Recent Developments in Violin-related Digital Musical Instruments: Where Are We and Where Are We Going?

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ABSTRACT
In this paper, some of the more recent developments in musical instruments related to the violin family are described, and analyzed according to several criteria adapted from other publications. While it is impossible to cover all such developments, we have tried to sample a variety of instruments from the last decade or so, with a greater focus on those published in the computer music literature. Experiences in the field of string players focusing on such developments are presented. Conclusions are drawn in which further research into violin-related digital instruments for string players may benefit from the presented criteria as well as the experiences.

Keywords
Violin, viola, cello, bass, digital, electronic, synthesis, controller.

1. INTRODUCTION
A violin-related digital musical instrument can be either a *physical instrument* that incorporates or mimics a bowed string instrument, a *software instrument* that is controlled by or mimics bowed string instruments, or quite possibly a combination of these two things. Figure 1 shows a few past and present developments in violin-related interfaces for electronic music.

In the case of *physical interfaces*, some new instruments can be played in exactly the same way as a traditional violin, while others require the performer to learn non-traditional gestural techniques. For example, Max Mathew's electric violin, which is one of the first developments in violin-family digital instruments, is played with traditional violin technique, while other developments such as Dan Trueman's BoSSA [15] are designed around an entirely new set of gestures (albeit borrowing from traditional technique as we discuss later). One example of a hybrid interface that combines these elements and brings together both traditional and non-traditional gestural techniques is the Overtone Violin [10].

A *software instrument* can be a synthesis algorithm or a processing algorithm, or a combination of the two. Synthesis algorithms are generated entirely from scratch in the computer and are typically controlled by parameter updates from an external controller with sensors that detect the performer's gestures. Processing algorithms take input from an external audio source (such as the strings of an electric violin) and either modify it with reverb, delay, etc. or use it as a stimulus for modulation of filters or other signal processing algorithms. One example of a violin-related synthesis algorithm is the use of physical modeling to simulate the Helmholtz motion of a bowed violin string [5]. An example of an algorithm that uses the audio from a viola's strings as stimulus is Audio Signal Driven Sound Synthesis [11].

A wide variety of violin-related digital musical instruments have been invented – the intention here is not to survey all known developments, but to outline the criteria that make a given development suitable or unsuitable for a specific purpose. A development that is weak in a certain area can often be strengthened by combining it with another technique to produce a hybrid.

2. LOOKING BACK
In order to get a view on where we are, it is helpful to take a look into the past. Surveying the last 10 years of developments, we analyzed the proceedings of the International Computer Music Conference ICMC (1995-2005) and the Proceedings of the conference on New Interfaces for Musical Expression NIME (2001-2005). We found 28 (18 ICMC and 10 NIME) articles that were related to the violin family.

Figure 1. Clockwise from top left: Max Mathews playing his electric violin, Neal Farwell's Funny Fiddle, Dan Trueman's BoSSA, 2 generations of Tod Machover's Hyperviolins, Chris Chafe's Celleto, and Suguru Goto's Superpolm MIDI violin.

The violin is often said to be an instrument with a high potential for musical expression and a high quality of sound. We wanted to investigate if the reason for the works presented in these publications were related to this expressivity or quality, and on which component of a digital instrument they were focused.

According to our statistics, 84% of the developments we looked at mentioned the bowed string instrument family in their reasoning when considering expressivity or sound quality. By separating the papers into the four categories of controller, synthesis, processing, and complete instrument we found the following: The majority (11 publications, 61% of the ICMC publications) focus on sound synthesis, wherein the majority of these (8) are related to physical modeling. The largest class of developments discussed in the NIME proceedings were complete instruments (6 instruments, 60% of the violin related NIME publications). Four of the 28 publications focused mainly on the development of a controller; two from ICMC and two from NIME. The remainder of the papers were divided among processing (one publication) and others (one publication on violin pitch tracking and two publications on software to do analysis of bow strokes).

While the majority of researchers said they would like to use the expressivity or quality of a bowed stringed instrument, it was interesting to see how expressivity or quality was defined, where in the instrument or playing process they thought it was located, and how it was assimilated into the development of a digital instrument. Except in one case, there were no publications that explicitly defined musical expression or expressivity of a violin.

Regarding synthesis-related research, the quality of the instrument is mostly thought to be located in the physically describable behavior of the instrument. The majority of the publications locate the expressivity in a fixed set of player gestures and playing parameters. These are: right hand—bow speed, bow pressure, bow position, and left hand—finger position and finger pressure. With respect to the connection between the gestures and resulting sound of a traditional instrument there is no major belief found which sound-conditions have to be met in order to keep an acceptable instrumental coupling and synthesized specific sound.

Concerning mapping, it was found that violin related publications directly addressing this topic are rare. One-to-one mapping was found predominantly, and one-to-many only occasionally. Many-to-one mappings were not explicitly found in our search, and only two publications addressed the mapping issue in a broader fashion, e.g. in the development of an "advanced and intelligent mapping interface" [3].

Most researchers were concentrating on scientific goals in the published literature. 11 developments (4 presented at ICMC, and 7 at NIME) were said to be ready for stage use. It was found that over 50% of the developments had the goal to sound like a traditional bowed stringed instrument, that over 50% of the developments had the goal to give the player the "feel" of a traditional bowed stringed instrument, and that over 75% of the developments behaved (in terms of articulation) similar to a traditional bowed stringed instrument.

In general, the evaluation of results and capabilities of the developments in terms of expressivity or quality were done by the authors. Six publications out of the 28 showed that external evaluation was involved, with two of the six using empirical methods to evaluate the work. This might be said to reflect the goals of the developments, which more often than not fell into the categories of personal use or research.

Additionally, there have been many important developments that to our knowledge have never been published. Some of these are quite significant in the field, and are discussed here—a few them that the authors have knowledge of include Max Mathew's electric violin, Chris Chafe's Celletto, Neal Farwell's "Funny Fiddle", Jon Rose's MIDI bow, and Peter Beyl's IR-violin.

One of the earliest examples of an experimental bowed string instrument is Max Mathew's electric violin, which used a piezo-ceramic bimorph pickup system to capture the vibrations of the strings. The same pickup technology was used on Chris Chafe's Celletto, which he began building in 1988 [2]. The Celletto is an ongoing and pioneering project, and has evolved through a series of embodiments in many performances. Along the way, various sensors have been used to capture the gestures of playing, such as strain gauge sensors and an accelerometer on the cello bow. In one context, a Buchla Lightning controller was used to track the bow, an elegant solution to the problems associated with developing custom sensor devices.

Neal Farwell's "Funny Fiddle" instrument was used in his composition *Gipsy Fugue* in 1996 and is also still undergoing development. Jon Rose's MIDI bow was developed at STEIM in Amsterdam, and incorporates sonar sensors to allow a violinist to lift the bow from the string and continue to play with the bow alone. Peter Beyl's IR-violin is an altered violin with infrared transmitters and receivers as sensors in place of the strings.

3. NEW VIOLIN-RELATED INTERFACES: THREE TOPICS TO THINK ABOUT

To be sure, any new musical instrument must consider the three areas of human interfaces, sound generation, and the mapping of data between these input and output systems. Here we uncover some of the concerns that arise when designing, developing, and performing with new violin-family digital instruments. Examples of specific instruments are given where applicable, and – inspired by David A. Jaffe's article "Ten Criteria for Evaluating Digital Synthesis Techniques" [6] — criteria for estimating effectiveness in performing scenarios proposed. We assume that the purpose of a new violin-family instrument is that of performance (other contexts for their use, such as individual or institutional research or personal enjoyment are beyond the scope of this paper). These recommendations are given as our personal opinion of how the criteria can ideally be met.

3.1 Human Interfaces – Gestural Controllers and Sensor Technologies

Although technical issues such as sensor resolution, latency of transmission, and wireless capability all have impacts on new interfaces, we will not focus on these engineering problems here. Instead, we start by looking at the gestures enabled by the interface, and how they allow a performer to extend or enhance the playability of a violin-related digital musical instrument.

3.1.1 How Intuitive are the Gestures?

When designing a new interface, one decision that needs to be made is what type of gestures are to be captured—the answer can fall into two different categories. Some musicians are interested mainly in using the gestures they have already developed through years of practice on traditional violin-family instruments, while others would prefer novel gestures to be available as control inputs. In either category, developers should consider how ‘natural’ a gesture feels when designing new human interfaces and sensor technologies. In the first case, sensors should be used to capture traditional gestures with as much accuracy and precision as possible, and in the case of non-traditional gestures the interface should use a sensor system that allows for gestures that are in some way related to the traditional playing motions of violin-family instruments. Of course an instrument easily becomes “something else” (no longer a violin-related instrument) if this relationship is broken.

Suguru Goto’s Superpolm violin [3] is an interface that requires alternate gestures to be used as performance input, by substituting electronic sensors for strings and synthesis algorithms for acoustics. The instrument is equipped with touch-strip sensors on the fingerboard and a bow that works as a resistor ladder pressed against a voltage sensor on the bridge, plus a chin squeeze sensor for an added dimension of control. While it is impossible to use traditional playing techniques on the Superpolm (since it doesn’t have strings), the gestures it requires are closely related to those of a traditional violin. Given this correlation, the Superpolm is a good example of an interface that employs non-traditional gestural input, and the use of a pressure sensor under the chin rest seems to be a natural fit for added expressivity. Although chin pressure does nothing on a traditional instrument, it could be argued that squeezing the violin harder or softer is an intuitive method of input as it relates to the overall player’s effort.

Another interface that captures non-traditional yet violin-like gestures is Dan Trueman’s Bowed-Sensor-Speaker-Array, or BoSSA [15]. This instrument includes elements of both the violin’s physical performance interface and its resonating body, yet eliminates both the body and the strings. It replaces the body with a “spatial filtering audio diffuser”, a spherical speaker designed with multiple drivers to eliminate the directionality associated with normal loudspeakers, and multiple sensors mounted on a moveable fingerboard in place of the strings. At first glance, most of the gestures (except bowing) associated with playing the BoSSA might seem to be counter-intuitive to a traditional violinist. However, as the developer is himself a violinist, the motions necessary to control the instrument have been carefully designed to overlap with several aspects of violinistic gestures.

In both traditional and non-traditional gestural interfaces, it is the authors’ opinion that those looking to extend bowed instruments should expect to spend some time learning a new set of gestures if they are to have an impact in far-reaching ways; it just helps this process if such new gestures are put forth by the instrument developer in an intuitive manner.

3.1.2 How Perceptible are the Gestures?

Gestures should cause an understandable change in the sound for the performer to best grasp an instrument’s playability. A gesture that causes a difficult-to-predict change in the sound may be interesting at first, but it can drive a performer crazy if they are trying to control such a sound in front of a live audience. On another level, the actions of the performer should have clear consequences in order for the interaction to be perceived by the audience. Preserving some sense of mystery in the performance is also important though, and may be accomplished partly through a composition but also via the design of the instrument itself.

A recent development that focuses on capturing traditional bowing gestures is the Ircam augmented bow [13] developed by Emmanuel Fléty. This system uses a coin-cell battery to power the electronic sensors mounted on a violin bow, and a radio link transmits the data to a receiver that communicates with the computer via OSC. The augmented bow can be used as a research tool to investigate the perception of bowing gestures as received by the computer, or as a live performance interface on stage. Gaining a better understanding of musical gestures such as those used in traditional bowing technique is an important step to perceptible gestures, and interfaces such as these greatly improve this by providing a high-resolution link to the digital world.

There have been several other developments involving the capture and perception of traditional violin family gestures, such as those from the Hyperinstruments group at the MIT Media Lab. The Hypercello [8] as developed by Joe Paradiso and Neil Gershenfeld was based on a RAAD electric cello, and had an extensive array of sensors to catch as much detail as possible. The left hand finger position, finger pressure, and right hand bow position were all detected through the development of custom sensors. The Hyperbow Controller [16] by Diana Young is the most recent of the MIT developments, and also uses a wireless transmitter on the bow along with strain gauge sensors to gather data showing the changes in bowing pressure over time.

Regarding the audience perception of violin-family instruments, public knowledge has accumulated to come to expect certain things from something that looks or is played like a violin – this common perception allows new developments that use traditional gestures to break the expectation, surprising the audience with previously unheard sounds. However, for non-traditional gestural interfaces there is no common reference as a key to comprehension for the audience, which puts the responsibility of helping an audience understand what is happening on the developer and performer of such instruments. Therefore, a novel instrument should carefully consider the perceptibility of its gestures both to the performer and to the audience.

3.1.3 How Physical/Powerful are the Gestures?

Making an obvious physical gesture should have a significant audible effect. Electronic technology allows even a tiny motion to have a huge outcome, however it is important to take into account the dramatic effects of a gesture in the design of a new instrument. As such, the performance interface should attempt to provide a vehicle for expressive communication with an audience. Human effort should be incorporated into the design where possible in order to bring out the inherent relationship between instrument and performer. Obviously, if a tiny gesture causes a big sound the performer may have difficulty controlling the instrument. In addition, the consideration of effort will have an impact on the music, lending it a “human feeling”, as more exertion is required for some musical ideas than others.

Finally, the choice of whether or not to leave behind the core elements (strings, horsehair, rosin) of traditional bowed-string instruments when developing a new interface is crucial. The history, convention, and institution that comes with traditional instruments may or may not be desirable for a certain development, but dropping these core elements leaves behind a powerful interface for the trained musician. If the instrument has strings that are still playable in the traditional sense, then a single gesture can be made more powerful by simultaneously controlling the sound of the strings along with the digitally generated sound. Hybrid instruments such as Curtis Bahn’s Sensor Bass [1] and the Overtone Violin can provide a way of bridging the gap between the world of acoustic instruments and the new possibilities offered by computer music, as they incorporate multi-parametric control along side the traditional instruments interface.

3.2 Sound Generation – Analysis, Synthesis and Manipulation

The method of analysis, synthesis or sound manipulation used in a violin-family instrument has a vital effect on its playability, and many researchers have identified and experimented with signal processing algorithms for this purpose.

3.2.1 How Well-Behaved is the Algorithm?

A frequent approach to controlling a synthesized tone with a violin-family instrument is to use a pitch and amplitude-tracking algorithm. While these trackers tend to be fairly well-behaved in some situations (for example when used with an electric guitar), the violin family of instruments can induce errors in many such algorithms. Bowed-string traits such as 'fuzzy' note-starts and indefinite pitches can be problematic for a tracker, and may result in incorrect pitch estimates. A synthesis algorithm that is fed this wrong information will then produce audible artifacts, an effect that can render them undesirable and displeasing to the performer and audience.

Clearly, synthesis and processing algorithms should attempt to avoid such artifacts. Work in this area has been done by Tristan Jehan, who has developed an enhanced version of Miller Puckette's *fiddle~* Max-object called *analyzer~* [7] that tries to avoid these problems, and also estimates loudness, brightness, and noisiness in the incoming signal. While it is imperative for some synthesis algorithms to know the pitch a performer is attempting to play, other processing techniques do not need this information at all, and therefore may be better choices in many situations. A simple example is a pitch-shifting algorithm, which manipulates the incoming sound directly, modifying the A/D input in either the time or frequency domain. This comes with its own challenges such as formant preservation, etc. but there is no external limit caused by errors in pitch tracking or loudness as to how well-behaved such synthesis algorithms can be. Developers should take these concerns into account when designing or choosing algorithms to use with a new instrument.

3.2.2 How Realistic/Unique is the Sounds Identity?

One development in synthesis that is related to the violin family is Bernd Schoner's Digital Stradivarius project [14], based on the mathematical technique of cluster-weighted modeling. This method concentrates on the simulation of acoustic phenomena, thereby attempting to emulate an actual violin. The potential of this approach is evident in the types of parameters the synthesis algorithm has—bow pressure and speed that are applied to the mathematical model. Input from a controller then is easily mapped and can provide results closer to real world instruments. However, there are cases where exotic (non-violin) synthesis algorithms are desirable as well, and many performers would like to take advantage of sounds that have a more unique identity. In the final analysis, the appropriateness of a given sound depends on the musical task at hand.

3.3 Mapping – Sensor Inputs to Synthesis Parameters

It should always be remembered that the physical input device and the synthesis algorithm are only pieces of the whole instrument, and one must take into account the importance of the mapping as well. This stage can in fact "make or break" an instrument.

3.3.1 How Rich is the Mapping Methodology?

This topic concerns whether the controller inputs and synthesis parameters map in an intuitive manner to musical attributes like musical dynamics and articulation, or whether they are just mathematical variables with very little correlation to real-world perceptual or musical experience. Mapping is heavily interconnected with both sensor inputs and synthesis parameters, in that limiting factors can arise from both sides. For example, an instrument without a sensor for bow position could not directly control a physical model that expects this as a parameter, and a sample-playback-based synthesis engine would not respond in complex ways to bow sensor input. Evidently, every instrument uses some kind of mapping methodology in order to connect performer inputs to sound outputs, but there can be many levels of richness and variety in treating the problem.

Camille Goudeseune has developed a system that uses a SpacePad motion tracker to map various synthesis techniques to the position of a violin in 3-dimensional space [4]. His examples proceed from very simple extensions of standard violin technique up to much richer demonstrations of what is possible when multiple layers of mappings are placed between the performer's physical input and the system's sonic output. The simplest uses the violin's position in space to control the position of its sound source in stereo. One of the more sophisticated mappings controls Hammond Organ additive synthesis by "letting an automatic timbre rover explore a few thousand times of the instrument, with instructions to choose a dozen timbres that differed enough from each other to adequately represent the whole space" (the definition of difference comes from a psychoacoustic model of the human hearing system). This timbre rover is a tool for setting up a very rich mapping methodology that allows for a wide variety of sounds.

3.3.2 What is the Widest Range of Expression?

It is the authors' view that new violin-related musical instruments should focus on deepening sensitivity to the control of micro-gesture that a well-trained violinist possesses. This can be accomplished in part through mapping by scaling control values and making the most of the available sensitivity of a given physical interface. Also, physical interfaces can incorporate very high-resolution sensors and force feedback – a technique Charles Nichols researched for his dissertation at CCRMA [9]. His development, the vBow, is a virtual bow controller designed to accurately sense the motions of a bowing gesture while providing haptic feedback in the form of tactile simulations of detents, elasticity, and barriers produced by electronic motors.

4. EXPERIENCES

In addition to the view of past developments, it is important to mention some personal experiences that we think give inside views on the contributions necessary to construct digital bowed stringed instruments.

4.1 Traditional String Players

Until now, we have focused mainly on developments that have culminated in research tools for the authors, however the next section deals with more general questions about the direction we are headed when it comes to string players throughout the world. As pointed out in [16] the study of the player – instrument interaction is important. One field to collect experiences for basic principles of violin playing is the field of violin pedagogy.

It is a known circumstance that the change from one violin teacher to another can cause the need to change playing techniques and gestures, sometimes beginning even from the basics again. Such changes very often come along with a different overall view on "how music should be performed in order to be of high quality". According to our experience, all the differences cannot be explained with the simple statement that one way is simply a bad one while another is a good one. We conclude that different answers to the question, "What are the main needs of a string player in order to do what is necessary for playing music if we build a new instrument?" may not be too big a surprise. Asking people around us, we indeed got many different answers on this question as presented in section 4.2.

Testing different versions of digital violas [11], it was interesting to see what each subject did with the sonic artifacts (e.g. wrong pitch detections) the systems were producing from time to time. While most string players tried to avoid these, there were some instrumentalists who started to play with it and mentioned this might be a good opportunity to special kinds of sound production. However, this is not a primary feature of the instrument, but it may or may not become a feature primary by the definition of the player.

4.2 >hot_strings SIG<

Confronted with the fact that the knowledge about the fascinating new developments was rare in the world of more traditional string players, the first author started to do workshops presenting these developments to them. In 2004 this lead to a community of people interested in general kinds of inventions to the family of bowed stringed instruments called >hot_strings SIG<. The SIG includes professionals from performers, instrument builders, researchers and composers based in Europe. Meetings occur twice a year with the goal of sharing knowledge, presenting and discussing new instruments, repertoire, research results and aesthetic positions.

Presenting some of the recent developments discussed here (using movies, sound examples, summaries of publications and demos) the assumption was that this would generate a lot of interest from the SIG members, since they are definitely interested in extending their expressivity and open for new sounds. However the feedback received was smaller than expected.

This result raised questions about the subjective reasons for such reluctance, and the follow-up question of what the needs and wishes of the SIG members were if they could have digitally extended versions of string instruments. The reasons mentioned for this lack of enthusiasm were different from person to person. Here is a selection of the statements:

- Some developments were not felt to be extensions of traditional bowed stringed instruments. By listening to sound examples and watching movies the most developments were estimated as to be interesting from a scientific point of view, but in terms of sound and expressivity estimated more as a reduction than an extension compared to existing instruments.

- Reducing the right hand input to the bow parameters of position, pressure, and speed was said not to cover playing techniques like pizzicato, col legno, and a lot of techniques used in contemporary music.

- In order to get the sound qualities of a bowed stringed instrument the resonances of the body (or in this case sound synthesis) have to resonate back to the strings. Otherwise there will always be a different playability and sound characteristic that may keep a lot of players unsatisfied.

Discussing the needs an extended bowed stringed instrument should have brought different answers. Asking further it became clear that the reasons came from different aesthetic points and different experiences with computer-based stringed instruments. Statements found here were:

- New instruments should not only have a string specific-playability, they should also have a string specific sound, different from the one of traditional instruments but within a specific range that enables the player to use the known gesture-input and sound-feedback loop. An important thing is to be able to create sensuality with the instrument.

- I want to make new music with the new instrument and therefore I need it to sound very different from a traditional violin. Keeping a basic set of similar gestures is necessary for me, however an instrument with a different feel and sometimes unconventional reaction is quite ok. A Zeta® violin with additional bow tracking methods would fit my needs.

- New Instruments have to be flexible and extendable in the playing parameters that can be tracked, the mapping and the methods of sound synthesis. Building an instrument is an act of composition and includes an aesthetic point of view since it has to be defined what kinds of gestures and sounds are more or less important.

- If we want to expand the violin with an electric/synthesizer violin, than the instrument has to be able to deal with the complexity of the player. The players string specific ability has to be assignable to the extended new instrument. Everything in terms of bow position, bow speed, more than that, everything that is done in nuances of sound has to be transmittable.

While the aspect of timbre plays an important role when a string player tests traditional instruments, it became obvious in discussions that the timbral color palette a violin maker may want to offer to the players is thought of in a completely different way than a synthesizer developer might. A violin may sound for a synthesist always like a violin and therefore be boring in richness of sounds. A violin player however, can have a completely different opinion in this regard, since all the colors of sound she or he is controlling fall within this space and are sufficient to give a full range of expressivity.

5. DISCUSSION

Facing the evolution of developments in recent years, we still see a challenge to make the areas of new interfaces and synthesis more rewarding for the broader world of string players. Regarding the evaluation methods in papers and looking at the opinions presented in section 4.2, we think it is necessary to obtain a better feedback loop between developers and string players (as long as the development is focusing on that area).

Taking the “top-down” approach, many of the developments analyzed in section 2 first define what the needs of a player are, then design the instrument, and finally evaluate whether the development has met the original criteria. Regarding the different needs articulated by musicians, different aesthetical positions, and different understandings of how to play bowed string instruments, we might try to avoid a view on string players through the glasses of an objective fixed average player-instrument interaction. We would instead like to discuss a “bottom-up” approach that is oriented at the needs of individual musicians as an apparent alternative. With respect to the criteria proposed in section 3 we feel there may be an effective way to build some basic digital instruments and then work to enhance them from the “ground up”, while incorporating feedback from instrumentalists. Of course we also expect that while our criteria is at present our best estimate of important design considerations, it may include presumptions which will have to be corrected according to individual positions that have yet to be found.

6. CONCLUSION

With respect to the fact that we find in the world of string players communities with similar aesthetic positions, we conjecture that over time some sets of criteria will arise that are specifically relevant for those communities. According to our own experiences and to the statements presented in section 4, we hypothesize that a set of three basic digital instruments in the violin family could look like this:

- Playing without a defined and fixed parameter-set but reduced to ASDSS-sounds: an instrument like the eviola presented in [12].

- Playing with predefined playing parameters able to use any known synthesis method: a Zeta® (or similar) type instrument expanded with a bow tracking system e.g. the Ircam Bow[13].

- Playing with the methods mentioned above and with new gestures: an instrument like the Overtone Violin[10].

With this approach we will be able to study the instrument-qualities within the not yet known quality-criteria of the players, their playing-style and their aesthetics. These three instruments as proposed will surely not be the only or even the main ones used in the future, but we see in this way a possibility to bridge the gap between the fascinating and powerful possibilities the digital age has brought to us and the culturally powerful community of string players who are seeking to enhance their musical language.

We have seen that many different approaches to violin-related instruments have occurred in last decade or two. While they all contribute to the whole, to a certain extent they tend to be idiosyncratic developments that have goals focused primarily on individual use. This could be partly because of the nature of doing research into new technologies, or possibly because we are simply in a transitional period in the history of violin interfaces, and the territory that lies ahead may lead towards developments that stick around longer. Call it a "new renaissance", if you will — when digital instruments transpire to allow a new generation of virtuosi to emerge by providing the right affordances to performers and becoming practical enough to make it outside of the research labs. For any instrument to survive the test of time, it must be accessible (available throughout the world), have a repertoire (even the violin itself would not have survived without this), and most importantly it must be inspiring to future generations of performers and composers!

7. ACKNOWLEDGMENTS

We have attempted to present a balanced view of the instruments discussed. Nevertheless, our bias toward hybrid instruments cannot be hidden. We apologize to those researchers whose developments were not explicitly cited in this article. The choice was biased by the instruments with which we were most familiar, having seen, played, or read about them in various articles.

8. REFERENCES

[1] Bahn, C and Trueman, D. Interface, Electronic Chamber Ensemble *Proceedings of the CHI 01 Workshop New Interfaces for Musical Expression (NIME01),* Seattle, USA, 2001

[2] Chafe, C. Personal Communication, 2006

[3] Goto, S. and Takahiko, S. The Case Study of Application of Advanced Gesture Interface and Mapping Interface, - Virtual Musical Instrument "Le SuperPolm" and Gesture Controller "BodySuit" *Proceedings of the 2004 Conference on New Interfaces for Musical Expression*, Hamamatsu, Japan, 2004, 207-208

[4] Goudeseune, C. Resonant Processing of Instrumental Sound Controlled by Spatial Position *Proceedings of the CHI 01 Workshop New Interfaces for Musical Expression (NIME01),* Seattle, USA, 2001

[5] Jaffe, D.A. and Smith, J. O. Performance Expression in Commuted Waveguide Synthesis of Bowed Strings. In *Proceedings of the 1995 International Computer Music Conference,* Tokyo, Japan 1995, 343-346.

[6] Jaffe, David A. Ten Criteria for Evaluating Synthesis Techniques, *Computer Music Journal* Vol. 19(1), MIT Press, Spring 1995, 76-87

[7] Jehan, T and Schoner, B. An Audio-Driven Perceptually Meaningful Timbre Synthesizer *Proceedings of the 2001 International Computer Music Conference,* Bejing, China 2001, 381-388.

[8] Machover, T. Hyperinstruments: A progress report 1987 – 1991. Technical report, MIT Media Laboratory.

[9] Nichols, C. The vBow: A Development of a Virtual Violin Bow Haptic Human-Computer Interface *Proceedings of the 2002 Conference on New Interfaces for Musical Expression* Dublin, Ireland, 2002, 29-32

[10] Overholt, D. The Overtone Violin: A New Computer Music Instrument, *Proceedings of the 2005 International Computer Music Conference,* Barcelona, Spain 2005, 604-607.

[11] Poepel, C. On Interface Expressivity: A Player-Based Study, *Proceedings of the 2005 Conference on New Interfaces for Musical Expression*, Vancouver, Canada, 2005, 228-231

[12] Poepel, C. and Dannenberg R. B. Audio Signal Driven Sound Synthesis, *Proceedings of the 2005 International Computer Music Conference,* Barcelona, Spain 2005, 391-394

[13] Rasamimanana Nicolas, Fléty Emmanuel, Bevilacqua Frédéric, *Gesture Analysis of Violin Bow Strokes*, GW 2005, Lecture Notes in Artificial Intelligence 3881, S. Gibet, N. Courty, and J.-F. Kamp (Eds.), 2006, 145–155.

[14] Schoner, B. Cooper, C. and Gershenfeld N. Cluster-Weighted Sampling for Syntheis and Cross-Synthesis of Violin Family Instruments *Proceedings of the 2000 International Computer Music Conference,* Berlin, Germany 2000, 376-379

[15] Trueman, D. and Cook, P. BoSSA: The Deconstructed Violin Reconstructed, *Proceedings of the 1999 International Computer Music Conference,* Bejing, China 1999, 232-239

[16] Young, D. S. New Frontiers of Expression Through Real-Time Dynamics Measurements of Violin Bows, Master's Thesis, M.I.T. 2001