AtoMIC Pro : a Multiple Sensor Acquisition Device

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Abstract

Research and musical creation with gestural-oriented interfaces have recently seen a renewal of interest and activity at Ircam [1][2]. In the course of several musical projects, undertaken by young composers attending the one-year Course in Composition and Computer Music or by guests artists, Ircam Education and Creation departments have proposed various solutions for gesture-controlled sound synthesis and processing. In this article, we describe the technical aspects of AtoMIC Pro, an Analog to MIDI converter proposed as a re-usable solution for digitizing several sensors in different contexts such as interactive sound installation or virtual instruments.

The main direction of our researches, and of this one in particular, is to create tools that can be fully integrated into an artistic project as a real part of the composition and performance processes.

Keywords

Gestural controller, Sensor, MIDI, Music.

SOLUTION FOR MULTI-SENSOR ACQUISITION

Introduction

Gestural controllers are often based on sensors which generate analog electrical signals [3]. For controlling sound synthesis or sound effects with such a controller, the sensors' analog signals must find a way to enter the computer in charge of the process. Unfortunately, those signals cannot directly be transformed into a digital form : they need to be conditioned. This operation of course depends of the sensor's type, its voltage range or its impedance, among other factors. Also, sometimes, the analog signal has to be filtered, amplified or gated. All these steps are usually specific to each gestural controller, even if some sensors are more often used than others. Moreover, signal conditioning requires certain skills which makes it difficult for non-technical people to design custom controllers.

In most cases, the chain composing a controller can be summed up as shown in figure 1. It is obvious that the Analog to Digital Conversion could be factored, as well as some of the conditioning processes which could be achieved digitally (filtering and amplification for instance).

The next question regards the protocol used for transmitting the digital value to the computer. In the musical domain, the MIDI standard[1] has been created for that purpose. It was basically used for connecting master keyboards to sound generators, but continuous controllers were soon added to the keyboard such as breath controller, modulation wheel or pitch wheel. We chose to use MIDI for exporting the sensor's data to the computer because this standard is fully implemented in a computer's software and hardware. However, we had to keep in mind the several drawbacks of MIDI such as its seven bit quantification and its slow bitrate allowing only about a thousand messages per second.

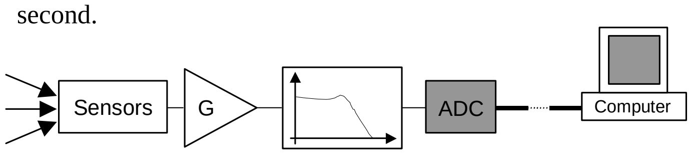

Figure 1 : Simplified structure of a gestural controller

Design of a new sensor to MIDI converter

In 1998, we needed to convert sensors' data to MIDI for live electronic music pieces, so we looked for commercial products able to do this operation. At that time, the available products featured either too much latency, low samplerate or not enough configurability[2]. So we decided to build our own analog to MIDI converter that would be able to manage multiple sensors, be stand-alone, be easy to configure and operate as much as possible in real-time.

While our main criterion were high samplerate and low latency, we also kept in mind the on-stage use of the device, which means robustness and full MIDI compatibility. As a matter of fact, the use of such a tool is not confined to a direct connection to a computer but could also simply drive a MIDI device such as a sound generator, a sampler, or an sound effects processor. Thus, it was very important to allow the user to configure accurately the message sent by the unit and not to constrain him to have a dedicated hardware such as a computer.

After taking into consideration what had been designed in the past [4][5], we proposed several improvements – while recognizing that this development would have to be a compromise between efficiency, speed and resolution on the one hand, and on the other hand versatility and cost. The latter is important because we thought from the very beginning about making this device available to several "targets" and not only to gestural controller specialists.

[1] MIDI : Musical Instrument Digital Interface
[2] Refer to Table 1. next page.

Table 1 : Comparison of some existing analog to MIDI converters

Interface	*ADB I/O*	*AtoMIC Pro*	*Digitizer (I-Cube)*	*MIDIBox*	*MidiCreator*	*SensorLab*
Manufacturer	BeeHive	Ircam	Infusion Systems	NOTAM	York Elect. Center	STEIM
Platform	Macintosh	Any	Any	Any	Any	Any
Max SR [Hz]	< 90	1000 / Nb active inputs	200 / 225 (12/8 bits)	Approx 400	120	250
Analog IN	4	32	32	8	8	32,2x3 (US)
Digital IN	4/6/8	8	-	16	8	8x16
Input Res.	8 bits	10/7 bits	12/8 bits	8 bits	8 bits	8/14 bits US
Outputs	max 8	8 switches + 4 MIDI	8 switches + MIDI	6 + MIDI	MIDI	MIDI
Size (HWD)[mm]	29x122x65	38x165x225	34x121x94	20x100x100 (PCB)	41x227x166	35x200x100

Thus, we designed the AtoMIC Pro which is a device able to convert thirty-two 0 to 5 volt analog signals into MIDI messages. Eight logic inputs (i.e. 0 or 5V only) were also added in order to keep the use of analog inputs only for continuous sensors. Eight logic outputs can also be controlled by MIDI messages to trigger on/off processes like lights, relays or DC motors.

The AtoMIC Pro features a liquid crystal display and a keypad so that the user can configure the behavior of each analog input directly on the unit without the need of a computer. Each input can have a particular configuration in which the user specifies, for example, the MIDI message to be sent, its MIDI channel, and its MIDI port. The configuration of all the 32 inputs is called a patch and up to 15 patches can be stored and named in a non-volatile memory. A patch can be recalled at any time, by selecting it in the "File" menu, or with a MIDI message sent by an host system. Since the patch is stored internally, there is no need to dump it as it takes only 500 µs to load. Thus, it's possible to change the whole configuration of the device in real time between two notes of a score, even with a fast tempo.

Figure 2 : The AtoMIC Pro unit

The patch setup can also be done within the Max/MSP software and dynamically dumped to the AtoMIC Pro. In version 2.0, we have added more remote control messages to drive the unit from the computer in order to synchronize it with an electronic score. Thus, it's possible to save the current patch, reset the unit, and activate or deactivate an input from the computer while the device is on stage.

In order to make electrical signal debugging easier, the AtoMIC Pro also features signal monitoring on its LCD. One screen allows the user to monitor the digitized value of a dedicated analog input on a 20 level horizontal bargraph. Another screen displays the whole 32 inputs on small seven level vertical bargraphes, as illustrated in figure 3.

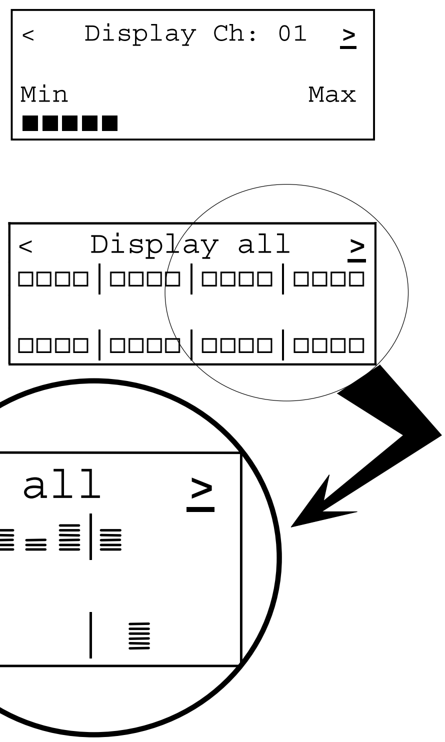

Figure 3 : Signal monitoring

The electrical signals enter the unit through lockable Sub-D plugs to guaranty the connections. Although this choice implies soldering wires to the plug, this kind of connector is very standard, cheap and secure. However, to provide a mean of easily connecting and disconnecting sensors, we built an extension that makes the bridge between three pin sensors[3] and the Sub-D connectors.

3 Such as the sensors proposed by Infusion Systems, designer of the I-Cube Digitizer.

Improvements

Since MIDI is painfully slow, it's quite difficult to keep sufficient bandwidth when many sensors are digitized on the same MIDI port. Because of that, we decided to implement data filtering inside the unit so that only useful samples are sent to the computer. For instance, in electro-acoustic music we often need to trigger events to synchronize the computer and the performer. The triggering operation is usually done by the performer who "tells" the machine he has reached a certain position in the score. The triggering can also be used to change parameters in the sound synthesis algorithm during the piece. Triggering is often done with a master keyboard sustain pedal, which is just a switch, i.e. a binary state sensor giving either 0 volt or 5 volts. Changing the pedal state will only generate one MIDI message and will not slow down the messages rate. But sometimes, it's not possible or desirable to use such a pedal, for instance when the performer cannot use his feet.

Roland Auzet, percussionist, wrote a piece for Zarb, a single head drum played while sitting cross-legged [6][7]. In that position, it is impossible to use a pedal for triggering. We decided to implement a trigger sensor directly on the drum, at a position that would not modify the percussionist's playing and without modifying the instrument itself. For this we chose to use an FSR sensor (Force Sensitive Resistor), which is a flat 2.5 cm diameter mechanical pressure sensor whose electrical resistance decreases continuously with the pressure.

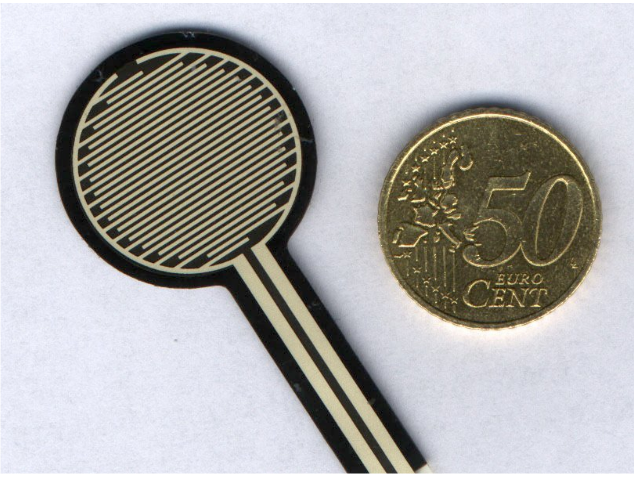

Figure 4 : FSR sensor

In order to make that sensor binary we need to setup a threshold. That can be done within the software running on the computer, but that would mean that continuous data would flow through MIDI before getting into the software, slowing down the system's bandwidth. Instead, we chose to threshold the signal directly inside AtoMIC Pro and this has led to dramatic improvements in system performance.

The problem of different sensors' dynamic ranges

The output from sensors can be quite different – current, voltage or ohmic resistance for example – but in most cases, it is quite easy to convert the sensor signal into voltage. Even so, the dynamic range can be very different between two "identical" sensors. In the first version of AtoMIC Pro we chose to implement a configurable voltage reference for the A/D converter[4] so that the conversion scale could be adapted to different sensors' configurations.

The configurable voltage reference helps to compensate for different dynamic ranges, as shown in figure 5, where the voltage reference has been changed from 5 volts to 4 volts, i.e. adapted to the largest dynamic within the sensor's population. However, this fixes only a part of the problem since the other sensors loose resolution as their dynamic range is not equal to the voltage reference.

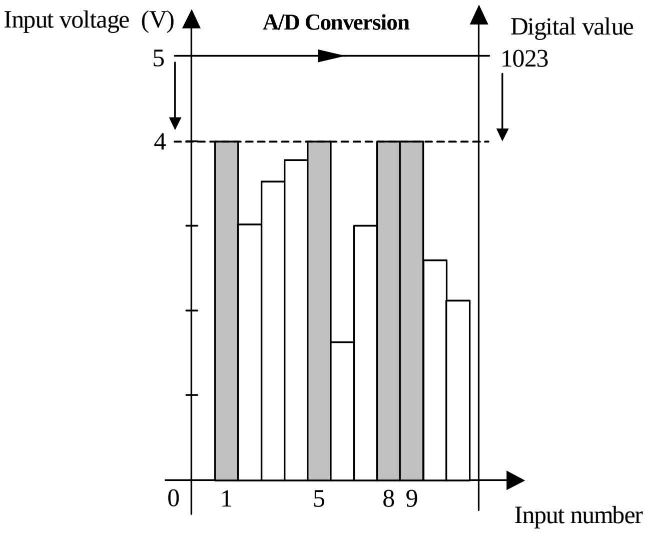

Figure 5 : Adapting the voltage reference

To solve that, one solution could be to amplify the signals, as a mixing table does. However, this means that external electronic circuits have to be designed and we wanted to have a fully integrated solution.

To get rid of this problem, we tried switching the voltage reference from one analog input to another. This didn't work because the A/D converter needs a stable voltage reference before being able to do the conversion and changing the voltage reference on the fly generates clicks and noise which is a disaster for the stability of the resultant digital value.

In version 2.0 we have implemented a custom scaled zoom on the digital value to take advantage of the 10 bit resolution of the A/D converter. First, the voltage reference is set to the largest dynamic among the sensors connected to the unit. Then, the user can select the sensor's range within the 10 bit dynamic by specifying a window size and an offset. The selected range can then be converted into 7 bit MIDI data without greatly increasing the quantification step, as demonstrated in figure 6.

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[4] The voltage reference specifies the upper boundary of the A/D converter's conversion scale, as shown on figure 3.

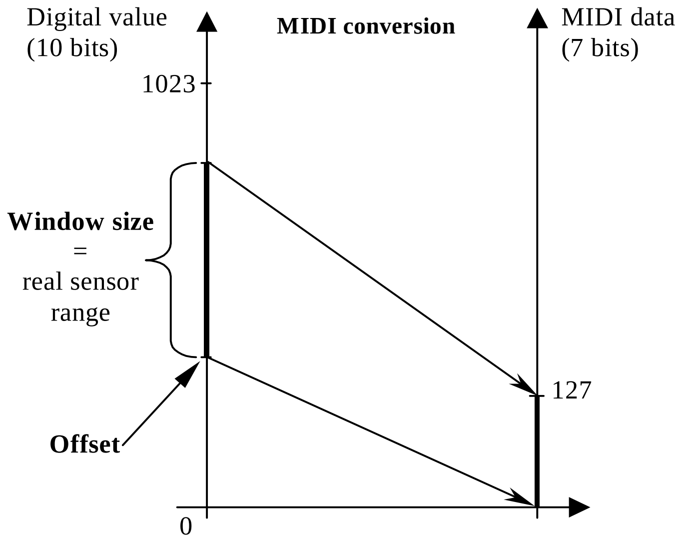

Figure 6 : Zooming the signal range

Data filtering and conversion tables

We have also added two filters and a noise suppressor. The filters will reduce the number of MIDI messages sent when the signal is not stable, like a low-pass filter. This is done either by down sampling the analog signal of the sensor or by applying a speed limitation algorithm to the digital value. The noise suppressor creates a band centered around the last sent value of the sensor and will not send MIDI data if the signal changes within the band, thus eliminating certain signal noise.

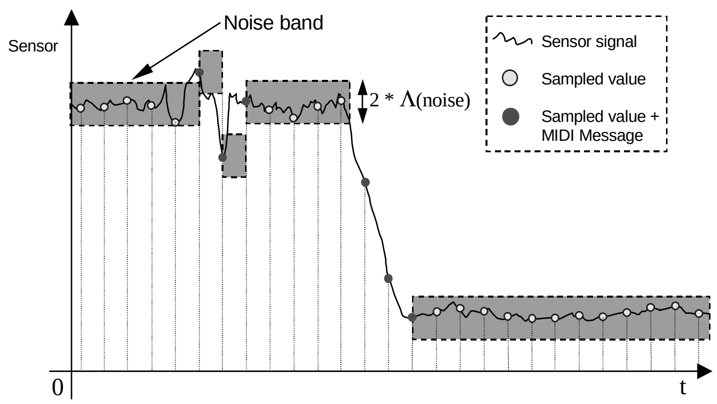

Figure 7 : Noise suppressor canceling unwanted MIDI messages

The sub sampling operation, as well as the speed limitation filter are configurable over a range of 128 possibilities for maximum flexibility. The use of the sub sampling filter underlines that it's possible to setup different sample rate for each sensor, specifying different priorities and time resolutions, which is very useful since not all sensors have the same bandwidth or activity. A temperature sensor, for instance, does not need to be sampled each cycle as a motion sensor might.

Conversion tables have also been added in order to apply a mathematical function to the digitized value of a sensor. The function can be *Linear*, *Logarithmic* or *Exponential*. The Linear function does not affect the value while the Logarithmic/Exponential functions can turn an exponential/logarithmic response into a linear one (i.e. by applying the inverse function to the response of the sensor). A custom table can also be edited or drawn on the computer then dumped to the unit.

MIDI aspects

All the MIDI messages defined by the standard have been implemented in the AtoMIC Pro. While the *Control Change* message is the most often used, messages like *Pitch Bend* (accepting 14 bits values) and *Note On*/*Note Off* are also available, among the others. The *Note* messages can be configured as triggered messages or as velocity detection messages. Thus, a continuous voltage can be transformed into a binary sensor with adjustable thresholds[5]. The same sensor can also produce a continuous envelope on which a maximum is detected and associated to the note's velocity. During sustain (i.e. while the sensor remains solicited), a *Polyphonic Aftertouch* message can be sent if selected, as illustrated in figure 8.

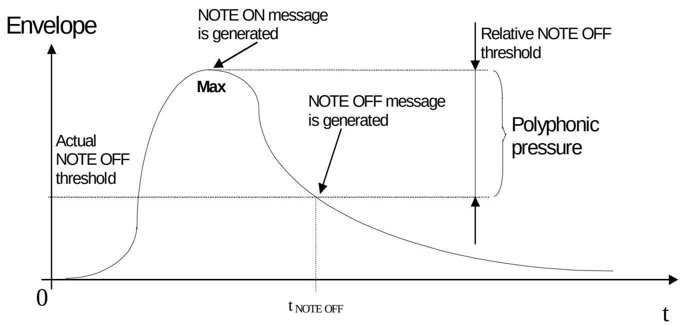

Figure 8 : Note On message generation

As mentioned above, the unit can be remote controlled by *System Exclusive* messages. A new setup of parameters can be dynamically dumped to change the whole configuration on the fly. Previously stored configurations can be recalled by a simple *Program Change* message. The current setup can be remotely saved allowing the user to update the whole configuration without the need to be close to the unit to perform the saving operation, which is really useful for stage applications where the unit and the computer are geographically separated.

Some MIDI routing has been implemented in version 2.0 to take advantage of the four MIDI outputs situated on the rear panel. Thus, it is possible to select the destination of a MIDI message among any combination of the four ports (i.e. 16 possibilities).

[5] As previously described in paragraph "Improvements"

Technical aspects and last improvements

The unit is driven by a 16 MHz Micro controller Unit (MCU). In version 1.0, we used the highest-end MCU from Microchip™ which includes a 8 bit analog to digital converter. The eight bit value was right-shifted to a seven bit value to be compatible with MIDI, leaving the possibility to send an eight bit value through *System Exclusive* messages. In version 2.0, we use a new, more powerful and pin compatible MCU that features not only more RAM and ROM but also a 10 bit A/D converter. RAM and ROM expansion gave us the possibility to improve the data filtering and to add new features to the device for more configurability. The 10 bit A/D converter increases the resolution of the analog to MIDI conversion. The digital value can be exported by *System Exclusive* messages, by a 14 bit *Pitch Bend* message (on the 10 most significant bits) but also by two *Control Change* messages sending MSBs and LSBs on two different controller numbers.

As mentioned in the previous paragraph, we have added hash tables to transform the sensors' response curves. A MIDI spy was also implemented to display all arriving MIDI messages, which can be very useful for debugging a MIDI installation.

AtoMIC Pro is now widely used for designing new gestural controllers, for managing interactive sound installations using sensors, as well as in theaters.

AtoMIC Pro has also recently been used for a psycho-acoustic experiment in which a 128 people evaluate different criteria during a concert [8]. Each person has a plastic box equipped with a fader that codes the criteria evaluated on a linear scale. The analog value of each potentiometer is converted into MIDI by four AtoMIC Pro units. The MIDI data and the concert are synchronously recorded on a computer running Digital Performer™ in order to post-analyze the answers through time and correlate them with the piece structure [9].

The envelope analysis algorithm was also improved and debugged thanks to a project of Patrice Moullet [10], called "*l'Omni*" which is a controller using 108 piezoelectric sensors mounted on a dome 1.2 meters in diameter. Four AtoMIC Pros are in charge of the velocity detection and *Note On* generation for all the sensors[6], resulting a real-time polyphony[7] up to 32 notes.

Future improvements

The current MCU is underused since its clock frequency could be doubled with the consequence of almost dividing by two the internal processing time[8], and thus improving the real-time aspect. We are now thinking about an AtoMIC version 3 with potential support of other protocols such as m-LAN or UDP. We are thinking in particular about the Open Sound Control protocol [11] which is now widely used by several programs and is simple to implement. Moreover, Ethernet provides a standard and very efficient way to transmit high speed data – meaning that a single analog to MIDI interface might be able to sample more sensors with a better resolution.

CONCLUSION

In this article we tried to describe our recent developments of an analog to MIDI converter as a tool for use in the contexts of electronic music and live performance. This tool has always been developed within a compromise of time and complexity, so it is far from perfect. Nevertheless, we always kept in mind that this kind of device is to be used in an artistic context, not just in laboratory experiments. Our main satisfaction is that AtoMIC Pro has been used several times in various pieces.

In spite of some drawbacks, this device has been fully integrated as a part of the compositional process, and used at its maximum capabilities. Analog to MIDI conversion is not something new, and we want to emphasize that our work was also achieved thanks to past developments by people at Infusion Systems and Steim, among others.

We would like to emphasize that this kind of development needs a tight relationship between the composer and the technical staff in order to obtain the right tools, not only in terms of capabilities but also in terms of shape and esthetics.

ACKNOWLEDGMENTS

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[6] Conditioning hardware for the piezoelectric sensors designed by Jean-Loup Dirstein.

[7] With a latency less than 10 ms.

[8] Currently 110 μs per active analog input.

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