

Designing for Intimacy: Creating New Interfaces for Musical Expression

SIDNEY FELLS

Invited Paper

Contemporary musical instrument design using computers provides nearly limitless potential for designing the mapping between gesture and sound. When designing effective and expressive musical instruments, the types of relationship between musician/player and his instrument and the aesthetics of the relationships must be considered. This paper discusses four types of relationships and their aesthetics. A high degree of intimacy is achieved when the relationship reaches a level where the mapping between control and sound is transparent to the player; that is, the player embodies the device. Ultimately, this type of relationship allows intent and expression to flow through the player to the sound and, hence, create music. Three new interfaces for musical expression, the Iamascope, Sound Sculpting and Tooka, provide examples of how instruments may be designed to develop and explore intimacy and embodiment of new musical instruments.

Keywords—*Embodiment, human–computer interaction, Iamascope, interface design, intimacy, musical instrument design, relationship aesthetics, sound sculpting, Tooka.*

I. INTRODUCTION

The possibility for easily creating new interfaces to control music has become a reality since the advent of computer generated sounds. However, the ability to make new interfaces and, hence, new instruments that make sound does not mean that all these new instruments are musical. There still needs to be a player who can play the instrument in a meaningful way to create music. Determining an agreed-upon meaning for “musical expression” is difficult. For this paper, musical expression occurs when a player intentionally expresses herself through the medium of sound. Thus, playing a melody on a piano or mixing prerecorded sounds such as when a DJ performs constitutes musical expression. A well-designed

instrument supports the ability to play music by allowing the user enough control freedom to explore sound space and make music while being sufficiently constrained to allow the user to learn to play the instrument. Obviously, making the interface constrained and simple enough allows the novice to acquire the ability to make sounds easily; however, the interface may not provide the player with any path to virtuosity, limiting the expressive capacity of the player. Creating such a new instrument design is difficult [1]. Research in human–computer interaction (HCI) can inform techniques to make the system easy to use, but generally falls short of providing methods to make the instrument expressive and musical [2]. The perspective taken in this paper is that the relationship between musician/player and her instrument affects whether the instrument can be musical. More specifically, we argue that the device should be designed to allow for the formation of *intimacy* between the person and the device. Our notion of intimacy, a generalization of Moore’s notion of *control intimacy* [3], is expanded in Section III. Briefly, intimacy is a measure of the player’s perceived match between the behavior of a device and the control of that device. As a player learns an instrument, he becomes more intimate with it. The ultimate goal in the process is for the player to have a high degree of intimacy such that he embodies the instrument. When the player embodies the instrument it behaves like an extension of him so that there is a transparent relationship between control and sound. This allows intent and expression to flow through the player to the instrument and then to the sound and, hence, create music.

As discussed in [4], there are four types of relationships that can form between people and objects. The relationships that form depend upon whether a person perceives: 1) the object as external to herself that responds to control; 2) the object embodied within herself, i.e., an extension of herself; 3) the object as external to herself that does not respond to control; and 4) herself as an extension of the object. Each type of relationship has its own aesthetic. These relationship types are explored in Section III. Understanding

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and exploiting these relationships are important when designing new interfaces for musical expression. Of particular importance, the second and fourth types of relationship are associated with high intimacy providing satisfying expressive experiences for players. In the works presented here, we explore the roles that intimacy and embodiment have for design. Three works are used to illustrate these concepts.

- 1) Iamascope: an interactive artwork which maps movement to sound and image using a video camera.
- 2) Sound Sculpting: a tool for sound space navigation using a metaphor of object manipulation.
- 3) Tooka: a two-person musical instrument somewhat like a recorder.

While there are many excellent examples of interfaces that support intimacy (musically as well as other modalities), these three systems are selected because the author has experience with them. Currently, there are few analytic or empirical methods to evaluate the variety of interfaces for musical expression. Anecdotal accounts are used in this paper. A secondary goal of this paper is to lay a foundation for evaluation methods to facilitate design of new interfaces for musical expression so that *ad hoc* design approaches can be used less often.

Designing for intimacy in an intimate musical controller helps create transparency with the musical mapping. This transparency facilitates musical expression. Through understanding the aesthetics of the relationship between humans and machines in the context of musical controllers, this paper explores a new way to design and evaluate complex interfaces. The three systems provide examples of these principles in practice and suggest how they may generalize to other interface designs.

II. BACKGROUND

Recently, much effort and research has been focused on the creation of new musical instruments. Much of this activity may be attributed to the emergence of electronic instruments, specifically those based on computers. The computer can be used to create arbitrary mappings between gesture and sound, thereby providing the possibility of computer-supported sound and directed musical interaction. Thus, the computer allows the creation of new interfaces and sounds never before possible. Unfortunately, with so much freedom to design the mapping between gesture and sound, there has not been a strong set of design criteria developed. In this Special Issue, Wanderley and Depalle [5] provide an excellent review of the state of the art of gestural control of sound synthesis and discuss strategies and guidelines for the design of these mappings. With only a few exceptions, much design work has focused on a single person who will be the first one to play the instrument with the optimistic outlook that other players will emerge. Instrument design in this tradition includes the *HyperCello* [6], *The Hands* played by Waisvitz [7], [8], *Tarabella Piano* [9], *Glove-TalkII* [10], Bonger's *Lady's Glove* played by L. Sonami [11], the *Cook-Morrill Trumpet* [12], the *Talking Stick* [13], the *SqueezeVox* [14], the *Accordiatron* [15], and many others. Unfortunately, the

fate of most of these novel musical controllers is to fall into disuse, as relatively few musicians other than the original designer(s) are committed enough to master the intricacies of each interface. Why is this? In this paper, we suggest that these controllers are missing elements that can be embodied through the development of intimacy with the device.

The need for design criteria and approaches has a rich history, as engineers, designers, and musicians have been actively creating new instruments to control sound. Electronically, as far back as 1949 with H. Le Caine's electronic Sackbut [16] to contemporary designs including Buchla's LightningII [17] and highly ambitious large scale interfaces such as the Brain Opera [18], technology has been pushing the possibilities of sound control. Section VIII covers additional readings in this exciting area that are not covered here.

The two most dominant issues dealing with the creation of these new interfaces as musical instruments include the following:

- 1) the necessity for these new interfaces to support virtuoso style performance but at the same time being accessible;
- 2) the definition of an appropriate mapping between the player's control of the instrument and the sound produced.

For the first issue, the difficulty arises because, with appropriate computer support, it is relatively simple to create an interface that allows for novice users to create musical sounds with little practice. However, it is open to debate whether these instruments allow the player to produce much musical expression. As an illustration to the degree with which instruments can be supported, consider two extreme positions for creating an interface mapping. At one extreme is a compact disk (CD) player; essentially, with a single press of a button, a novice can stop and start the music; thus, they can play entire symphonies very easily. At the other extreme is an instrument such as a violin. Considerable practice is required even to be able to reliably generate the same sound. Thus, the pathway to virtuosity is fairly lengthy. It is relatively easy to argue that the former is not really a musical instrument at all, but the distinction is blurred by increasing the complexity of the mapping only slightly. For example, if we take the same CD player but provide additional control by adding a mechanism to allow a player to easily select where a song is played as well as the direction of play, we get the basis of a DJ controller. The line between what is a musical instrument and what is not becomes gray.

Contemporary musical design encounters the gray area of what is musical and what is not because the computer provides incredible flexibility. The flexibility tempts the designer to provide a simple, easy-to-use interface for novices so that anyone can produce pleasing sounds and music immediately. However, this often comes at the expense of restricting the types of expression possible for the expert, since the interface eliminates control subtlety to make it easy to use. As Wessel and Wright [19] point out, "...many of the simple-to-use computer interfaces proposed for musical control seem, after even a brief period of use, to have a toy-like character and do not invite continued musical evolution." In

contrast, Cook [14] supports utilizing the capabilities of the computer for making devices accessible to the novice. He suggests the phrase “Instant music, subtlety later” to represent his position.

In some situations, though, the need for a low entry fee outweighs the need for expressive, virtuoso-style musical performance. As argued in [1], in collaborative interfaces, the musical interfaces provide a common space for multiple participants to communicate. In this respect, if the interface is intended for novices, it is more important that all participants can easily begin to control the musical space so they can communicate with each other. These types of interfaces are typically found in installations where the expectation is for people to just walk up and play together. In these contexts, the interface places musical communication between players at higher priority than musical expression; hence, the computer is used to provide an easy-to-use, simple interface that generally lacks much range for expression. In contrast, in this paper we describe *Tooka*. It is a collaborative instrument that attempts to provide a pathway to virtuosity for the two players at the expense of ease of learning. Ideally, music as a communicative medium between players and musical expressiveness are both present such as found in chamber music ensembles. However, in *Tooka*, an additional element is added, since gestural coordination and communication is required even before sound is heard.

For the second issue in new interface creation—defining the mapping—debate generally centers on what types of sounds should be mapped for the musician to control. This is as complex as the notions of what is musical and what is not. Perhaps at the heart of the matter is whether new interfaces for musical expression require the player to be able to play reliably a particular effect such as a note or the timing of a timbral element (i.e., a percussive sound). At the ACM SIGCHI First Workshop on New Interfaces for Musical Expression,¹ the community was divided on this issue. With computer-based synthesis and control, it is possible to provide mappings to timbral elements, underlying musical process parameters, and other, more esoteric controls. Thus, the relationship between what the player does and what sound is produced becomes opaque to the audience, making the piece more difficult to appreciate. Therefore, the transparency of the interface both for the performer and for the audience is important when considering the musicality of the instrument and, thus, is an important design consideration [20].

The role that the mapping between the player’s gesture and the parameters of the sound being produced plays is very complex. In [21], a counterintuitive finding is reported which illustrates that hard-to-learn-and-understand mappings may be preferred to straightforward, simple mappings of the same parameter space. In their experiments, subjects were allowed to vary volume, pitch, timbre and panning using either: 1) a mouse manipulating on-screen sliders for each parameter; 2) a set of physical sliders for each parameters; or 3) a complex arrangement of mouse and physical sliders adjusting a

¹Personal communications.

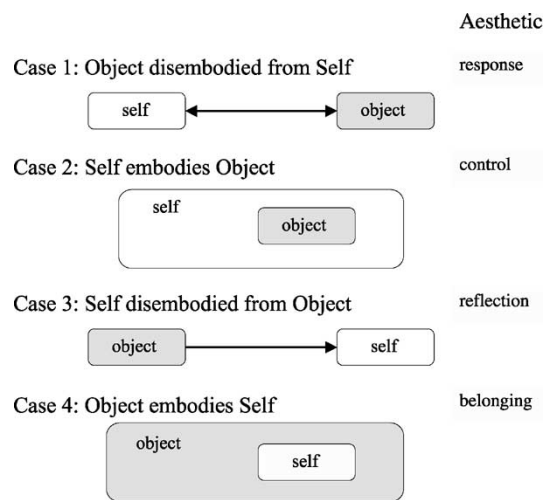


Fig. 1. Four types of relationship between a person and an object including the aesthetics. The relationship types are not mutually exclusive and may be happening simultaneously at varying degrees.

complex correlated mapping of all the parameters together. The interesting result is that after practice, subjects found the obvious mappings boring. However, they were engaged with the complex mapping and felt that it had much more expressive potential than the other mappings even though it was very difficult to learn to use. Remember, the parameter space is the same in all conditions; however, the gestural requirements is very different due to the mapping. Thus, we see that obvious, simple-to-use interfaces do not always yield engaging, expressive instruments.

III. INTIMACY AND EMBODIMENT

There are four types of relationships that can form between people and objects, as shown in Fig. 1. The relationships that form depend upon whether a person embodies an object, i.e., feels the object is an extension of himself, or whether the object embodies the person, i.e., the person submits to the manipulations of the object. In the first situation, the process of embodiment can be seen as the development of intimacy between a person and the device. In the latter case, the process of embodiment often has to do with the desire for belonging or the dissociation of oneself from an object being controlled. Each of these relationships has its own aesthetic appeal. Understanding and exploiting these relationships are useful when designing new interfaces for musical expression.

A. Embodiment

The four types of relationships can be categorized depending upon how deeply embodied an object is into the person or vice versa. These relationships are not mutually exclusive; that is, they may be all occurring simultaneously. Also, as shown in Fig. 1, each relationship has its own aesthetic. The types of relationships are as follows.

- 1) The person communicates with the object in a dialogue.
- 2) The person embodies the object.
- 3) The object communicates to the person.
- 4) The object embodies the person.

In the first case, the aesthetic is cause and effect. That is, the person exercises control on the device and the result is communicated back. The result is critical for evoking an emotional response in the person. A typical example is when people first learn to use a computer. Being unsure of themselves, they begin keying in commands. When the computer responds by doing something useful, they feel happy, whereas if it does nothing, they are unhappy. The key point is that the result, separate from the control, evokes the response.

In contrast, in the second case, it is the act of control that provides the aesthetic. In this situation, the person embodies the object. Persons have integrated the object and its behavior into their own sense of self. The object becomes part of them; it becomes an extension of their own bodies and mind. This situation is common among skilled operators, for example, a painter and her paintbrush or a musician and his instrument. In this type of interaction, the emotional response comes from the control of the instrument rather than the result itself. The pleasure is in the doing, not the achieving.

In the third type of relationship, we have the object conveying information to the person. In this case, the object does not respond at all to the person in any type of dialogue. There is no interaction. From the object's perspective, the person does not necessarily exist. The aesthetic, for the person, in this case comes about as reflection or contemplation of the output coming from the object. This type of relationship is common in traditional art forms. For example, a painting on a wall may evoke a response in a person looking at the painting; however, the response is a function of introspection by the person. The painting does not alter its output in any way depending upon the person. Likewise, for music, the audience generally has this type of relationship with the musician. The audience listens to the sounds for the aesthetic but does not typically have much influence on the music itself.

In the fourth type of relationship, we have the object embodying the person. In this situation, the person derives an aesthetic feeling through relinquishing control of themselves so that the object can manipulate them. The emotional response arrives through submission and belonging. For this type of relationship, the object must be able to control the person and the person must be in a state to allow the control. This type of relationship is more complex to achieve as the construction of the object requires close attention to the person who will be manipulated. Of particular note, though, is that when the embodiment of musical instruments is sufficiently strong, it is possible for performers to experience this fourth type of relationship with the music. This is an exceptional moment as suggested by Mazzola [22]:

As a [sic] improvising jazz pianist, I have learned that the best moments of performance are those, [sic] when you do no longer control your actions, but when you are, instead, controlled by the music.

This type of experience is common when people are in the state of flow as described by Csikszentmihalyi [23]. It occurs when the person has sufficient skill with a device.

While the relationships have been discussed here as separable categories, they most likely follow a continuum and

exist simultaneously. At least in the case of the first two types of relationships, a measurement called intimacy can be used to specify the degree to which a person is embodying an object. Additionally, the objects here are discussed as if they were inanimate; however, some of the same discussion holds for animate objects such as people and animals. As indicated, these various relationships may occur simultaneously; an example of where this happens is when the player is also an audience of his own performance such as in an interactive piece. This situation can happen with a musical instrument when players are sufficiently skilled. This complex set of relationships is discussed below in the context of the Iamascope.

Of interest for new musical instrument design is to create interfaces that can be embodied. An embodied interface allows expression to flow. In more extreme cases, the player actually dissociates from the instrument and feels the music controls him and hears the music separate from his control, demonstrating aspects of both third and fourth types of relationships [4]. To achieve embodiment, initially, it is necessary for the aesthetic of the first type of relationship to be strong. This requirement is needed so that a novice can learn what movements control sounds, leading to expert performance. The aesthetic for the first type of relationship may be achieved in two ways.

- 1) Make the interface easy to use.
- 2) Provide sounds that are unique.

The first approach allows the response from the device to quickly agree with what the player wants. If simple enough, the interface will be embodied quickly, providing the second type of relationship aesthetic. The pitfall though is that the ease of learning is made at the expense of musical complexity and expression. Effectively, the instrument does not provide additional musical complexity as players become experts. Essentially, the music becomes boring. The second approach provides sounds that are new and interesting but possibly difficult to learn to play. This is especially true if the new sounds have no obvious physical representation, implying that there will likely be no obvious physical metaphors to help the player to learn the mapping. However, the novelty of the sound provides the aesthetic in response to player control, providing motivation to continue to practice. These early adopters get new sounds to play with; however, the path to embodiment and virtuosity may be very difficult.

In the next subsection, we explore the notion of *intimacy*. Intimacy is introduced as a measure that provides an indication of the degree of aesthetics that are occurring in relationships that have formed between player and device. A high degree of intimacy is required for embodiment to occur; thus, if we have a mechanism to measure intimacy, we can predict the success of an interface.

B. Intimacy

The notion of *control intimacy* introduced by Moore [3] may be generalized to *intimacy* for all human-machine interfaces. When a person has a high degree of intimacy with a

device, she can communicate ideas and emotions effectively through the device as if it were an extension of herself. Intimacy deals with the perceived match between the behavior of a device and the operation of that device. For a musician to be expressive with her instrument, it is critical for her to have a high degree of *control intimacy*. As stated by Moore [3],

The best musical instruments are ones whose control systems exhibit an important quality that I call “intimacy.” Control intimacy determines the match between the variety of musically desirable sounds produced and the psychophysiological capabilities of a practised performer.

If there is low intimacy, the interface is not embodied, implying that the effectiveness of communication between player and device is poor. A typical case where intimacy is very low is when a person first uses a new software package. At this early stage, the person does not know what commands cause what actions, often leading to frustration with the software. There are many interacting factors that control the degree of intimacy a person may feel with a machine (or person) and the rate at which intimacy grows. For a more detailed discussion of the factors that influence intimacy, see [4]. By extending Moore’s notion of control intimacy, we can develop a framework for examining the relationship between player and device as well as player and audience. Further, in the context of relationships, we can explore the idea that intimacy provides a measure of the type of relationship dynamics that occur while a performer learns to play a particular instrument.

From the perspective of interactive systems, including new musical instruments, it is interesting to explore intimacy with those instruments (or machines) which were developed by us. In Iamascope (see Section IV), we begin to see intimacy forming between the machine and the participant very quickly. Within a few minutes, a person is completely unaware of the machine and is intimately linked to the images he is creating. From this perspective, the participant moves along the intimacy continuum so that the movement in the Iamascope is emotionally charged and disconnected from the result obtained, i.e., the participant has embodied the Iamascope. This separation due to the intimate relationship that forms quickly is critical to the formation of the fourth type of relationship, that is, the participant inside the Iamascope is embodied in the Iamascope.

High intimacy implies an embodied device. In this situation, one can conjecture that expression flows naturally when a device is completely embodied. This can be seen when an expert’s emotional state is expressed through the usage of his tools. Masking this effect requires effort such as that of an actor being able to mask his own emotions while performing. Interestingly, there is support that the aesthetics and personal growth that arise from the experience associated with highly intimate embodiment of tools as well as mind and body provide meaning and enjoyment of life [23], [24]. Further, these aesthetics may also provide some of the selection criteria for learning and complex behavior [25].

The three systems discussed herein provide support for intimate interfaces through three different means:

- 1) identification with self by providing a type of mirror (Iamascope, Section IV);
- 2) metaphor (Sound Sculpting, Section V); and
- 3) mapping intimacy with another person to sound (Tooka, Section VI).

IV. IAMASCOPE

The Iamascope is an interactive, electronic kaleidoscope [26]. It creates intimacy by giving the player a strong sense of control by providing identification with the player himself. The Iamascope combines computer video, graphics, and audio technology for participants to create striking imagery and sound with this aesthetically uplifting device. In the installation, users takes the place of the colorful pieces of floating glass inside the kaleidoscope and simultaneously view a kaleidoscopic image of themselves on a huge screen in real time. By applying image processing to the kaleidoscopic image, participants’ body movements also directly control music to accompany the image. The responsive nature of the whole system allows users to have an intimate, engaging, satisfying multimedia experience.

A block diagram of the Iamascope is shown in Fig. 2. For input, the Iamascope uses a single video camera whose output is distributed to two separate video processes, one for imagery and one for sound. Imagery output from the Iamascope is displayed on a wall-sized projection screen. Audio output from the Iamascope is played through stereo speakers beside the display. In the current implementation, a pie slice from the video image is selected to form the original image O , which is used to create the desired reflections O' for the kaleidoscope. The image processing part of the vision-to-music subsystem uses the exact same pie slice O for the music, so that movements that cause kaleidoscope effects also cause musical effects. A picture of a person using the Iamascope is shown in Fig. 3.

The kaleidoscope subsystem maps the participant’s movements to imagery in a direct, one-to-one manner. This mapping is discussed in [26]. Of interest here is the gesture-to-music mapping. The musical mapping maps active *zones* to musical notes as discussed in the following section. The feedback available to the participant comes from sound, video, and proprioception.

A. Vision-to-Music Subsystem

The vision-to-music subsystem has two parts, image processing and music production. The image processing is responsible for capturing the video image, extracting the correct part of the image and calculating intensity differences. The music production part is responsible for converting a vector of intensity differences into musical instrument digital interface (MIDI) signals to control a MIDI synthesizer. Using image processing to map video to music has been used by other researchers, including [27] and [28].

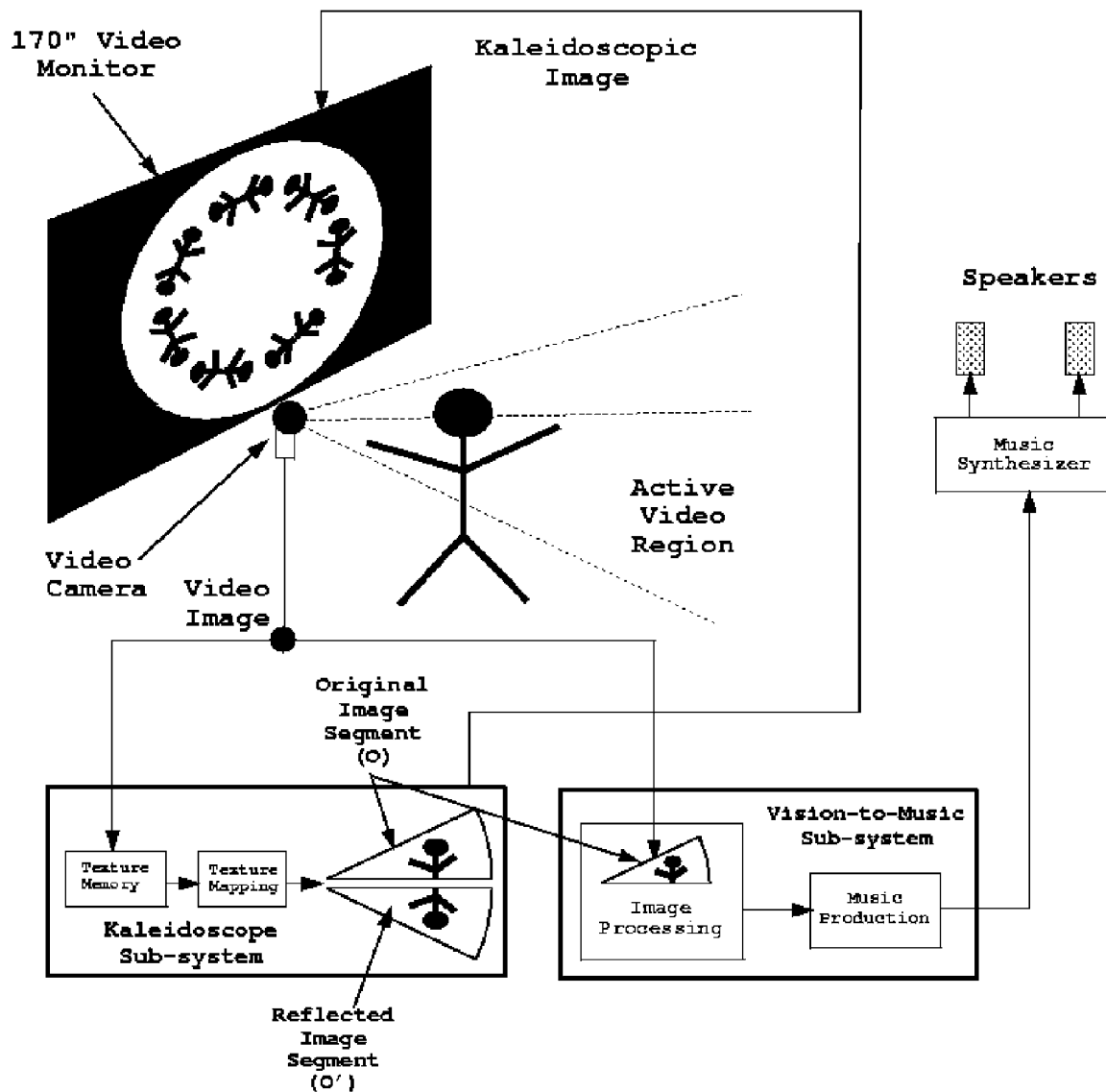


Fig. 2. Block diagram of the Iamascope. Output from the video camera feeds into both the kaleidoscope subsystem and the vision-to-music subsystem.



Fig. 3. Example of a person enjoying the Iamascope.

1) *Image Processing:* A block diagram of the image processing system is shown in Fig. 4. The function of the image processor is to divide up the active video region into bins and compute the change in intensity in a bin over time. The

number of bins is configurable, but normally ten bins are used. The vector of intensity differences for all the bins is sent to the music production part of the subsystem. The entire image processing code is written in C.

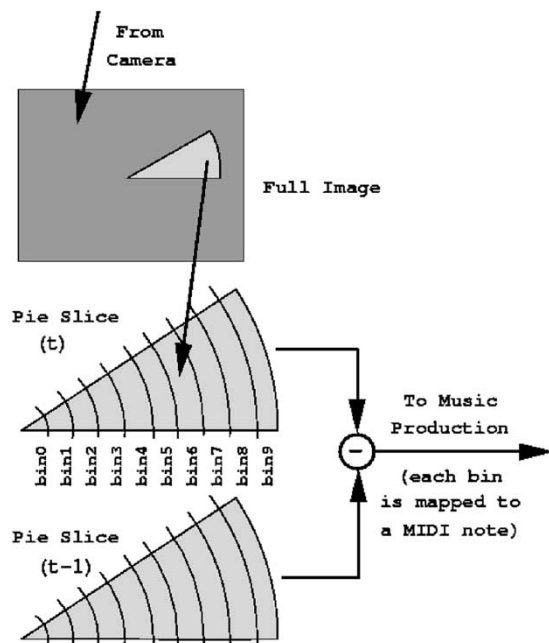


Fig. 4. Diagram showing image processing in the vision-to-music subsystem.

2) *Music Production*: The music production part of the vision-to-music subsystem runs every time a new vector of bin intensity differences is received from the image processor. Many schemes are possible for musical control based on the input from the image processor. We chose a production scheme that did not require any absolute positioning of the body and would play euphonic music to match the beautiful kaleidoscope images. Within these constraints, there is room for some musical control and expression by the performer.

In Iamascope, the musical key is selected by the computer. Each bin represents a semitone offset from the root note of the current key. The offsets are chosen so that each bin in ascending order is associated with a I, III, or V note from the current key in ascending order, providing consistently harmonic sounds. For example, if the current key is C then bin 0 represents a 0 offset (C note), bin 1 represents an offset of 4 (E note), bin 2 represents an offset of 7 (G note), bin 3 represents an offset of 12 (C note, one octave higher) and so on. A note plays when the image intensity difference for a bin exceeds a threshold. The note velocity is controlled by the intensity difference. Notes turn off as a function of time and intensity change as described in [26].

B. Mapping and Expression

The musical mapping in the Iamascope is mostly technology driven. The algorithm uses a simple video processing technique to map a player's movements to MIDI notes. The player's movements are unconstrained and the player has to discover the mapping on his own. The closest metaphor is that the interface is like a ten-string guitar where the computer holds down the chords automatically. The player strums the strings by moving in the bins. While this metaphor helps make the mapping easier to understand, it does not help in

learning to play the device. This is because the metaphor is not quite accurate. The Iamascope's musical mapping suffers from two shortcomings.

- 1) Players do not know where strings are, since they cannot see or feel them. This makes note timings very difficult and, thus, the music lacks expression; this is a technological shortcoming, as haptic feedback could restore the metaphor.
- 2) Players cannot select their own chords, restricting expressivity. This is a mismatch of the strict guitar metaphor. A different approach may solve this problem.

In general, this attribute of freehand or free-form gesture mapped to sound is problematic. Very few metaphors provide a strong enough link between gesture and output to provide an easy-to-learn mapping. Thus, even if the metaphor and mapping are easy to understand, they will not necessarily lead to a very expressive instrument. While the mismatched metaphor for music interferes with the development of intimacy in the Iamascope, the use of the video imagery to provide a "mirror" of the participant enhances intimacy. This happens very quickly, making the Iamascope highly engaging and expressive visually and helping to mitigate the effects of the mismatched metaphor for the musical control.

C. Intimacy and Embodiment in the Iamascope

Participants in the Iamascope have several levels of aesthetic experience arising from the different types of relationships that form inside it. Interestingly, the participant controls two different aspects of the experience, music and imagery. The musical control part of Iamascope demonstrates the difficulties with easy-to-use approaches to musical interfaces. However, the imagery control demonstrates how the use of "mirrors" provide effective design strategies. At first, the participant typically does not appreciate the influence he has on the imagery and spends time moving his body to see what effect it has. The responding images and music at this time are generally pleasing and give the participant a good feeling; however, the participant does not associate it very well with his movement. This level of intimacy occurs in the first type of relationship where the effect provides the emotional response.

With practice in the Iamascope, the participant finds that he can precisely control the image that he produces. This exploration is possible due to the highly responsive nature of the video images. This process stimulates the increase of intimacy with the device. Soon, he becomes unaware of the machine and moves as if the images are direct extensions of himself. At this point, he has embodied the Iamascope and feels satisfaction just from moving in it.

It is also at this level that the Iamascope becomes a "graphical instrument." That is, a performer plays images as a musician would play a musical instrument. Thus, the performer becomes an *imagician* [29]. The performer can express himself through the imagery very easily. In contrast, the vision-to-music subsystem is allowing the participant to control the music. However, the musical control is not nearly

as great as the imagery control. Only the coarse details of the music are controlled. These coarse features allow the music to be synchronized with the imagery without allowing very much intimacy to form. This is important for the participant to be able to allow the Iamascope to embody him, since if he became a musician it would be difficult to separate from the control he is exerting on the Iamascope.

While the feeling of being an imagician is very satisfying, with time, the fourth type of relationship can form. That is, the Iamascope can embody the participant. This is possible because the intimate relationship that has formed while he is being an imagician allows him to disassociate the imagery from himself. This is assisted by the abstraction formed by the kaleidoscope and the music which is accompanying the imagery. The imagery is just abstract enough with enough symmetry that the participant can look at the beautiful imagery as separate from his own control. In this case, the image then imparts an emotional effect. However, the image is of the participant. Hence, the participant sees an abstraction of himself in the image and lets it manipulate him. The performer needs only watch and listen as if from afar while the images seep through him. The occurrence of this emotional influence is coincident with the fusion of part and whole. That is, the performer is able to control the part (i.e., the pie slice) which is satisfying, but at the same time, due to the symmetrical and round quality of the image and the musical accompaniment, his perceptual system sees and hears the whole, beautiful Iamascope.

The shape, pattern, and music of the Iamascope are critical for this process. Other tilings have been tried such as three-mirror kaleidoscopes where the image extends to all the edges of the screen, wrapping the three-mirror image around a spinning sphere, and a four-mirror kaleidoscope that mirrors a square image. These were considerably less successful than the current two-mirrored based kaleidoscope image. The two-mirrored version has several qualities that support these multiple sources of aesthetics. First, the image is round. Thus, there is an inclination to see the circle without seeing the parts that make up the circle. Second, the image converges at the center that tends to pulsate images into and out of it as the participant moves. This further tends to make the participant see the whole rather than the parts. Third, the image is not too abstract. That is, the participant can easily see the parts of his body that are in the Iamascope if he wants to. This is important to allow him to become intimate with the Iamascope and embody it. The Iamascope runs in real time, making it very responsive to the movements of the participant. This is also important for supporting the amount of intimacy so that the participant can embody the Iamascope. Finally, the music is controlled by the participant, though coarsely. Though, the timing, pitch, and key are automatically controlled by the Iamascope, the feeling of the music is controlled by the performer. This provides enough disassociation so that participants do not feel strong intimacy with the music. However, they know they are controlling it so that they allow it to move them. Even though the music is simple and always harmonic, it provides a satisfying feeling.

One of the difficulties with Iamascope's musical mapping is that participants did not have a strong enough mental model of the mapping to overcome the lack of haptic feedback. One solution is to provide haptic feedback in addition to aural and visual so that participants can feel where they are and what sounds will play to provide more effective control of the music. However, this approach requires complex and encumbering hardware. An alternate method is to provide a better metaphor for the musical mapping to help improve the intimacy with the device. One metaphor that we explored that does provide a strong link between gesture and effect is the hand manipulation of nonrigid objects such as balloons and rubber sheets. We explored this tight coupling for a metaphor in Sound Sculpting described next in Section V.

V. SOUND SCULPTING

Sound Sculpting [30] is a controller for sound design, which involves navigation through the multidimensional parameter space of a synthesis engine. It uses the metaphor of sound embodied in a small object. Manipulations of the object produce corresponding manipulations in the sound output.

The goal of a sound designer is to find the correct set of parameters to produce a specific sound. Common controllers for this task center on the keyboard and mouse. These input devices, however, are not well suited to smooth navigation through high dimensional spaces. One controller that may be better suited to this task is a glove-input device, which permits the hand, through gesture, to simultaneously vary many (possibly correlated) parameters with ease.

Previous work in the use of gesture as a controller has mainly centered on formal gesture recognition. It has been noted (in [10], for example) that, since humans do not reproduce their gestures very precisely, natural gesture recognition is rarely sufficiently accurate. Classification errors and segmentation ambiguity cause many of the problems with gesture recognition. Only when gestures are produced according to a well-defined formalism, such as in sign language, does automatic recognition have acceptable precision and accuracy [31]. However, the use of a gesture formalism requires tedious learning by the player. Also, these formalisms typically map unconstrained, free gestures to action. However, these types of gestures are difficult to control making them poor choices for interfaces. Metaphor allows the player to hold a mental model of the gesture space. The mental model constrains gestures to a meaningful space if it is sufficiently strong. Using pseudohaptic feedback with isometric input devices [32], for example, creates a compelling physical sensation using virtual haptic feedback.

In Sound Sculpting, a virtual object is used as an input device for the editing of sound. The sound artist literally "sculpts" sounds using a virtual sculpting computer interface [33], i.e., by changing virtual object parameters such as shape, position, and orientation. The mapping was designed based on pragmatics, and can be explained using the metaphor of sound embodiment.

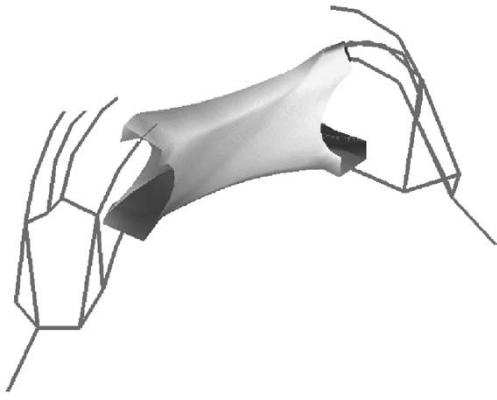


Fig. 5. Example of the sheet clamped to the index and thumb tips of both hands.

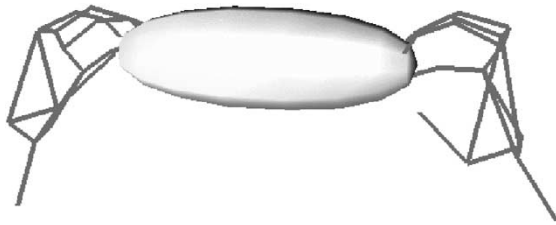


Fig. 6. Example of the balloon clamped to both hands.

A. Pragmatic-Based Design

Sound Sculpting applies pragmatics to the metaphor of small object manipulation. Consider object manipulations such as changing the position, orientation, and shape of an object. The pragmatics for position and orientation manipulations on small, light objects are simple and do not involve any tools. The analysis by Mulder *et al.* [30] of methods employed by people to edit shape with their hands leads to the identification of four different stereotypical methods. The types of pragmatics include claying, carving, chiseling, and assembly. Sound Sculpting uses the pragmatic of claying, including stretching, to define its gesture set.

B. Sculpting FM Synthesis

Two virtual objects were created to control the parameters of FM synthesis: a sheet and a balloon. The claying method used to sculpt these objects was difficult to control without tactile feedback. A derivative method, based more on elasticity, was developed.

A thick rectangular sheet and an elliptical balloon can be virtually manipulated in Sound Sculpting, as shown in Figs. 5 and 6. Sound parameters such as panning and reverberation are mapped to the virtual positions of these objects. Other FM synthesis parameters, such as flange amplitude, chorus depth, and modulation index, are mapped to object shape properties such as length, width, and curvature. Pitch and duration of notes were difficult to map to free gestures, so they were either fixed, preprogrammed in a MIDI sequence, or input in real time using a MIDI keyboard.

Manipulation was originally based on touching. The player would reach out with her hand, sensed by a Polhemus

Fastrak² and a Virtual Technologies CyberGlove,³ and sculpt the object in virtual space. Although sculpting in the physical world is most effective with touch and force feedback, the assumption was that these forms of feedback could be replaced by acoustic and visual feedback with some compromises. This assumption was found to be partially valid. While the player could see and hear the changes made by her actions, it was very difficult to predict where the object actually was. This made motions such as gentle surface strokes difficult.

The claying pragmatic was extended to allow the player to attach her fingertips to control points on the virtual object. This created a more elastic feel to the interface; the player could stretch and pull the object like taffy. This interaction paradigm helped compensate for the lack of tactile feedback, since the player did not need to acquire the object; instead, it was always attached to her hands. All control then was, in effect, based on the relative positions of her hands only. Further, the metaphor constrained her model of what makes sense semantically in the mapping.

C. Sound Sculpting Evaluation

Sound Sculpting was evaluated informally [30]. Two main conclusions were made.

- 1) **Manipulation**—The control of virtual object shape often required some effort to master due to the need for exaggerated movements and/or the need to learn limitations to the control of shape. Due to these limitations to manipulation, unwanted coarticulation of virtual object features could occur. While it is possible that such coarticulation can be used to the performer's advantage in certain tasks, in the real world the virtual object features used can be controlled separately. The "touching" of virtual objects was difficult due to a lack of tactile and force feedback, or suitable depth clues.
- 2) **Sonification**—The mapping of position and orientation to spatialization parameters proved easy to use. The mapping of virtual object shape to a variety of timbral parameters offered no obvious analogy to the physical world to the player. Thus, learning was required to obtain desired acoustic feedback in a natural way using the manipulation methods. Forced coarticulation of some shape features prohibited independent control of the sound parameters they were mapped to. Scaling and offsets of virtual object features for mapping to sound parameters was somewhat arbitrary.

D. Intimacy and Embodiment in Sound Sculpting

The results of Sound Sculpting support the notion that the use of metaphor facilitates the development of intimacy with the device. Parts of the mapping were easily explained and, thus, made it easy for a player to create a mental model. Unfortunately, other parts of the mapping were more difficult to understand because of the mismatched metaphor. This impairs the formation of intimacy, as also noticed in the Iam-

²A magnetic tracking device.

³A dataglove that senses hand posture.

ascope. Also, the sheet manipulation metaphor was found to be more useful, indicating that the choice of metaphor is important.

The metaphor of sound embodied in an object worked well for spatialization parameters such as panning and reverberation. It broke down when the parameters of the sound did not match those of the object. For example, the modulation index of an FM synthesizer does not intuitively map to the qualities of a physical object. A more appropriate metaphor may be useful to control FM synthesis.

Claying and stretching were both implemented in Sound Sculpting. Claying is a compelling metaphor for shape manipulation, but is not useful without tactile feedback. Stretching, however, allows the player's frame of reference to remain attached to the object. The lack of tactile feedback is circumvented at the expense of the ability to vary contact position. This result indicates that it is important to choose a metaphor that can be supported by the input and output interfaces. Claying should be revisited if freehand tactile feedback becomes technically feasible.

Of particular interest with Sound Sculpting is that the stretching metaphor was sufficiently strong that players using the device developed some intimacy with the device. In practical terms, the player's mental model provides mental constraints on what actions make sense musically. Thus, there was no requirement for force feedback as the user's mental model implicitly provides the feedback. The use of metaphor for allowing the mental model to be formed easily increases intimacy. However, even with the clear mental model, the sound space still was difficult to explore inhibiting the embodiment of the interface. Further, while not explicitly created for real-time performance, the same metaphor strengthening the intimacy with the device also helps an audience understand the relationship between control and sound.

Finally, Sound Sculpting illustrates the importance of choosing a good metaphor. One approach that has been used is to base the metaphor on an already existing instrument. This may be achieved either through actually instrumenting a musical instrument (such as [6], [15]) or using a mental model of a musical instrument and measure the player's gestures (as in [9]). These approaches leverage off the existing intimacy musicians have with their instruments. The difficulty comes when these metaphors are used to control sound spaces that are not like to original instruments used for metaphor. In the case of Sound Sculpting, the sound space is created through direct control of an FM synthesizer. Thus, it is not clear how metaphors based on preexisting instruments could be used effectively for novel sound spaces.

VI. TOOKA

The last instrument, Tooka, shown in Figs. 7 and 8, is a two-person instrument that attempts to transform the intimacy that can form between two people who are interacting and communicating into musical expression [34]. The design of the instrument is loosely based upon a traditional wind instrument to facilitate the creation of intimacy with the device.



Fig. 7. Picture of Tooka.



Fig. 8. Two players playing Tooka.

This is important, as the main objective is for the controls of the instrument to be embodied quickly so that the participants can focus on communicating with each other, allowing intimacy between the players to develop.

The first version of Tooka is a hollow tube with a pressure sensor and three buttons for each player (Figs. 7 and 8). Players blow into opposite ends and modulate the pressure in the tube with their tongues and lungs, controlling sound amplitude. Each player has three buttons to control pitch. The mapping between button presses and notes is designed such that to play a simple scale each player must be attuned to the other at every step. Notice that the communication between Tooka players is quite different than that of typical multiple players on one instrument or ensembles. In typical multi-player instruments and ensembles, such as a duet on a piano, each musician plays his own instrument independently and coordinates the sounds together. With Tooka, players must coordinate the input controls and cannot play independently. Thus, both gesture and sound require coordination between the two players for expression. Naturally, duets and ensemble play require intimacy between player for expression, but Tooka focuses explicitly on having sound only being possible when two players coordinate their gestures.

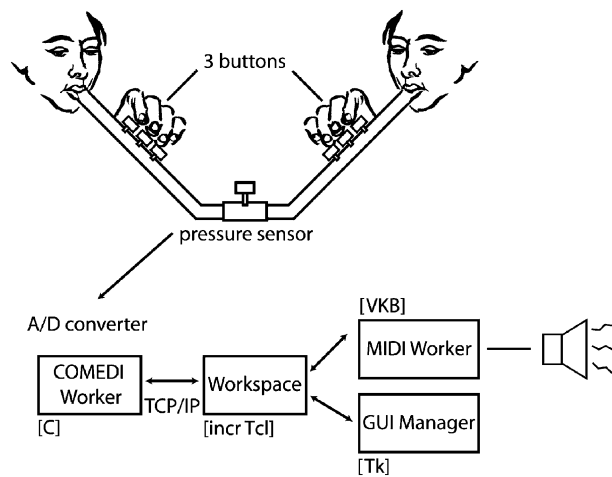


Fig. 9. Block diagram of Tooka.

A. Tooka Architecture

Fig. 9 shows a block diagram of Tooka. The overall architecture uses a *Workspace* model to connect all the computational elements called *managers* and *workers*. The *Workspace* is implemented as a Tcl/Tk [35] process that workers and managers attach to and do the work in. Effectively, the *Workspace* is a common interpreter environment where workers and managers execute Tcl/Tk commands. The workers and managers attach either through a TCP/IP connection or are embedded in the Tcl/Tk workspace using dynamically linked libraries.

For Tooka, there is one manager and two workers. The manager is the graphical user interface that controls data flow and configuration of the data acquisition and music production via the workers. The data acquisition worker is responsible for reading data from the instruments buttons and pressure sensor. It runs as a separate process written in C and uses the Comedi libraries [36] for reading/writing to the data acquisition board. It attaches to the workspace using a TCP/IP connection. The second worker is the MIDI Music worker. It is responsible for mapping data inputs to MIDI notes. It has been implemented as a dynamically loadable music module. It was created by modifying the virtual keyboard (VKB) [37]. Currently, all the processes run on a single-processor machine running Linux.

Players can modulate the pressure in the tube using their tongues, pharynxes, and lungs. Each mechanism has different precision as well as feedback, providing a diverse control and feedback space. This property of Tooka suggests that with a well-designed mapping from air pressure to sound it should become an expressive instrument.

Tooka's pressure sensor is a NovaSensor 410-015G3L that detects medium-range pressures. The pressure sensor is connected to an instrumentation amplifier, and the signal is passed to a National Instruments analog-to-digital (A/D) converter (PCI-MIO-16E-4). The buttons are also connected to the digital inputs of the A/D converter. All the information from the A/D converter is available to our application through a Tcl/Tk interface. All the music code for mapping

Table 1
Player Button Pitch Mapping

Note offset	Player 1		Player 2	
	B1	B0	B1	B0
-2	1	0	0	0
-1	0	0	1	0
0	0	0	0	0
1	0	0	0	1
2	0	1	0	1
3	0	1	1	1
4	1	1	1	1
5	1	1	1	0
6	0	1	1	0
7	1	0	1	0
8	1	0	1	1
9	1	0	0	1
10	1	1	0	1
11	0	1	0	0
12	0	0	1	1
13	1	1	0	0

Notice the use of a gray code so that each player alternates control for each semitone. Also, each player is holding the same buttons down for the tonic, III, V, and VIII notes. The octave is selected by the combination of the third button as shown in Table 2

sensor data to MIDI is performed using Tcl/Tk and then sent to the modified VKB system.

B. Controlling Tooka

Tables 1 and 2 illustrate the mapping of three of each player's buttons to pitch. A new version of Tooka has a fourth button that when pressed provides harmonies with the current notes being played. To intentionally control or to play a melody, both players must work together.

Table 2
Mapping of Players' Third Button to Octave

	Player 1	Player 2
Octave	B2	B2
0	0	0
1	0	1
2	1	1
3	1	0

The greatest degree of control over sound amplitude is from players' tongues. Players can form a completely closed tube with their mouths, tongues, and pharynxes to block any airflow into their lungs or out their noses. Keeping the back of their tongues against their pharynxes creates an airtight seal. Players move the front of their tongues to adjust the volume of air in their mouths, providing a very precise pressure controller. As their mouths and tongues are forming the seal, any pressure changes made by either player are immediately felt by both of them, providing excellent feedback as to the state of the instrument as well as an indication of what the other is doing. Air pressure changes using just the tongue can be quite substantial. During this type of interaction, each player can breathe at the same time as he is modulating the tube pressure.

Players can control their pharynxes to allow air to flow through their noses. This ability allows each player to be able to quickly change and/or modulate the tube pressure by adjusting the amount of air that flows through his nose. Generally speaking, this mechanism only allows for one player to lower the tube pressure to zero without going negative. Further, this control allows a continuous stream of air for the duration of one player's breath.

In contrast, a player may use his lungs to adjust the air pressure. While this control is fairly coarse grained, it does allow players to create large negative and positive pressures in the tube. For a rush of air to pass through the tube, one player has to allow the air to pass into his or her own mouth while the other is blowing. This is reversed to have air flow the other way. While airflow is not currently measured, it is planned for future versions of *Tooka*. While the use of lungs to play the instrument provides coarser control of the air pressure, visually it provides a clearer image of what the players are doing. This is helpful both for the other player and for the audience to make the instrument's mapping more transparent. Note, though, that the players typically use the high-fidelity sensing of the air pressure to understand each other's effort and intentions.

C. Intimacy and Embodiment With *Tooka*

Tooka is still a recent creation and has not been played extensively. The concept behind *Tooka* comes from recognizing that the mutual effort expended by the performers for an audience is a critical motivation behind musical expression. *Tooka*'s design requires a high level of close communication between two players. The intimacy between the players and the effort required to play expressively

together comes through in the performance. This should lead to very powerful modes of expression not possible with single-person instruments or even multiplayer ensembles where performers play separate instruments together. The intimacy is heightened by the fact that the two players share the same air and feel each other's breath. Upon seeing the instrument, many audiences react quite strongly to the connotations of the connection between the two performers. This reaction lends support that *Tooka* has excellent potential for player expression.

Since *Tooka* necessitates some degree of mastery for both players together, the expectation is that they spend time together learning to play the instrument. As the instrument requires players to develop intuitive control methods, practice consists of learning to anticipate and essentially embody the other person, by feeling another person's breath in one's lungs. Ideally, with practice, the two players will feel a sense of embodiment with each other as well as the instrument itself. The embodiment of each other, facilitated by the design of the instrument, should lead to a deep aesthetic experience for the players, which would then be transmitted through the music they play for the audience. It is anticipated that this will provide a deeply moving aesthetic for the audience. *Tooka* is still under development and only a few players have spent any appreciable time with it. The idea of multiperson instruments that only make sound through the combined efforts of expert performers has been explored in such historic works as Stockhausen's "Mikrofonie I and II" [38] and Globokar's "Laboratorium" [39], among others. It continues to be an area rich for investigation, especially as new technologies provide new ways for people to interact.

VII. CONCLUSION

Intimacy was introduced as a measure of the subjective match between the behavior of a device and the operation of that device. It is framed as a generalization of Moore's control intimacy. This measure provides an index to guide design of new musical instruments. The basic idea is that as intimacy increases with a device the player begins to embody the instrument. An embodied interface is an extension of the player and allows a player's expression to flow through the device without cognitive effort focused on the control of the device itself.

The aesthetics of control are associated with an embodied interface. That is, the control of the device, independent of the output, provides a positive experience for the player providing satisfaction just using it. With this type of relationship, expression necessarily flows through the device as the mapping is transparent. In essence, the device is an extension of the player's body. Of course, the aesthetics of the result—that is, the musical output—also provides satisfaction. In extreme cases, the musician also can dissociate from the control and experience the aesthetic of being controlled by the music. The relationship between player and instrument is not stationary. As a player continues to practice, the requirement for embodiment, including the aesthetics of the result and control, need to change to keep the player's interest. Thus, a

musical interface designer needs to embed continuously increasing musical complexity for the player or the instrument will likely be abandoned. Unfortunately, this goal is often antithetical to making the new musical instrument easy to learn. Finding a balance remains a difficult challenge.

Three distinct methods for supporting intimacy with a device were introduced via examples of interfaces in the literature. The three methods were providing mirrors, creating metaphors, and remapping existing intimacy. The Iamascope used mirrors to achieve intimacy, Sound Sculpting used metaphor, and Tooka exploited human–human intimacy to create music. Each approach has its merits and limitations.

The Iamascope uses a conceptual mirror to provide a means of identification for the player. The player can easily change focus from the macro image of the kaleidoscope to the micro image of his own image. The abstraction is sufficient so that players are not self-conscious. However, it is concrete enough so that a player can see himself if desired. This property makes for quick development of intimacy and embodiment with the device. The visual imagery, being a mirror of the actual person, continues to provide complexity in the image as players became experts. However, the musical mapping quickly reaches its limits of expression.

Mirrors provide an effective means for developing intimacy with devices. However, they have limits for expression depending upon the context. The main difficulty is that there is a delicate balance required in the degree of reflection and abstraction. If the mapping is too direct, users may become self-conscious (such as in a public installation), or it does not allow significant benefit over what the player would do himself directly. If the mapping is too abstract or indirect to provide new functions (i.e., through some computer support algorithm), the player may not recognize himself and the advantages of mirrors are lost.

Sound Sculpting uses a metaphor to overcome the limits created by the absence of tactile or force feedback on the instrument and the mapping between gesture and sound is complex. Claying and stretching of virtual rubber objects are used to manipulate parameters of an FM synthesizer. The metaphor of rubber objects works very well for stretching manipulations, but not so well for claying operations. However, Sound Sculpting demonstrates effectively that with a good metaphor players very easily grasp the mapping and develop intimacy. It also demonstrates the difficulties with metaphor when it does not match the task space well enough.

Finally, Tooka attempts to remap the intimacy between two people by creating a two-person musical instrument. The instrument requires two people to coordinate their efforts to play sound. While not yet played by experts, Tooka has some of the necessary qualities to be an expressive instrument. Tooka leverages off the intimacy between two people to create an expressive instrument. The approach in Tooka is novel in the sense that the interface is exploiting humans ability to form relationships. The output of the device is intended to represent that intimacy, and this provides feedback to the two people to keep them engaged and satisfied. The expectation is that the human dynamic will be strength-

ened sufficiently so that people are engaged on a continuous path to virtuosity and will tolerate the complexity of the interface. This same principle may apply to devices that support human–human communication, such as cell phone interfaces.

The systems described here all use different techniques to facilitate the development of intimacy and ultimately to the formation of an embodied interface. At this point, empirical techniques to measure intimacy do not exist. We are investigating adapting experimental methods from psychology to measure the relationship between a person and a device as he learns to use it. This is the subject of current research.

The use of the computer for developing new musical instruments has created new opportunities for expression. However, the expansive possibilities for mapping gestural control to sounds is complex. Researchers have only had limited success finding the right mix of an interface that is possible to learn and at the same time continues to grow in expressive power as expert performance is achieved. Further complicating the situation is the fact that the audience as well as the players requires a transparent mapping to understand the causal relationship between control and sound to have an expressive instrument. New music synthesis techniques, new sensing technologies, better understanding of human–computer interaction and new techniques for measuring intimacy will help explore the nearly infinite possibilities for musical instrument design.

VIII. FURTHER READING

The field of new interfaces for musical expression covers a large body of knowledge. Some selected readings for additional coverage include conference proceedings from New Interfaces for Musical Expression (NIME);⁴ the symposium on Human Supervision and Control in Engineering and Music in Kassel, Germany, in 2001;⁵ *Organized Sound: An International Journal of Music and Technology* published by Cambridge University Press, Cambridge, U.K.; and the *Journal of New Music Research*, published by Swets & Zeitlinger, Lisse, The Netherlands. In addition, research based around the term *kansei*, a Japanese word roughly meaning emotion or emotional expression, incorporates new music interfaces. Readings can be found in the Proceedings of KANSEI, the Technology of Emotion Workshop, held in Genova, Italy, in 1997, among others. Reports on new interfaces for musical expression also appear in research publications on human–computer interaction such as the Proceedings of IEEE Multimedia and Exposition (ICME), the ACM Special Interest Group on Computer-Human Interaction (SIGCHI), the ACM Special Interest Group on Graphics and Interaction (SIGGRAPH), and *ACM Multimedia* and associated journals. Finally, musicians looking to expand their expressive capabilities create many new interfaces. These often go undocumented and only appear in performances. These are sometimes described on CD liner notes or concert reports.

⁴www.nime.org

⁵www.engineeringandmusic.de/

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