ABSTRACT
The paper describes the design, production and usage of the "Rumentarium", a computer-based sound generating system involving physical objects as sound sources. The Rumentarium is a set of handmade resonators, acoustically excited by DC motors, interfaced to a computer by four microcontrollers. Following an ecological/anthropological perspective, in the Rumentarium discarded materials are used as sound sources. While entirely computationally-controlled, the Rumentarium is an acoustic sound generator. The paper provides a general description of the Rumentarium and discusses some artistic applications.

Categories and Subject Descriptors
J.5 [Arts and Humanities]: Performing arts, Music—sound installation, music, multimedia, performing interfaces

General Terms
Algorithms, Design, Theory, Experimentation

1. INTRODUCTION
The Rumentarium is a set of handmade percussive sound bodies (resonators) which are acoustically excited by DC motors (sources). The motors are controlled via computer through microcontrollers. The project is rooted into four, often intermingled, traditions: percussive instruments, musical robots, programmable mechanical devices, kinetic art and sound installations. It extends the percussive tradition by assembling resonators from a huge variety of recycled/reused materials (see later). With respect to the tradition of musical robots, the Rumentarium—being resolutely non-antropomorphic and avoiding the use of traditional instruments—is a sort of "extension" robot [3]. Its aim is to be programmable and interactive, so that different control strategies can be implemented, putting together algorithmic and gestural control. Finally, it is intended both as an instrument to be performed in a musical context and as a standalone sound installation. Similar works includes ModBots, digitally controlled acoustic percussive robots developed by Bill Bowen (2002), in collaboration with Lemur and installed at Angle Orenszanz Foundation in 20021. ModBots are miniature, modular instruments designed with an emphasis on simplicity, and making use of only one electromechanical actuator (a rotary motor, or linear solenoid) remotely operated by a microcontroller2. While Bowen’s ModBots are used mainly as components of sound installations, Lemur is the main technological provider of Pat Metheny recent Orchestrion project, where solenoid actuators are used interactively by the renowned guitar player in real time3. The ModBots project has been at the origin also of William Brent’s LudBots (2008): LudBots have been used as instruments in live performances, but also as components of the "False Ruminations" installation4. In the "Constante" project Ivan Puig and his collaborators built a set of mechanical instruments from discarded objects and industrial materials which were remotely operable (in this case by means of analog equipment), so that they can be played live but also automatically sequenced5.

2. HARDWARE DESIGN AND PRODUCTION
In the Rumentarium, the design and production of the instruments (hence on, "sound bodies") follow three main principles, inspired by sustainable design [6]: refabrication, softening, flexibility.
The name "Rumentarium" originates from rumenta, in Northern Italian meaning “rubbish, junk”. The design embraces an ecological perspective against the huge amount of wasted resources which characterizes the “mature” capitalism, determining a growingly relevant place of recycling policies in national and international agendas. Still, many practices around the world have traditionally developed specific attitudes towards the “refabrication” of objects as a normal way of shaping and reshaping the semiotic status of material culture [5]. In the Rumentarium, the DC motors are scavenged from discarded electronics (CD/DVD players, mobile phones, toys) and they can be extended by adding parts of various materials (plastic, wood, metal), thus implementing different modes of excitation (percussion/friction). Res-
ware development. More, in the Rumentarium the wiring their parts, can be replaced easily and effortlessly, as in soft-
hardware nature is quite soft: sound bodies, as a whole or
produced while designed” in an improvisation-like mood, start-
simple and intrinsically costless, sound bodies can be “pro-
A second principle is the softening of the hardware. Being so
the glass bowl.
forward/backward motion determines the beating rate over
tions are converted into linear motion by means of a crank:
The beater is driven by the motor, but this time radial mo-
rotating. In the tinkling ball (3), originally a toy generating
contributing to the balance of the of the motor while this is
while rolling, the beater is again connected to a mo-
time inserted into the Lego structure. Number 4
shows a structure containing a beater for a large glass bowl.
The beater is driven by the motor, but this time radial mo-
tion is converted into linear motion by means of a crank:
forward/backward motion determines the beating rate over
the glass bowl.
A second principle is the softening of the hardware. Being so simple and intrinsically costless, sound bodies can be “pro-
duced while designed” in an improvisation-like mood, start-
ing from the available materials. As a consequence, their hardware nature is quite soft: sound bodies, as a whole or
their parts, can be replaced easily and effortlessly, as in soft-
ware development. More, in the Rumentarium the wiring
connections uses exclusively alligator clips (see Figure 2).
This allows to easily assemble/disassemble the whole setup, thus implementing another feature of sustainable design, de-
sign for disassembly [6].
Finally, a third principle is flexibility. Flexibility is here in-
tended as the capability of the Rumentarium to be modified in relation to specific needs. As an example, in an installa-
tion the setup is primarily defined according to the exhibit space: the number and the kind of sound bodies can be adapted to the context of the setup. The Rumentarium uses a variable number of Arduino microcontrollers [2] as DAC interfaces between the computer and the electrical devices. Each microcontroller, and the relative basic electronic components, are inserted into a plastic box: the six output ports of the Arduino are accessible through common loudspeaker terminals, again for easy wiring connection (Figure 2, no. 5). In short, a controller box is connected to the computer via USB port and to the motors via loudspeaker terminals. Thus, there is a 6-element unit, made of 6 DC motors, a con-
troller box and a power box. The Rumentarium uses up to 4 units (the controller boxes are connected by means of a USB hub), allowing to control 24 sound bodies. In the Rumentar-
ium, the only parameter available to drive the sound bodies is voltage applied to motors, that can be set by sending a
numerical value to the microcontroller. Thus, the numerical value acts as a general “dynamic” control. Higher values
result in faster rotation and higher sound volume, even if de-
tails depend strictly on the mechanics of each sound body.
Unpredictable mechanical behaviors are a structural part of
the project, as they allow to introduce noisy patterns from the
physical (in this case, mechanical) environment, instead
of using algorithmically generated noise (see [4], 188). Dif-
derently from computer music where all sound synthesis de-
tails are up to the composer, semi-random variations allows
the artist/composer to focus on high-level organization, de-
manding to sound bodies the generation of sounds, just like
with a musical performer.

3. SOFTWARE AND MAPPING STRATEGIES

In order to drive the Rumentarium, various software ap-
plications have been created, all written in SuperCollider [7].
To control the Arduino boards, SuperCollider offers software
bindings to the ArduinoSMS library that forces Arduino to
listen to the USB port, where it can receive messages from
the host computer. Figure 3 shows the general structure
of the Rumentarium, including both hardware and software
elements. The main software component is the RuMaster
class (1). A RuMaster instance allows to treat a set of dif-
ferent Arduino microcontrollers (2) as a unique abstract de-
vice. Through the RuMaster, the user can access e.g. four
Arduinos like a unique abstract microcontroller with 24 ab-
tract ports indexed from 0 to 23, to be sent values in the
range [0, 1]. On this abstract software layer it is possible to
easily build mapping strategies. Such strategies can be re-
lated to data coming in real time from external inputs, such
as MIDI gestural controllers (3) or from the keyboard (4).
Data can also be gathered in non real-time from external
sources such as a handmade graphical score (5), or from dig-
tal information (6). In all these cases, mapping algorithms
(7) are needed to specify the Rumentarium’s behavior. It
is indeed also possible to directly generate control data for
the RuMaster (8). Also, the RuMaster allows to store the
requests it is asked to send to Arduinos in a log file, so that

Figure 1: A metal box with a rotating beater.

Figure 2: Sound bodies using Lego support struc-


tors are assembled from a huge variety of recycled/reused
materials: e.g. pipe tobacco boxes, glass bowls, broken cym-
bals, kitchen pans. The resulting sound bodies are generally
assembled via metal wires, glue, soldering. Sound bodies
can include Lego parts, as Lego is suitable for fast proto-
typing, in particular when support structures are needed. A
typical example of percussive instrument is shown in Figure
1. A metal box, originally for needles, is used as resonator.
A plastic disc is connected to the DC motor by an iron wire.
While rotating, the disc beats the box four times for each
rotation cycle. The friction of the disc against the metal can
be opportunely tuned by bending the wire by hand. Figure 2
shows four sound bodies making use of Lego supports. Two
sound bodies (2) consist of little bells, in which the beater
is driven by motors. The wire is also a mechanical component,
contributing to the balance of the of the motor while this is
rotating. In the tinkling ball (3), originally a toy generating
sound while rolling, the beater is again connected to a mo-
tor, this time inserted into the Lego structure. Number 4
shows a structure containing a beater for a large glass bowl.
The beater is driven by the motor, but this time radial mo-
tion is converted into linear motion by means of a crank:

3.1 The Braille and Alphabet mappings

While experimenting with a single unit of the Rumentarium, the Braille mapping has emerged as a way to relate keyboard input and control of the sound bodies. The Braille writing system for tactile reading consists of raised dots arranged in cells. The “Braille Cell” is made of 6 dots: spatial arrangement of the dots in two vertical columns is fundamental for the blind user while practicing tactile reading, but it is not relevant for encoding. As each dot is given an index, braille can be thought as a 6-bit alphabet, where each character is described by a binary word, indicating presence/absence of the raised dot for each position. Braille mapping treats the Rumentarium unit as a braille encoder. As shown in Figure 4, when a key is pressed (1), the associated character is retrieved (2), and converted into braille (3): the resulting binary array (4) is used to drive the Rumentarium (5), mapping each dot to a sound body, and assuming that 1 represent activation, while 0 is no powering. In the example, the key “e” triggers simultaneously the sound bodies 1 and 5, connected to the first and fifth ports of the unit. Simply by typing different words, the Braille mapping allows to generate and explore in real time fast sequences of (sets of) sound bodies.

The Alphabet mapping is an extension of the Braille mapping. When using 4 units, 24 sound bodies are fully available: it becomes possible to associate each sound body to a certain alphabet character. For Italian, a number of 21 is enough, while English (or French) requires 26 symbols. In these cases, opportune adjustments can be made, e.g. “Q”, very rare in English, can be associated to the same port of letter “U”, as it appears always in the digraph “QU”. The Alphabet mapping allows to explore and exploit in a more analytical fashion the sound bodies setup, as each of them is directly controlled by a letter. In other words, each letter has a unique sonic identity.

3.2 MIDI controller and Loop station

Apart from keyboard, real-time input can benefit from MIDI controllers, to set values to be sent to microcontroller ports. In particular, a Behringer BCR2000 rotary controller has been chosen, as it includes up to 32 rotary encoders: 24 of them are directly associated to sound bodies. By means of the BCR2000 it becomes possible to play the Rumentarium as an ensemble of acoustic sound sources. As each motor keeps on moving until a zero voltage is applied, complex textures are easily created: a general layering technique involves adding progressively sound bodies, and changing their speeds while they keep on playing. A loop station has been implemented, capable of recording MIDI input over time, and playing them back. The loop station allows to start/stop recording input events into a history array, and to play the history back while other incoming events from the same MIDI controller are arriving.

3.3 Score reading

While Braille/Alphabet mapping allows to inject into the Rumentarium the structure of textual information, and the MIDI controller allows to play it like an instrument, a completely different strategy involves handmade graphic scores. As the only control parameter in Rumentarium is voltage, notation needs to represent only one (continuous) dimension. The devised score uses n-space staves (where n is the number of involved sound bodies) to be printed on paper. On the score, it is possible to draw by means of pencils or pens, assuming that the horizontal dimension represents time (as in standard notation), staff spaces represent sound bodies, and gray level represents voltage to be sent to motors. Figure 5 reproduces a score for 18 sound bodies (3 units). A software application has been implemented that allows to scan the digitized score in real time at the desired sampled rate and retrieves grey levels to be sent to microcontrollers. The handmade score technique provides the artist/composer an immediate way to organize large temporal frames, with a good approximation from score to performance.

4. PROJECTS

In the following section, we discuss three projects using the control strategies we introduced before.
First of all, the Rumentarium has been extensively used live (most recently in Milan, Festival Audiovisiva, May 2010; Rome, Riunione di Condominio, June 2010) in an instrument-like fashion by means of the MIDI controller/loop station mode. A live album—including the Rumentarium—has been published by AMP2 collective [1].

*Vedute della luna scritte in braille* (“Moonsights written in Braille”) is a musical project resulting in a 53-minute long concept album. It is inspired by the Moon, but more in particular by the discovering of the real lunar surface by Galileo Galilei, as described in his *Sidereus Nuncius* (1610). The project uses 18 sound bodies, organized in three families (one for each unit): metals, rattles/pitched sound bodies, miscellaneous sound bodies. The project features three sets of pieces. The first set make use of scores, inspired by lunar soil patterns. An example is the one in Figure 5. The second set is dedicated to *maria* (i.e. Moon seas), and features improvisations using MIDI controller and loop station. The third set uses the Braille mapping. For each piece a fragment from Galileo’s book, related to Moon’s description, is chosen. Fragments can have very different lengths, from 80 to more than 1000 characters. The control parameters are mapping type, amplitude scaling factor, scan rate, space scaling factor. As there are three units involved, and Braille mapping is defined for just one, mapping type allows to specify which unit is used. Combinations of units are allowed: in this case, the mapping is mirrored on all the selected units. The amplitude scaling factor is used to set the voltage sent to motors. In this way, dynamics can vary from full volume (with maximum available voltage) to much quieter dynamics, with motors hardly moving, their electric buzzing creating a specific textual mood. The scan rate is the rate at which each character is read from the text and mapped to sound bodies. It defines the general tempo of the piece, and it influences sound density. Finally, space scaling factor represents a multiplier for the duration of space character. In Galileo’s Latin text, the only punctuation mark is space. As space is mapped to silence (non activation), by multiplying its duration it becomes possible to control sound density. To summarize, the “Moonsights written in braille” project exploits different ways of controlling the Rumentarium. A second project, *La Terra Guasta*, is inspired by “The Waste Land” by T.S. Eliot (the Italian name being an etymological translation of the poem) and has been shown in 2009 at the Share Festival in Torino and at Spazio Orioleti in Palermo. In Eliot’s text, the desolation of human condition in modernity is often acutely shown by a landscape (and a soundscape) of waste. Inspired by this feature, the installation places the Rumentarium on the floor of the exhibit space (Figure 6), in a unstructured form, underlying the randomness and the heterogeneity of the whole, reflecting the residual nature of objects and materials. In “The Waste Land”, a characteristic aspect is wandering: hence, a random walk is used as the inspiring concept for the installation behavior. A special function, brownFunction is dedicated to update all the control parameters: mapping type, amplitude scaling factor, scan rate, space scaling factor (as discussed before). The resulting overall behavior has proved to be very interesting for audience, as it alternates gradual changes in the parameters (“normal” brown motion) with hectic moments when parameters rapidly change between the extremes. The mapping type contributes relevantly, as different subsets of the Rumentarium can be activated, up to a “tutti” where all the sound bodies play. The large range of different behaviors, unpredictable from the user’s perspective, injected in the mass of heterogeneous objects, let the visitors suppose a sort of animistic nature in discarded things. A final relevant element lies in textual structure. In form of a string, the poem includes large blank spaces (e.g. separating two adjacent sections). As they are mapped to silence, the blanks determine long periods of inactivity, leading the audience to think that the the installation has ceased its activity. But then, often surprisingly, it starts again.

5. CONCLUSIONS

The Rumentarium project aims at generating complex sound content starting from available, discarded materials and low cost technologies. Its goal is acoustic computer audio, both for musical and installation applications. Its motto is “acoustic sources and computational control”.

6. REFERENCES