gestures that are meaningful in performance situations.

Description of the Modular Feedback Keyboard

The complete device is built from two basic components: the sensor-motor module and the packaging of the unit. Both of these allow for the two types of modularity that we mentioned above.

The Sensor-Motor module

As its name suggests, the sensor-motor module takes charges of the two functions that are integrated in the device. We might say that its role is precisely to fulfill these two functions according to strictly defined basic characteristics. It must measure displacement according to a degree of freedom and supply an electric analog of this displacement. It must also produce a force that is proportional to a given control signal across a given displacement range following the same degree of freedom.

Its most noteworthy property is its geometry. To meet the first bulk constraint—not to be thicker than a single piano key (13.75 mm) and still produce sufficient power—we had to think in terms of special technology. The result was what we call the sliced motor (which we have now patented).

The Sliced Motor

The principle behind the sliced motor is to create a single magnetic polarization circuit (which is rectangular in this case) for all the motor modules in a keyboard unit. The keys are independent and are designed to be combined into a composite system (i.e., a keyboard). The system is thus composed of an alternating series of polarization magnets and flat mobile coils, as can be seen in Fig. 2. The unit is extended with additional keys by adding a mechanically autonomous slice, composed of a magnet-coil pair, and then closing off the magnetic circuit by means of a sealer module. Modularity is assured because the forces produced by the coils are completely independent of each other. The power of this system is obtained by the additive combination of the magnetic fields of each module.

Figure 3 shows a single sensor-motor module. The physical characteristics of this module are as follows: the stroke distance of the mobile motor coil is 15 mm and the slice thickness is 13.75 mm (that of a standard piano key). The sensitivity of the position sensor is approximately 3 μm. The motor is made of vacuum-soaked, flat, copper, mobile coils and rare, earth-cobalt magnets. Its effective in-

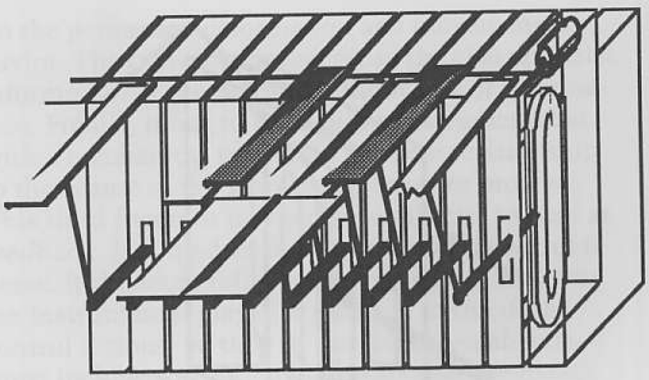


Fig. 4. *Diagram of the modular feedback keyboard.*

Fig. 5

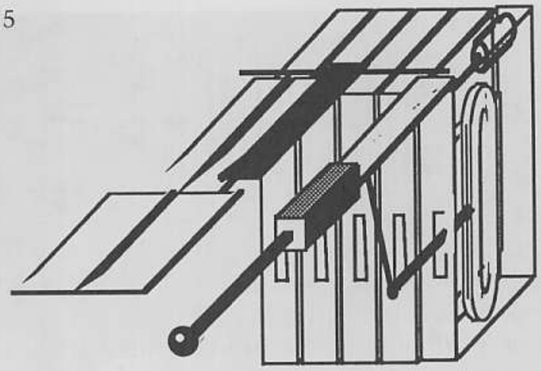


Fig. 5. The use of the sliced motor for a one-dimensional, lever-type controller.

Fig. 6

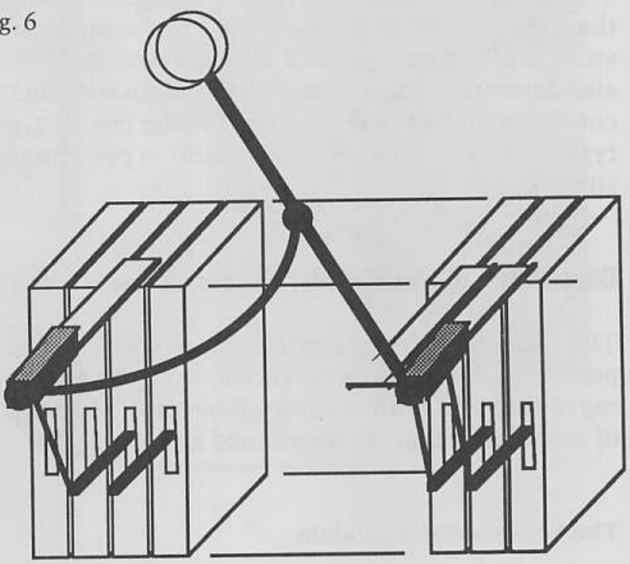


Fig. 6. The use of the sliced motor for a two-dimensional, joystick-type controller.

duction is 0.65 Tesla. The mobile coil's mass is 200 g; and the friction on the coils is less than 0.009 Newtons. The maximum permanent force of the magnets is 40 Newtons; the maximum transitory force is 80 Newtons. The maximum zero-load acceleration is 660 m/s^2; and the response delay to the input control (measured when the coil's movement is blocked) is 0.2 ms.

Covering

The modular feedback keyboard device's effective morphology is determined by the association of a certain number of sensor-motor modules and the covering that is given to the unit. This covering consists of a very simple and strongly built mechanical device, chosen from an assortment of various possibilities, which is mounted onto the sensor-motor bank. We will illustrate the principle of interchangeability of the covering with three examples: a keyboard and one- and two-dimensional joysticks.

Figure 4 shows the use of the sliced motor as a more-or-less traditional piano-style keyboard. The key arms, which can be permanently mounted on the base module, enable us to mount different plates that correspond to the various black and white keys of a regular keyboard. The position of the black keys and the white keys can therefore be maintained but can also be chosen completely arbitrarily, since the rest position height can be controlled by the controller program. The figures on the cover of this issue of *Computer Music Journal* show two different views of the modular feedback keyboard we constructed in this manner.

A mechanical transmission arm that clicks into the place of the key plates used in the previous example allows us to use one module as a one-dimensional, lever-type interface device, as shown in Fig. 5, or to combine two independent sensor-motor modules to create a system with two degrees of freedom, as shown in Fig. 6.

A similar device allows the combination of three degrees of freedom in the same manner. It can thus be seen that modularity can effect the combination possibilities of the interface's degrees of freedom to make up one or several simple or multidimensional sets.

Applications and Conclusions

The device we have described is currently used in the ACROE laboratory for experiments in the control of a real-time music synthesis system. It is also being used for the synthesis of animated images. Since the introduction of force feedback in its present high performance version, in particular, in the context of synthesis derived from physical models, it has turned out that this is not simply a plus in the accuracy and richness of control, but an opening to a genuine new dimension in the area of human-computer interaction for animated image synthesis. In the realm of artistic, musical, or graphic creation, it is patently clear that this is important and promising for the future. We should also point out that very principle of the gestural force feedback transducer—and the implementation of the instrumental situation that we are referring to here—seems to be relevant to numerous other fields and will probably be generalized in the future. We could mention space manipulation here, to broaden our horizons, as it were.

ACROE intends to develop further this type of device to meet eventual demands in the field of space manipulation, but we naturally give priority to those who wish to obtain it for musical creation or image animation.

Acknowledgments

The work presented here and the patent of the keyboard are generously supported by the French Ministry of Culture.

References

Cadoz, C., and J-L. Florens. 1978. "Fondements d'une démarche de recherche en informatique musicale." *Revue d'Acoustique* 45.

Cadoz, C., J-L. Florens, and A. Luciani. 1981. "Synthèse musicale par simulation des mécanismes instrumentaux. Transducteurs Gestuels Rétroactifs pour l'étude du jeu instrumental." *Revue d'Acoustique* 59:279–292.

Cadoz, C., J-L. Florens, and A. Luciani. 1984. "Responsive Input Devices and Sound Synthesis by Simulation of Instrumental Mechanisms: The CORDIS System." *Computer Music Journal* 8(3):60–73.

Florens, J-L. 1978. *Coupleur Gestuel Rétroactif pour la Commande et le Contrôle de Sons Synthétisés en Temps-Réel.* Thèse de 3$^{\text{ème}}$ cycle, INPG Grenoble.