The Musical Glove

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Abstract. *The following work describes the technical and theoretical details of the realisation of the first prototypes of the Musical Glove, a glove that is able to recognize the positions of the fingers and the folding of the wrist (with respect of the axis of the arm), and make sound according to it. The Musical Glove that can be easily worn by any user-musician. Besides playing accordingly to user's hand position, it can send messages to other Musical Glove wearers in close proximity in order to "jam" together with them. The users hand position recognition, interpretation and adaptation algorithm, as well as the user-to-user communication one, are based on common Artificial Life techniques.*

Introduction.

The goal of this paper is to try to depict some specific problems and properties of new art forms, based on electronics and digital instruments, which we all might be facing in the near future. The theoretical approach we initiated from is the so-called *Alive Art* approach, where a distinction is made between a *Material Art* and an *Immaterial Art* (see Pagliarini et al., 2000 for further details). This is because, when facing the design of the Musical Glove we inevitably came across two specific kinds of problems: some technical ones and some conceptual ones.

It should have become clear to all of us that electronics is going to deeply modify both the art (and therefore music, in this specific context) production and perception. It seems to us that, one of the ways electronics deeply affects the world of art is by modifying the relationship between the artist(s) and her/his instrument(s). For example, when using traditional musical instruments, human beings have, and always had, the quality and quantity of their performances related and constrained by some specific human physical limitations (related to the evolution of some body parts as arms, fingers, etc.). On the opposite, it has became evident that, electronic musical devices can enhance performances, both in terms of speed and duration, by giving authors and executors "inhuman" possibilities, therefore opening for them new artistic horizons.

Recently, few, pioneering, explicit works have been proposed by different artists that have pushed this concept up to the limit of bionics and cyber principles based art (see Stelarc for an example) where the body, much before a properly conscious mental process could take over, is left dealing with the surface of art specific materials and spaces, like the sounds, colours, etc. In the context of such art pieces, the use of electronics (sometimes together with a good mechanics) has been demonstrated to be indispensable as well as necessary. No doubts, this has been a big jump ahead in the conception of new forms (and instruments) of art, in particular, in what we call *Material Art*.

Nevertheless, when dealing with the design of our Musical Glove, we came across some new, and unexpected problems, and therefore challenges, specific of electronic based instruments and art, and that concerns artist-to-artist, as well as artist-to-public, relationships.

Indeed, our idea for a Musical Glove, was not founded much on the principle of building an instrument that could better enhance some human-body anatomical properties as on the idea that we could give it the possibility of communicating with its similar (and as a consequence with other artists).

This approach has opened fully new perspectives that seem to overcome the standard artist-to-artist (and in our case musician-to-musician) communication and relations and where the use of a given protocol might deeply affect the resulting performance, art piece and, in our case, music. Indeed, with this point of view, the meaning and the focus of the research is shifted from 'what kind of music the glove might be able to generate' to a much more complex and intriguing question, that is: How should the signal be and what meaning should be carried by the signal that the glove sends out to the other gloves? What if they are the close or far, few or many? What about synchronization, musicality, roles, etc.?

Moreover, when looking at this phenomenon and comparing it to traditional musical settings, it becomes evident that something strange and new is about to take place. Traditional musicians, indeed, are used to 'jam' by using only the feedback coming from their ears, while, in our case, an artificial process, or pre-process, could easily take place.

This topic brings along with it a huge number of scientific considerations very much related to any natural 'communicational system' such as the definition of a 'language', the construction of a specific emitter-receiver protocol, their coordination, and the definition of the hierarchies. Still, music specific topics, such as role taking, orchestration, doubling the sound, pauses, polyphonic and polyrhythmic phrases, are relevant. Finally, electronics, or more in general artificial, communication problems arise, such as reliability, identification, redundancy of the signal.

The experiments

The study we report here is to be considered an early (maybe even poor) prototype that, more than giving solution and propose a well defined model, might be considered as a forerunner set of experiments that opens a wide number of new, interesting questions in the field of electronic music. Because of that, our piece of research does not concentrate as much on the technology as on the methodology (or on the way it should be built).

Here, we will report about two prototypes. The first one was built during our Robots Interfaces course, in August 2002, together with Ingo Nielsen and Mayank Sharma (Pagliarini et al, 2002), while the second is a refinement of the former prototype made in September 2002. The two prototypes differ very little on electronics hardware and much more on mechanics and software. In both cases, we used a 'low budget' experimental set-up for which we used traditional, cotton made, gloves and LEGO MINDSTORMS.

The first prototype: Hardware.

Our first prototype consisted of an ordinary cotton glove, which is housed with four flex sensors around fingers (see Figure 1). The flex sensors were placed in this way: one on the thumb, one on the index, one the third finger and the fourth one on the last two fingers of the hand. We made it so because of a lack of input channels and, consequently, because it results very difficult to most people to articulate the movements of the fourth finger independently from the pinkie. The sensors were taped to the gloves with enough freedom to accommodate the bending of the fingers.

Figure 1. Flex sensors location on the fingers.

The flex sensors we chose are those who are usually used in VR applications and suits (see Figure 2). The sensor consists of a unique component that changes resistance when bent. An unflexed sensor has a nominal resistance of 10,000 ohms (10 K). As the flex sensor is bent the resistance gradually increases. When the sensor is bent at 90 degrees its resistance will range between 30-40 K ohms. The approximate force needed to deflect such sensor end 90 degrees is of 5 grams. The flex sensor measures .25 inch wide, 4.5 inches long and only .019 inches thick. The advantage of using these flex sensors consists of the fact that they can be interfaced to the LEGO MINDSTORMS, our hardware platform, with no need to build additional hardware.

Figure 2. The Flex Sensor.

Further, as a fifth input, on the glove we placed a strip, which has a gradient from black to white, and which is used by a LEGO MINDSTORMS Light Sensor to measure the rotation/twisting of the arm (see Figure 3).

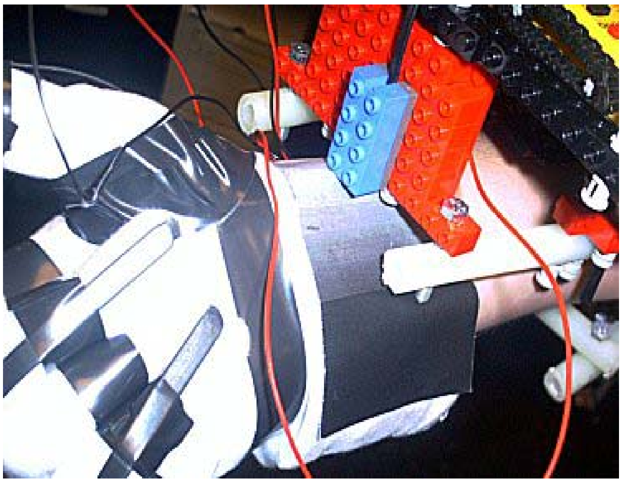

Figure 3. Black to White Gradient on the wrist and Light Sensor (i.e.: blue brick) location.

As mentioned above, we decided to map our input-output relations with the standard LEGO MINDSTORMS computers and operative system. This gave some good advantages as well as some unfortunate disadvantages. The advantages are that we were able to run our first experiments in a very few days and at a very low cost. The disadvantages are that, using this system, we found two major limitations: 1) the number of inputs (indeed, we ended up by using two RCXs without even reaching the desired granularity); 2) the quality of the output (indeed, the standard sound emitted by the LEGO MINDSTORMS buzzer is very poor). Nevertheless, we decided that it could be a quite reasonable starting point to show the theoretical considerations. The output of the flex sensors is fed into the LEGO MINDSTORMS RCX through the use of appropriate connections suitable for the brick. Unfortunately, since an LEGO MINDSTORMS RCX can be fed with, at most, three input channels we had to use two RCXs for each glove, a Master and a Slave, to reach the desired number of channels (see Figure 4). There are two ways of connecting two RCXs. One way, *wired*, is by connecting one RCX output to the second RCX input, the second way, *wireless*, is by using RCXs infrared communication. In the first prototype we used a wireless communication where the Master brick “knows” what has to be done and has the most functionalities while the Slave brick, on the other hand, “tells” the Master about the inputs from different sensors. These two bricks communicate through the infrared port using a special protocol developed in our software architecture.

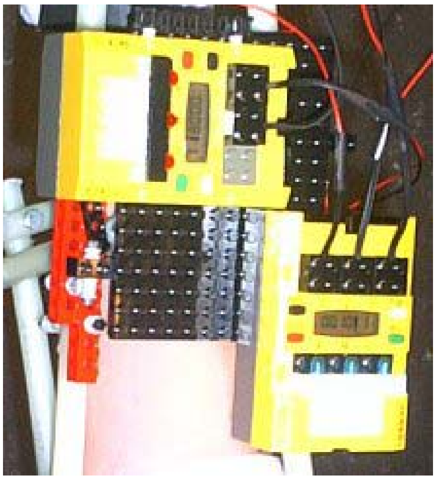

Figure 4. The RCXs (master and slave) location on the arm.

To keep all of this assembled we used an Arm-Cage (see Figure 5). The Arm-Cage was built using ordinary garden pipes connected with nuts and bolts. The use of the Arm-Cage is to support the RCXs on the arm. The Arm-Cage is also used to hold the LEGO Light Sensor in place and to allow it to measure the rotation/twisting of the arm. During the twisting movement of the wrist the whole arm twists, in order to support this movement. The only successful way to place a sensor that measures the rotation of the twist is to place it on a structure that is connected to 'Bicep' and 'Triceps' region of the arm. Also, during the twisting of the arm the lower muscle of the forearm do not move as much as the upper muscle of the forearm. The Arm-Cage is thus securely fastened to the 'Upper Arm' region using 'Velcro'. This helps the Arm-Cage to stay in place when the arm is moving. The Arm-Cage is also attached to the lower muscle group of the Forearm for extra support. The Cage pieces are attached together using nuts and bolts that do not lock the various pieces together but just hold them together in place, so the various joining pieces are able to move relative to each other thus giving the cage flexibility needed to adjust according to the position of the arm.

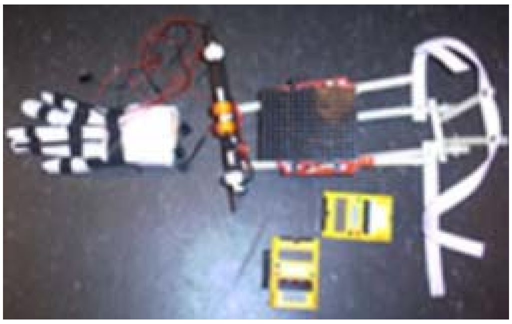

Figure 5. The Musical Glove components.

Finally, to emulate the behaviors from other Musical Gloves, and not to build them, we decided to use a number of RCX as a “Choir” (see Figure 6). The RCX components of the Choir basically emulate the behaviour of the Glove Master brick and (also) communicate through infrared port with each other as well with the real glove master brick.

Figure 6. The Choir.

The first prototype: Software.

Essentially, on our glove, we had five inputs: the bending of four fingers plus the wrist rotation. All of our sensors can easily detect continuous values for either the bending of each sensor (consequent to the bending of the fingers) and for the gradient detection (consequent to the wrist rotation). Despite of that, we decided to scale down to three discrete states all of this information. Therefore, we did choose to reduce the description of each finger position to: *Bent*, *Relaxed*, and *Stretched*. Similarly, we defined three discrete states for the wrist position: *Inward*, *Relaxed*, and *Outward*. Since there are 5 inputs with 3 states, a glove can have 3^5 *Static-Positions* (see Figure 7).

Figure 7. Examples for hand Static-Positions.

Besides, by creating a history of the last couple of static-positions, we were able to recognise *Sequences*, which can be assigned special meanings. Waving, shaking, finger tripping, and etc. can be taken as examples for possible sequences. The Slave RCX has only one responsibility, which is handled by one task: To read its inputs and convert it to infrared messages. It does not make any sound. On the opposite, the Master RCX has multiple responsibilities, which are handled by different tasks. Two tasks are always active: *Reading Infrared Messages* from the Slave (this task is started once and never changes) and express *Musical Behaviour* (one task with one behaviour runs at a time). All choir members (Choir RCX) have the same code of the Master. When starting up, they "Distribute the Voices" (i.e.: bass, tenor, alto, soprano). After that, they have only one task: to read the infrared messages from the master, which means chords, and then make the corresponding sounds. In this fashion, the Choir Members play the sound as per the instruction while the Master brick also plays sound as per the programming. Every behaviour is based on an endless loop (which can be exited with a special sequence of gestures though). In the loop, the global gesture variables are updated, and then evaluated in a switch-structure. The simple behaviour just plays one note for one gesture. It evaluates the thumb separately, because the thumb switches one octave up or down, and the other static positions together define a note on the pentatonic scale. The interval behaviour remembers the last note and changes it up or down according to the gesture. The infrared chords selects different chords (combination of "chord" and "key") and combines them to an infrared message, which is sent to the choir members. The protocol combines the two variables *Chord* and *Key* (where Key ranges from 1-12 and Chord from 0-9) into a *Message-ID* (i.e.: Message-ID = Key*10+Chord). In this first experiment the "Voices" distribution among the Masters is forced (somehow), which means that each Brick will have a specific Voice hard-coded into it. Also, in this first experiment Rhythm is fixed to a given rate and all members play at the same time.

The first prototype: Results.

The result is a nice musical scenario, which is nevertheless a bit primitive since is neither polyrhythmic nor truly polyphonic and, because of infrared-communication constrains, is slow in changes. Further, no “intelligent” algorithm is applied to interpret and adjust sounds execution and, finally, the above scenario presents a one-to-many communicational paradigm, which is, by definition, quite limited.

The second prototype: Hardware.

Our second prototype hardware differs from the first one only for one sensor and the Master-to-Slave RCXs communication. Indeed, the Light Sensor is replaced by a fifth Flex Sensor, placed on the palm of the hand, while infrared communication between Master and Slave was replaced by wired communication (form one of the Slave outputs to one Master inputs). This simple change allowed us to get rid of most of the mechanical complications deriving from the need to measure the wrist rotation and to place one RCX in front of the other (in order to allow infrared communication between RCXs). By doing so, we only had to ensure the two RCXs on the opposite side of the wrist. The final structure of the Musical Glove resulted much more comfortable and wearable.

The second prototype: Software.

Oppositely, major changes were applied to the second prototype software. In a first phase, we did get rid of all the Master-to-Slave infrared communication problems and, secondly, we substitute the Light Sensor reading routines with a Flex Sensor one. In a second phase, thanks to the improvement of the Master-to-Slave communication system, we modified the frequency of musical output emission (i.e.: the bit rate) range and we could make it much wider as well as independent from the Glove-to-Glove communication. Apart from these two aspects, the basic principles of the first experiment algorithm remained the same. Therefore, the entire event-based algorithm, including *Static-Positions*, *Gestures, Sequences, Chord, Key* and *Message-ID* concepts, was not modified. On the contrary, we decided to fully rewrite the basic principles for communication and orchestration. For this improved version of the Musical Glove we decided to introduce Artificial Life based, adaptive, algorithms. Since infrared communication, in general and within the LEGO MINDSTORMS RCXs in particular, is very unreliable, distance-dependent and slow, we decided to apply adaptive mechanisms on this, the most fragile element of our system. First of all, we decided to go for a many-to-many paradigm, where all the "gloves" can communicate to each other all the existing information. Following Stoy's (2001) experience, we tested aspects of the communication properties of the RCX by placing a transmitter pointing to different positions and distances sending 30 messages per 30 seconds. A receiving RCX was then placed for every half a meter from the sender, also pointing in different directions. This receiving RCX counted the number of messages received. The results show that the ranges of the communication changes with respect of the pointing direction of both emitter and receiver and the size of the (hosting) room. Overall, we found that both room size and emitter-receiver orientation strongly affect results. The communication range is reliable within 2 and 5 meters under the optimal condition while it soon decays when either the size of the room gets above 3 meters or the sender-receiver orientation angle gets larger than 90 degrees. Despite of such a signal uncertainty, we decided that these conditions were ideal to test a Glove-to-Glove communication algorithm.

The basic assumption of the new algorithm was that, when started, all the gloves should stay close in front of each other. Under this conditions the communication gets started and the RCXs initiate by pulsing signals in and out, therefore, after a while, synchronizing each other (see Lund and Pagliarini 1999 for a similar example). After this is computed, and gloves move away, both in distance and orientation, any firing-rate (i.e.: signal frequency) becomes possible. At this point, the adaptive algorithm takes place. Incoming signals were stored in a set of buffers accordingly to their meaning and frequency. Outgoing signals (i.e.: sound and messages) are then calculated accordingly with the recent inputs history. The Artificial Life algorithm we used to handle information was a Behavior-Based one (see Pfeifer and Scheier, 1999, for a description or Lund and Pagliarini, 2000, for an example). The Behavior-Based algorithm is built on two branches logic. The first branch, a primitive (i.e.: low-level) set of behaviors, decides *what note* to play accordingly with the meaning of last of 5 signals received. Similarly, the second branch decides *at what frequency* to send out the next signals, accordingly with time distance elapsed within the last 5 signals captured. This can be regarded at as the "semantic" level. Above this level of behaviors, there is a further layer that takes in account two different problems. The first is *when and how many times* to play the next note(s), accordingly to both received signals significance and frequency. The second regards *the duration* of the note(s) and is computed accordingly to both emitted sound frequency and value. We could call this last layer the "metrics".

The second prototype: Results.

Although we run a limited number of tests, the resulting musical scenario was very nice and, sometimes, reasonably complex and various. Both tendency to polyrhythmic and polyphonic states occurred. Most often, we noticed the emergence of patterns of behaviors. For example, the harder signal detection was, within two gloves, the lower the frequency of sound emission became. Because of the logic the algorithm was built, the opposite also happened. Another interesting pattern of behavior emerged, with regards of role taking. For example, we often noticed a switch of role (i.e.: bass, tenor, alto, soprano) after a given period of role overlapping (or, vice versa, a non-overlapping period) of two gloves sound. Over all, and apart from all of that, it was a particularly satisfying wearing the Musical Glove. Wearing the glove, indeed, gives the user the feeling to be within the evolution of the immediate musical process and still independent from it.

Conclusion.

Results obtained from the first and, especially, the second prototypes are quite encouraging. It seems to us that a quite new, unexplored, scenario is about to be opened in the field of electronics mediated music. Further, this paradigm could be taken into account as a metaphor, to investigate, more in general, the users-to-users or users-to-machines electronically mediated communication. We do think that this research field is as much important as unexplored. Nevertheless, our study finds major limitations because of the poor level of input, output, and communication. Because of that, we are now taking into consideration the possibility of enhancing the glove capabilities by using a better computer (i.e. the WARC, see Jørgensen, 2002, for further details) and communication system (i.e. the Bluetooth communication).

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