The Manipuller: Strings Manipulation and Multi-Dimensional Force Sensing

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ABSTRACT
The Manipuller is a novel Gestural Controller based on strings manipulation and multi-dimensional force sensing technology. This paper describes its motivation, design and operational principles along with some of its musical applications. Finally the results of a preliminary usability test are presented and discussed.

Keywords
Gestural Controller, Strings, Manipulation, Force Sensing.

1. STRINGS AND FORCE SENSING
The integration of strings and force sensors within Gestural Controllers is a powerful combination towards higher grades of feedback and expressivity in a live performance. Strings provide excellent tactile feedback, which is crucial for the performer and also a key factor for the audience to follow the performance. Furthermore the manipulation of a string requires some physical effort, which helps to the funneling of performance expressivity. Hence strings manipulation has intrinsic expressive qualities, for both performer and audience; somehow reflecting the musical duality of tension-release. Strings are common items of our daily life, and have been since ancient times. That makes them very familiar to everybody, turning their manipulation into a very intuitive action: grabbing, pulling, twisting, plucking, etc. Therefore the learning and adaptation time in a string based Gestural Controller should become minimal for the performer.

In the other hand, the use of force sensors within Gestural Controllers aims to register effectively the dynamic physical effort of the performance and transmit its expressivity to an audience. In fact, since effort corresponds to power, and power is defined as the product of the force and the speed (energy over time), then force sensors should effectively register this effort during live performance.

1.1. Related Gestural Controllers
The Web [7] uses interconnected string segments within a hexagonal frame, each one equipped with a tension sensor. The performer pulls a segment, which influences its neighbour segments, distributing the tension over the whole web. The registered tension of each segment represents an input variable to the sound synthesis system. The tension variations were then mapped to produce sound of complex changes in timbre.

The way *The Web* worked proved to be very easy and effective: grab the strings, pull the segments, and hear immediate complex changes in timbre. Within a short time, musicians with no theoretical knowledge about the system were able to master a great amount of control over the timbres. The strings provide good tactile feedback and the tension force sensors are highly responsive to the strings manipulation.

Some potential limitations of *The Web* are: small manipulation range, which may result in no appreciable visual feedback for the audience; complex synthesis with simple gestures, affecting to the grade of control over the output sound; the physical distribution and the interconnection of the strings, which makes the system to work as a whole where segments cannot be isolated completely.

The Soundnet [9] is a large scale version of *The Web*, allowing several performers to climb all over its stringed structure. Eleven transducers are distributed along the 11x11meters structure to detect stretching and movement. The data extracted from these is then mapped to control filter parameters and granular synthesis. Whilst *The Soundnet* provides good feedback to the audience, the control capabilities in a performance are subject to extreme physical effort. Furthermore the requirement of a large space makes it very hard for performers to rehearse and master *The Soundnet*.

The concept of the *Pullka* [5] is based on a single fixed string with one strain gauge which measures the tension as the performer pulls the string behind one of the two bridges. In fact it was thought as a two person interface, each actuating over one string end. This simple controller would reduce the gestures sensing to only one parameter (the string tension), representing a real challenge towards sound mapping. Nevertheless there seems to be no further documentation or tangible evidence claiming the *Pullka* was ever further developed or implemented.

The *Strimidilator* [3] senses the deviation and the vibration of a set of four parallel strings manipulated by pulling and plucking actions. The vibration is sensed in two strings using electric guitar pickup coils, and the deviation is sensed in the other two by attaching a variable resistor to one of the fixed ends. All parameters are converted to MIDI messages. However the main instrument controls correspond to buttons and knobs placed in a box adjacent to the frame. The sensed string parameters are mapped to envelope or dynamics, while the buttons and knobs control the main parameters such as note-on, note off, and variation mode. This means that the four strings will be mainly played or manipulated with just one hand, since the other one will have to spend most of the time on the knobs and buttons. Direct tactile force feedback is provided only on the two strings whose deviation is being sensed. However the attachment mechanism of the deviation transducer to the string seems very poor and unreliable, causing significant damping and affecting the vibration mode of the string.

1.2. Towards Multi-Dimensional Sensing

In the Gestural Controllers described above, the force is only sensed in one dimension, limiting the kinetic range of tracked gestures. The combination of strings and force sensing has to be fully exploited in terms of the range of gesture parameters to be tracked for sound mapping. The path to improve the gestures tracking range of such controllers passes through adding the capability to sense the forces in more than one dimension. Hence the combination of strings, force and multidimensional sensing for musical applications is the *leitmotiv* of the developed prototype of Gestural Controller: The Manipuller.

2. SYSTEM OVERVIEW

Figure 1 shows the general block diagram of the Manipuller.

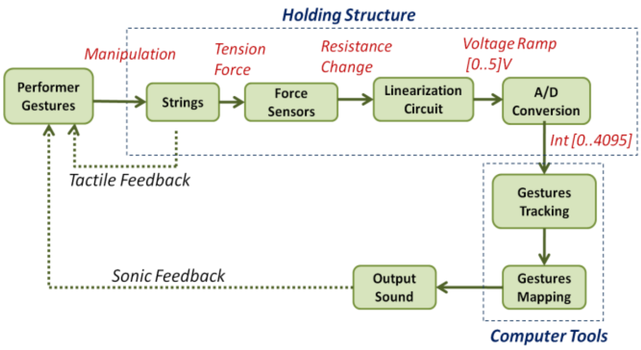

Figure 1. General Block Diagram

The primary interface consists of four parallel elastic strings manipulated by the performer. The holding structure is a semi-open wooden frame containing the strings, sensors and electronic circuitry (Figure 2).

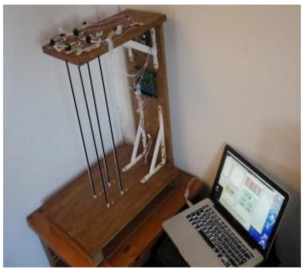

Figure 2. The Manipuller System

The performer actuates over the four strings by manipulating them in group or independently. Each string tension is independently sensed at both top and bottom ends by a pair of Force Sensing Resistors (FSRs) [6]. The force sensors are placed on the opposite sides of the top and bottom platforms. The string is vertically guided and clamped at the sensors sides to a mechanical actuator which will transmit the pulling force *proportionally* over the sensing area. Each sensor's output is linearized and converted to voltage by hardware means [6] before being digitized.

The Analogue to Digital conversion is carried out by programmable microcontroller board Arduino Mega [1]. Its USB connection to a laptop computer also provides the power supply for the linearization board. The eight analogue inputs are oversampled and decimated [2] to produce integer values between 0 and 4095 (virtual 12bit), which are then scaled to floats ranging from 0 to 1. Valid data from each sensor is ready for computer processing every 10ms.

3. GESTURES TRACKING & MAPPING

Gestures coding is achieved by the algorithms and numerical interpretation of the different gestures, such as 3D position tracking, pull-release, angular speed and sign of turn. All coding is carried out within the digital domain by computer means. In this case the software tool chosen was the visual programming environment MaxMSP [4].

3.1. Simple Parameters

The first step to test the system is to focus on single string parameters. For instance, if we take String 1 and use the top (S_{1T}) and bottom (S_{1B}) sensor readings we can map the differential (S_{1T} - S_{1B}) to the frequency of a pure tone. Therefore pulling the string downwards results in more tension being registered at the top sensor, resulting in higher pitches. Similarly, pulling the string upwards results in lower pitches.

As an example of more complex mapping, we carried out a Frequency Modulation synthesis, where the carrier frequency is given by S_{1T}, the modulation index by (S_{1T} - S_{1B})*10, and the harmonicity ratio by S_{1T}/S_{1B}. To obtain meaningful sound S_{1T} and S_{1B} were rescaled from [0, 1] to [100, 3500] Hz. Similar type of combinations and procedures were used for other synthesis methods, such as Amplitude and Ring Modulation.

Furthermore it is possible to assign different sound or control parameters to each string. One of the recently developed applications is to use the strings to control different aspects of a sample-buffer-based granular synthesis: String 1 would determine the rate at which grains are triggered; String 2 would affect the grains pitch; and String 3 and 4 would determine grain size and sample buffer offset respectively.

3.2. Pull-Release

It is possible to detect whether the string is being pulled or released by means of gradient calculations. An effective application is a *sound file playback control*, where pulling the string plays the sound forward, and releasing it does it backwards. The average value registered by the force sensors control the ratio of the playback speed. The approach is as follows: if F_0 is the registered pulling value at a given time t_0, and F_1 is that value at a later time $t_1 = t_0 + \Delta t$, then: a) if $F_1 > F_0$, then the string is being *pulled* and the playback is *forward*; b) if $F_1 < F_0$, then the string is being *released* and the playback is *backwards*; *c)* if $F_1 = F_0 \neq 0$, then the string is being *held* and the playback *continues* at the speed given by the sensors; and *d)* if $F_1 = F_0 = 0$, then the string is in *standby* (no manipulation) and the playback is *stopped*.

On hold, the playback direction corresponds to the previous state. For instance, if the string is being released and then set on hold, the playback would continue backwards. In a practical implementation it will be necessary to include determined threshold values and marginal limits in the conditions.

Similarly the differential values of each string can be mapped to a portion of a *pitches scale*. The first string is mapped to the lower pitches; the second to the low-mid pitches; the third to the mid-high; and the fourth to the higher pitches. Therefore, when a string is pulled and then held, a pitch of the assigned scale portion is played accordingly to the top-bottom differential value. The velocity of the pitch is determined by the average string tension. Hence manipulating all strings results in chords of separated pitches.

3.3. Multiple Strings

The most interesting feature of the Manipuller lies in the configuration of the strings within the frame. When all strings are grabbed and manipulated at once, the combinational reading of the differential tension forces of each string can be used to track spatial gestures, such as position vector, direction and sign of the force, or the angular speed for a circular gesture. These gestures, when effectively mapped into musical parameters, provide excellent correlation between performance and output sound.

In order to obtain a spatial position vector which would correlate with the kinetics of the strings manipulation, the Manipuller has to be placed within the Three-Dimensional Space by defining a Cartesian Coordinates Reference System (Figure 4).

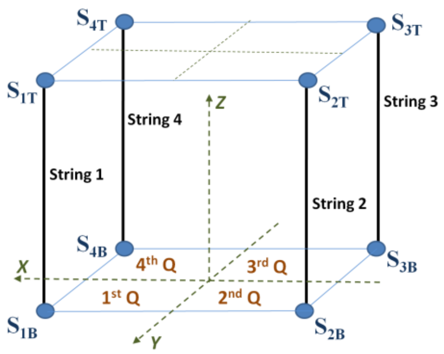

Figure 3. Configuration within the Reference System

Since each string will correspond to one quadrant, we can assign one base vector from the X-Y plane per string. Each base vector will be scaled accordingly to the average tension (AVG_n) registered by the top and bottom sensors (S_{nT}, S_{nB}). The virtual Z coordinate will be given by the differential top-bottom tensions at each string ($d_n = S_{nT} - S_{nB}$). Since the sensor values are float numbers between 0 and 1, then the range for the average values is [0, 1], and [-1, 1] for the differential.

Table 1. Associated Base Vector and Spatial Coordinates

String	(X, Y) Vector	(X, Y, Z) Coordinates
1^{st}	(1, 1)	$R_1=(AVG_1, AVG_1, d_1)$
2^{nd}	(-1, 1)	$R_2= (-AVG_2, AVG_2, d_2)$
3^{rd}	(-1, -1)	$R_3= (-AVG_3, -AVG_3, d_3)$
4^{th}	(1, -1)	$R_4= (AVG_4, -AVG_4, d_4)$

For instance if String 1 is pulled, this results in a 45 degrees vector in the 1^{st} Quadrant, whose (x, y) coordinates are (AVG_1, AVG_1). Similarly, pulling String 2 results in a 45 degrees vector in the 2^{nd} Quadrant, with coordinates ($-AVG_2$, AVG_2). Hence when Strings 1 and 2 are pulled simultaneously the result is a vector which is the algebraic sum of their respective Cartesian coordinates. Hence by grabbing and pulling all four strings at once it is possible to track the kinetics of the manipulation (Figure 5).

Since it is possible to know the X-Y coordinates, then the evolution of the position vector over time can provide information about whether a circular movement is taking place, its angular speed, and its sign of turn. For instance, when a circular gesture is detected, a sound file can be played back or forward accordingly to the sign and value of the angular speed (rpm) detected by the algorithm. This application would emulate a *turntable*. It is also possible to incorporate a lap counter to control reverberation or delay times.

Furthermore the capability of spatial tracking makes the system an ideal candidate as a live performance tool for sound spatialisation control in a 3D speaker setup, such as Ambisonics [8]. Figure 6 shows a set up of eight speakers equidistant in the horizontal plane but with different elevations. In this case, the resultant vector places the source within the 2^{nd} Quadrant of the Ambisonics monitor; the resultant *Z* indicates there is a significant elevation. This correlates with the output levels shown in the indicator panel.

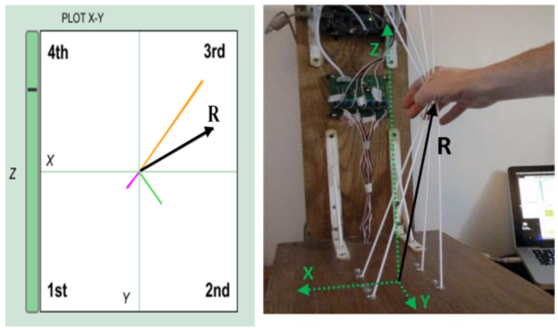

Figure 5. Four Strings Spatial Tracking

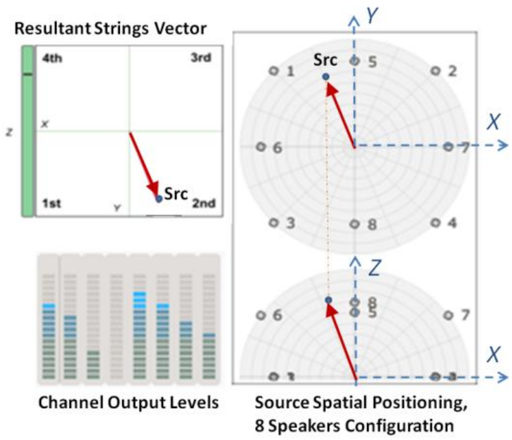

Figure 6. Sound Source 3D Spatialization

4. EVALUATION

The evaluation of the Manipuller should provide valuable information about crucial aspects such as *Learnability, Explorability, Feature Controllability, and Timing Controllability* [10].

In general terms we aim to estimate the amount of time needed to learn how to control a performance with the Manipuller; to evaluate its intrinsic feedback properties, the degrees of freedom and the number of different gestures that can be tracked; to determine its potential in terms of performance expressivity; to test its accuracy, resolution and manipulation range; and to hear suggestions about new musical applications which could be added to the mapping strategy.

4.1. Method

A usability test was designed to evaluate the main features of the Manipuller. Participants will compare the stringed interface against a Game Pad standard controller by performing determined musical tasks.

The Game Pad emulates the (X, Y, Z) coordinates by actuating on its two joystick controllers (X-Y for the left, Z for the right controller). However, due to its intrinsic characteristics, the Game Pad cannot effectively emulate all the musical applications implemented for the Manipuller. For this reason, and to keep the duration of each test under 30 minutes, only three musical tasks were chosen for the test (section 4.3).

4.2. Set Up

A total of seven individuals with diverse musical and technological background kindly agreed to participate in the usability test without any economic compensation. Their ages ranged from 23 to 39 years (mean=29). Each individual test took around 25 minutes, and consisted on a brief introduction to the setup and to the operation principles of the Manipuller. The participant was then asked to perform three tasks alternating the Game Pad and the Manipuller. At the end of the session the participant was asked to complete a comparative questionnaire about relevant aspects such as expressivity, feedback, learnability, responsiveness and control accuracy. An additional page was provided for additional comments.

4.3. Musical Tasks

The first task allowed the user to freely perform on both controllers. The task consisted on a Frequency Modulation patch where (X, Y, Z) were mapped to carrier frequency, modulation index and harmonicity ratio.

The second task used a patch to map the coordinates to a parametric filter (cut off, Q, Gain). The input chosen for the filter was a white noise source. The user was asked to freely manipulate the controllers (first the Game Pad) with special attention to the correlation of the gestures with the produced sound.

In the third task the participant was asked to emulate a turntable by performing circular gestures on the Game Pad left controller and then in the Manipuller by grabbing all four strings and making sure the circular gesture was well defined. A pair of sound files would then play forward or backwards accordingly to the angular speed and the sign of turn of the circular gesture.

4.4. Results

At the end of each session the participant was asked to fill in a questionnaire, which consisted on a header section containing information about the age, musical instruments and preferences; a main section with eighteen affirmative sentences relevant to the tests which had to be rated in a scale from 1 to 5 (1: Strongly Disagree, 2: Disagree, 3: Neutral, 4: Agree, 5: Strongly Agree); and a closing section with two questions about possible additional gestures and other musical applications, and a space for any additional comments. The mean results from the main questionnaire were displayed in a bar graph for later analysis (Figure 8).

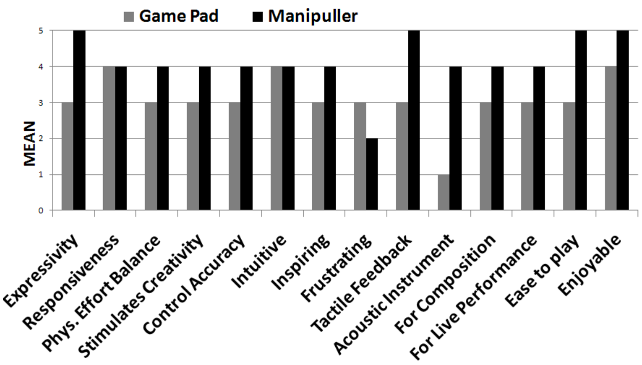

Figure 8. Usability Test Results

5. DISCUSSION

Overall the Manipuller received more positive results than the Game Pad, particularly in terms of expressivity, tactile feedback, “feel-like” acoustic instrument, and ease to play. With less difference, but still better rated, the Manipuller provided better balance between the delivered physical effort and the generated sound, and better perceived control accuracy over the output. Similarly, it also rated higher as a stimulus for creativity, and resulted more inspiring (and less frustrating) than the Game Pad. Participants found the Manipuller more enjoyable, and also preferred it for music composition, live performance or other artistic purposes. Both controllers got the same positive assessment in responsiveness and intuitiveness. Nevertheless we can then say the Manipuller is as responsive and intuitive to use as a Game Pad.

The comments left by the participants provided valuable suggestions to improve the Manipuller with additional gestures detection and other musical applications. There were suggestions about the possibility of actuating over the strings by plucking; to incorporate motion detection to reinforce the tracking of hand movement and position; or to explore the possibility of detecting the hand position over the string while being continuously pulled or held. Some participants suggested some other musical applications, such as the addition of an analogical input for an external line input to use the Manipuller as a real time sound modifier. One participant reported the Manipuller as confusing in the way it handled more than one parameter for musical mapping. Another participant commented that the physical effort needed to actuate over the Manipuller would eventually lean him towards the Game Pad.

6. CONCLUSION

We have presented the Manipuller, a novel gestural controller based on strings manipulation and force sensing technology. It combines the differential tension force sensing of fixed strings to track Three-Dimensional spatial gestures. The combination of strings and force sensing adds tactile feedback and physical effort, which are crucial to achieve high grades of expressivity during live performance. The Manipuller is highly responsive, flexible, intuitive and relatively easy to use. It provides a meaningful correlation between the performer’s actions and the perceived output sound.

7. ACKNOWLEDGEMENTS

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