Classification of marimba mallets based on objetive parameters measured with a striking apparatus

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Percusionists know that using different mallets while playing the marimba greatly changes the tone. In this work we propose a simple method to provide an objetive classification of the marima mallets based on well known objetive parameters related to the timbre. With this aim, an experimental striking apparatus is conceived and used to produce repeatable marimba tones. The mallets are pre-classified and labelled into 3 groups according to its hardness: 'hard', 'medium' and 'soft'. Objective parameters related to the timbre are measured and analyzed from the measurements in order to provide the input for a mathematical model used to classify the mallets according to its hardness.

1 Introduction

Today, the marimba is one of the most commonly played percussion instruments. Its warm, distinctive tone color sets it apart from other percussive instruments such as the snare drum or the glockenspiel. This uniqueness gives excellent cause to study the physical characteristics of marimba tone and timbre.

Many works have been consacrated to the vibration of a marimba bar. In Ref. [1], authors investigate the material and geometric properties of synthesized impacted bars with a tube resonator by using psychophysical methods. They account for the perceptual salience of energy-loss phenomena in sound source behavior.

A perceptual approach is presented in Ref. [2] where authors relate perceptual dissimilarity ratings with mechanical properties. They show that listeners focus on cues related to damping. Results were independent of the material of the mallet striking the plate (rubber or wood).

In Ref. [3] a time-domain model is proposed of xylophone bars excited by the blow of a mallet. The model includes the action of the mallet against the bar described by Hertz's law of contact for linear elastic bodies. The geometrical, elastic, and damping parameters of the model are derived from experiments carried out on actual xylophones and mallets. Various comparisons are made between measured and simulated impact forces and bar accelerations, confirming the validity of the model . An extended study is presented in Ref. [4] by accurately considering damping parameters in the realism of the simulated sounds by adding perturbation terms in the rigidities.

Using different mallets while playing the marimba changes the tone. For some musicians a 'dark' tone is desired, whereas for others a 'bright' sound is appropriate. The variability and inhomogeinity of the mechanical properties of the mallets is a source of complexity when the mechanical and acoustical behaviour of the mallets is under study. That is the reason why in most of the studies consacrated to analyze the sound of marimba tones, a generic mallet is used in Ref. [5].

The physical models from mechanical equations provide an accurate approach of the marimba bar and also the excitation of the mallet. However, these models are not simple and require appropriate and multiple sensor measurements and several physical input parameters to obtain meaningful experimental results.

In this work we design and build a striking device to produce repeatable marimba tones. The spectral parameters based on their timbre are used as input for a mathematical model that allows the determination of the mallet hardness.

2 Methodology

2.1 Striking apparatus

In order to perform meaningful experiments, an experimental striking appartus has be designed to be able to produce marimba tones in a repeatable way. The design of the apparatus was motivated by consistently and accurately reproduce proper mallet technique. A first prototype is shown in Figure 1.

Figure 1: Striking apparatus. Prototype

A holder is transformed by using a square piece of cork that is placed in one of its axis. Mallets can be easily exchanged without disturb of system repeatibility performances. By dropping free the mallet from a fixed heigh, it hits the bar by the action of the gravity force. In order to avoid secondary rebounds on the bar, an additional piece of cork is fixed to the system with a rubber band as shown in Figure 2.

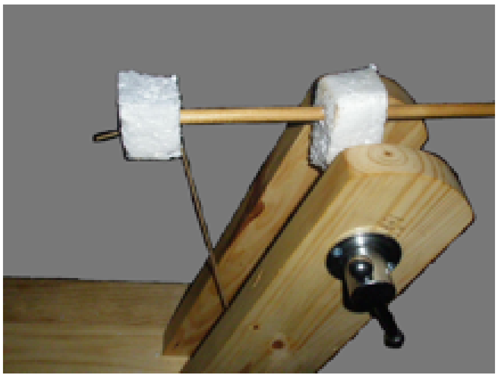

Figure 2: Detail of the striking apparatus. Prototype.

The final design of the apparatus is based on the prototype but made of aluminum (see Figure 3 and Figure 4) . A significant mechanical improvement is achieved: in order to assure that all the mallets are hold at the same point, a ring bolt is fixed at the place where the mallet is hold by the fingers of the percusionist. In this way, all the mallets produce the impact in the same conditions. The striking apparatus is used over a flat surface as the usual trap tables used by percusionist to hold the mallets. During the design process, it was crucial that the apparatus be experimentally quiet, consistent, flexible and reliable.

Previous to the acoustic measurements, the shaft is greased to reduce the noise during the movement of the mallet. The background noise produced by the device working without mallet (without percussion on the marimba) is checked to be negligible.

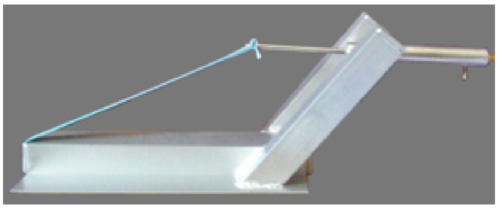

Figure 3: Striking apparatus. Final design

Figure 4: Detail of the striking apparatus. Final design

2.2 Mallets

Twelve different mallets have been used in this work from four different brands: Morgan Mallets, Elite Mallets, Malletech and Adams. From each brand, three mallets where selected and used, each of them belonging to the usual classification of hardness by percusionists: *Soft*, *Medium* and *Hard*. Remark that these 3 types are not defined by a standard neither the physical properties of the mallets but by the usual practice and experience of professionals. Next the list of twelve mallets used in this study is presented (the labelling for the experiments is in brackets):

- Soft: Malletech Stevens (LS1), Morgan Mallets Sisco Aparici (MSA46), Adams Robert Van Sice (M11) and Elite Mallets Nexeduet (Green)
- Medium: Malletech Concerto (CN14) , Morgan Mallets Sisco Aparici (MSA44), Adams Robert Van Sice (M4) , Elite Mallets Nexeduet (Grey)
- Hard : Malletech Michael Burrit (MB21Z), Morgan Mallets Sisco Aparici (MSA43), Adams Robert Van Sice (M5), Elite Mallets Nexeduet (Black)

2.3 Experimental setup

The experimental setup consists on the striking apparatus described before, a marimba Adams Concert MCHV 43 of 4 octaves and a third, a microphone Bruel and Kjaer 4189 1/2". The experimental measurements had placed in an anecoic chamber (see Figure 5). The striking apparatus was mounted on a stand to position and kept it at an optimum height to impact the marimba bars. The microphone was placed approximately 1 meter far from the instrument. All the impacts have been measured three times verifying the repeatability of the setup and the stability of the acoustic parameters evaluated.

The series of experiments include several variables that have been considered for the analysis:

- **Mallet response.** As mention the mallet response is the main characteristic to be evaluated in the experiment. The mallets have been classified into three groups attending to the stardard classification of percussionist: *Soft*, *Medium* and *Hard*.
- **Timbral dependence on bar position.** Percussionists use a technique of playing on distinct bar locations to change the particular tone color. Two strike positions were considered to account of this effect: 1) in the *center* of the bar, fitting with the antinode for the first harmonic and 2) in a *lateral* position 2*cm* far from the center.
- **Resonator function.** Directly beneath each marimba bar is a resonator tube. This tube has a metal plate in the bottom. Marimba resonators are designed to resonate with the fundamental of the bar. Thus, a resonator's length is determined by the note it must resonate. The resonator tube amplifies and changes the decay time of a note [6]. Measurements *with* and *without resonator* have been considered for the study.
- **Note.** All the measurements have been played in two notes in the central registre of the marimba: *A3* and *A4*. In the general practice of percusionists these notes are played with all three types of mallets. However, in low octaves hard mallets are not used and in high octaves soft mallets neither.

In total, after checking the repeatability of the process, 12 mallets where used with the sticking appartus to impact in two notes (A3 and A4) at two different positions (center and lateral) with and without the resonators providing 96 sound events of the analysis.

2.4 Acoustic parameters

A note from any acoustic musical instrument typically changes dynamically throughout in its pitch, loudness and timbre. Among these features of sound, the timbre does not have a simple one-dimensional subjective scale. Several methods and parameters of potential acoustic correlattions of timbre-space dimensions have been proposed in the literature. In this work, three very well known parameters have been used for the analysis of the spectral feature of the different sounds:

- **Spectral Centroid.** It is the amplitudeweighted average, or centroid, of the frequency spectrum, which

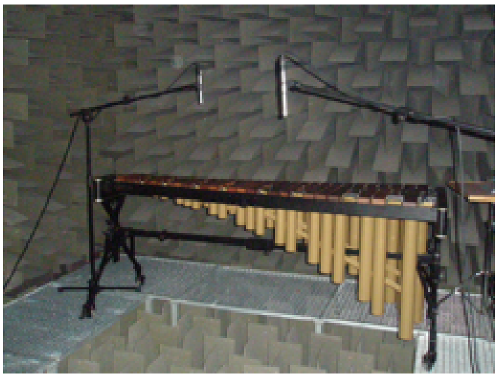

Figure 5: Marimba and microphe disposition in the anechoic chamber.

can be related to a human perception or brightness of the instrument [7]. The spectral centroid is given by:

$$SC = \frac{\sum_{k=1}^{K} P(f_k) f_k}{\sum_{k=1}^{K} P(f_k)} \tag{1}$$

where $P(f_k)$ is the magnitude spectrum of k-th sample, f_k is frequency corresponding to each magnitude element and K is the last armonic value considered to compute the parameter. In this study $K = 5$.

- **Tristimulus.** The tristimulus diagram enables the relationship between different components of the spectrum of the sound [8]. It gives the relative weighting between the fundamental component, those significant harmonics other than the fundamental and the higher harmonics. The tristimulus coefficients are computed as follows:

$$T_1 = \frac{P^2(f_1)}{\sum_{k=1}^{K} P^2(f_k)} \tag{2}$$

$$T_2 = \frac{\sum_{k=2}^{4} P^2(f_k)}{\sum_{k=1}^{K} P^2(f_k)} \tag{3}$$

$$T_3 = \frac{\sum_{k=5}^{K} P^2(f_k)}{\sum_{k=1}^{K} P^2(f_k)} \tag{4}$$

- **Odd/Even Harmonics.**. A specificity of many instruments is related to the relative energy of its even harmonics in comparison to the odd ones. This occurence indicates that it might be interesting to split the spectrum into two parts and observe the spectral behavior of odd and even partials separately. These to descriptors provide a proper definition of this property:

$$H_{odd} = \frac{\sum_{k=1}^{K} P^2(f_{2k-1})}{\sum_{k=1}^{K} P^2(f_k)} \tag{5}$$

$$H_{even} = \frac{\sum_{k=1}^{K} P^2(f_{2k})}{\sum_{k=1}^{K} P^2(f_k)} \tag{6}$$

3 Mathematical model for the mallet hardness

In this work we propose a mathematical model to determine the mallet hardness based on the spectral parameters calculated from acoustic measurementes using the striking apparatus. This model is based on a generalized linear model regression assuming normal distributions [9]. In this study two approaches were followed: The first one is a predictive approach in which some data were used to train the model and the resting data were used to test the model, and the second one is a descriptive approach in which all data available were used to train the model and to test it. As a result of the study, we have obtained a simple mathematical model that can be described in a linear equation and that allows the determination of the mallet hardness based on their spectral parameters.

3.1 Input selection and target encoding

The spectral parameters used in this study were T_1, T_2, SC, and H_{odd}. In this work these spectral parameters have been obtained in different measuring setups. After testing, we decided to use the spectral parameters measured in the following measuring setup: the note considered is $A3$, percuted in the lateral with resonator. The mallet hardness or target of our model was encoded using the value of 1 for soft mallets, the value of 2 for medium mallets, and finally the value of 3 for harder mallets.

3.2 Feature extraction

In order to improve the performance of the generalized linear model regression algorithm we have performed Principal Component Analysis (PCA) [10] on the input variables (spectral parameters) in order to reduce the number of variables of the model while maintaining the main relevant information for the model. Once the PCA was performed the most discriminant principal components (first and third) were selected. The seconc princap component PC_2 is not significant for the analysis. $PC1$ and $PC3$These components are defined as:

$$PC_1 = -0.0403\,T_1 + 0.9126\,T_2 - 0.3965\,SC - \\ -0.0916\,h_{odd} + 0.7709 \tag{7}$$

$$PC_3 = -0.1843\,T_1 + 0.2227\,T_2 + 0.3231\,SC + \\ +0.9011\,H_1 - 1.7099 \tag{8}$$

Plotting the distribution of hardness in terms of PC_1 and PC_3 allows us to visualize a clear relation between the mallet hardness and the values of these components (see Figure 6).

3.3 Predictive approach

The predictive approach evaluates the predictive capability of the methodology used to build the model. To do so, a subset of the whole data is used to train the model and the resting data is used to test the model. In this study, we have chosen the *leave-one-out* strategy to validate the model. That is, training the model using all the available samples less one, and using this sample to test

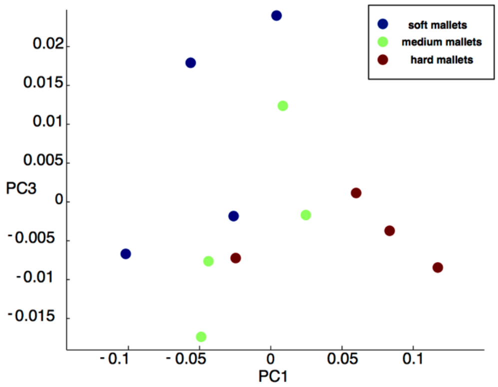

Figure 6: Scatterplot of the values of PC_1 and PC_3 for each of the mallets included in the study. Soft mallets are presented in blue dots, medium mallets in green dots, and hard mallets in red dots.

the model. Repeating this procedure 12 times, varying the samples used for training and testing we obtain an averaged estimation of the predictive capabilities of our methodology. If we discretize the output of the regression model we can compute figures of merit such as: Accuracy (*ACC*), balanced accuracy rate (*BAR*) or the confusion matrix (*CM*). The results obtained for the predictive models developed were:

$$\begin{aligned} &ACC = 0.75 \qquad BAR = 0.75 \\ &CM = \begin{pmatrix} 3 & 1 & 0 \\ 0 & 4 & 0 \\ 0 & 2 & 2 \end{pmatrix} \quad MSE = 0.30 \end{aligned} \tag{9}$$

The relations between discrete mallet hardness values assigned by the manufacturer and the mallet harness value assigned by the model purposed can be seen in Figure 7.

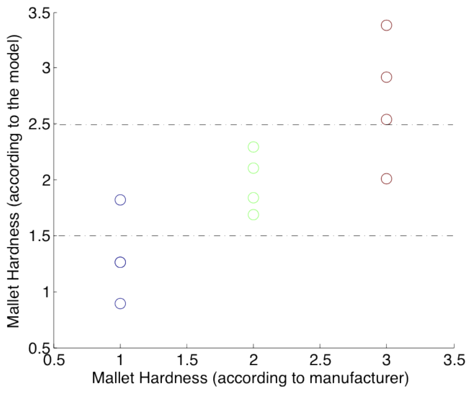

Figure 7: Correspondence between the discrete mallet hardness values assigned by a standard classification of percussionists (x-axis) and the mallet harness value assigned by the model purposed (y-axis). Each point represent each individual mallet included in the study.

3.4 Descriptive approach

Once we have tested the predictive capabilities of the purposed methodology we can use it to develop the descriptive model using all the samples to train the model. In this case the figures of merit were improved as expected obtaining the following values:

$$\begin{aligned} &ACC = 0.83 \qquad BAR = 0.83 \\ &CM = \begin{pmatrix} 3 & 1 & 0 \\ 0 & 4 & 0 \\ 0 & 1 & 3 \end{pmatrix} \quad MSE = 0.20 \end{aligned} \tag{10}$$

Once we have trained the model, we can easily obtain an equation that determine the hardness of a mallet from the four spectral parameters measured using the stricking apparatus:

$$hardness = 2 + 9.4359\, PC_1 - 32.4258\, PC_3 \tag{11}$$

where PC_1 and PC_3 are defined in terms of T_1, T_2, SC, and H_{odd} as described in Equations 7 and 8. Moreover we can obtain the mean squared error (*MSE*) of the hardness value predicted by the model with respect to the hardness value given by the manufacturer. In this case the *MSE* obtained was 0.30.

4 Conclusion

A stricking apparatus is designed and used to impact on marimba bars and generate sounds in a repetible way. In this work we propose a mathematical model to determine the mallet hardness based on the spectral parameters related to timbre. Using the Principal Component Analysis we are able to obtain a simple mathematical model that can be described in a single equation and that allows the determination of the mallet hardness based on their spectral parameters. The model show based on the PCA Analysis a more fine classification can be obtained providing intermedium classes of hardness in-between. This classification is not based on the perception of the sound produced by the mallets but on the spectral parameters of the sound produced by them.

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