Study of the brightness of trumpets' sounds by analysing impedance curves

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Introduction

Studying the quality of musical instruments is particularly interesting to help their development and to improve quality assessment procedures.

In the literature, two types of study tackle the quality assessment of musical instruments. On the one hand, subjective studies, which aim to characterize the subjective response given by a musician or a listener. The main difficulties with these approaches are that the subjective answers of a "subject" are generally non-reproducible, semantically ambiguous, and dependant on cultural and training aspects of the subject. Several studies using user-tests and sensory analysis techniques are proposed [1]. On the other hand, objective studies, where the aim is to find out which physical measurements govern the subjective quality of the instrument [2]. Concerning the brasses, the main physical measurement is the input impedance of the bore [3]. In order to propose a model for predicting certain qualities of brasses, the approach consists of discovering correlations for a set of instruments between the subjective response (given by the subject) and measurements (extracted from the impedance curve). These experiments are difficult to make, because one must finely control which parameters vary between the set of instruments, in order to be sure that the differences observed in the subjective assessment are effectively due to these variations. Furthermore, correlation is not equivalent to causality, i.e. an observed correlation between an objective measurement and a subjective assessment may be due in fact to underlying variables of the phenomena. Because of this, interpretations of the results remain in many cases difficult to make.

In order to isolate and finely control the influencing variables of the timbre quality of brass instruments, we developed a trumpet mouthpiece with a depth that can be easily and continuously adjusted from "deep" to "shallow". Using this device and the same trumpet, we generated a set of instruments with notably different acoustical behaviour, varying only the internal geometry of the mouthpiece. This set of instruments has been evaluated in two ways : (1) a particular attribute of tones (played by a musician and an artificial mouth), the "brightness", has been assessed via hearing tests [5] ; (2) the input impedance of the instruments has been measured.

In this paper, we present the extend to which various indicators extracted from the impedance curves correlate with the brightness of trumpet tones. We used principal component analysis techniques in order to reveal the underlying variables of information extracted from the impedance curve. The brightness scores are interpreted by multiple regression on the principal components. As a result, a very good correlation between the rating of the brightness and the positions in the factorial space is observed.

Measurements on trumpets' tones

The Brightness

The brightness is a typical subjective attribute for the study of the timbre of musical sounds. We carried out an assessment of the brightness of trumpet tones via hearing tests with 20 subjects [5]. The tones, corresponding to the note Bb4 (partial n°4), were played by the artificial mouth, and with the variable depth mouthpiece. Eleven positions of the mouthpiece, from T0 (shallow) to T10 (deep) have been proposed for the evaluation (the mouthpiece is designed in such a way that the variation between position Ti and T(i+1) is equivalent to the addition to the bore of a 0.5mm thick cylinder).

The subjects had to rank the sounds on a scale from dull to the bright. All the subjects showed clearly the following tendency: the deeper the mouthpiece, the duller the sound perceived. The average scores of brightness *b* of the tones (average of the ranks given by the subjects), are given in table 1.

Position	T0	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10
brightness *b*	9.8	9.1	8.4	6.4	5.8	7.6	4.7	3.9	3.7	3.8	2.7

Table 1 : Brightness scores according to mouthpiece position

Objective measurements of trumpets

Impedance curve

For the position T0 of the mouthpiece, a fine frequency range measurement of the input impedance of the trumpet was made [3]. Eleven resonance frequencies f_i (peaks of the impedance curve) were extracted. For the other positions of the mouthpiece, the resonance frequencies were calculated using the electro-acoustical line theory.

Acoustic parameters

The following acoustic parameters were extracted from the 4^{th} and 8^{th} impedance peaks of the impedance curve: the resonance frequencies f_4 and f_8, the quality factors Q_4 and Q_8, and the amplitude of the impedance $|Z_4|$ and $|Z_8|$. A quantity called "Inharmonicity" has been calculated (Inharm = $f_8/2f_4$|).

Results are given in table 2.

	4th resonance			8th resonance			Inharm.	*b*
	f_4(Hz)	Q_4	$\|Z_4\|$	f_8(Hz)	Q_8	$\|Z_8\|$	$f_8/2.f_4$	
T0	464	37.12	36.3	912	43.12	35.05	0.983	9.8
T1	464	37.85	36.8	908	41.61	33.34	0.978	9.1
T2	460	34.41	36.73	908	39.48	31.75	0.987	8.4
T3	460	37.31	37.28	904	37.37	30.29	0.983	6.4
T4	456	33.68	37.1	904	35.22	28.85	0.991	5.8
T5	456	37.01	37.7	900	32.85	27.55	0.987	7.6
T6	456	33.53	37.45	900	31.58	26.42	0.987	4.7
T7	452	36.69	37.98	900	30.00	25.35	0.996	3.9
T8	450	33.66	37.7	898	28.58	24.4	0.998	3.7
T9	448	36.48	38.15	896	27.23	23.52	1.000	3.8
T10	446	32.18	37.66	896	26.23	22.71	1.004	2.7

Table 2: resonance frequency, Q , |Z| and brightness *(b)*

Results

We suppose that the assessment of the brightness of a tone at frequency *f* is influenced by characteristics of the impedance curve at frequency *f* and 2*f*. Our objective is to test the following assumption: "*The brightness of the played tone Bb4 is governed by the following data of the impedance curve:* $f_8/2f_4$ Q_4, $|Z_4|$, Q_8, $|Z_8|$". In order to reveal the underlying variables among the 5 variables ($f_8/2f_4$ Q_4, $|Z_4|$, Q_8, $|Z_8|$), we performed a principal component analysis on the standardised data (correlation matrix) concerning 11 individuals and the 5 variables. The first factor accounts for 79% of the variance, the second factor for 18%. So a representation on a plane account for 97% of the variance. Figure 1 represents the position of the individuals (T0 to T10) in the factorial plane, and the directions of the initial variables ($f_8/2f_4$, Q_4, $|Z_4|$, Q_8, $|Z_8|$).

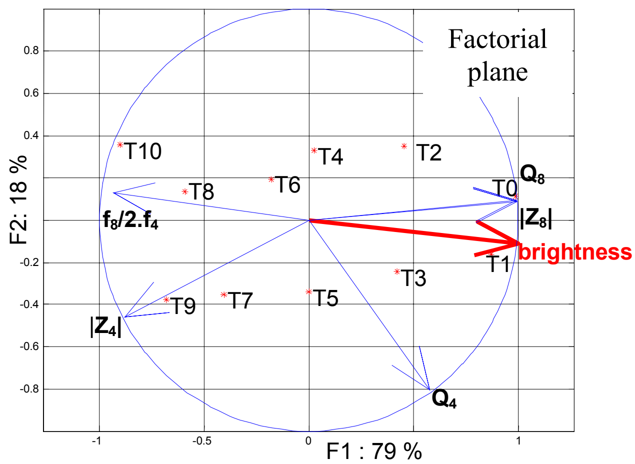

Figure 1: positions of the instruments Ti, directions of the variables ($f_8/2f_4$, Q_4, $|Z_4|$, Q_8, $|Z_8|$) and the attribute "brightness".

In order to interpret the brightness scores, we performed a multiple linear regression of the brightness scores b_i (the dependent variable) on the factorial coordinates ($F1_i$ $F2_i$) (independent variables). This classical technique in sensory analysis leads to the determination of the coefficients (α, β) of the regression, given by:

$$b_i = \alpha.F1_i + \beta.F2_i + \gamma \quad (1)$$

A very good correlation is observed (determination coefficient R^2 = 0,90 - significant with p-value < 1%). A graphic interpretation of the regression can be given by plotting in the factorial plane the vector model of the attribute "brightness" (figure 1). The origin of the vector is arbitrarily located in the origin of the frame, the values of the regression coefficients (α, β) give the position of the arrow, the arrowhead points in the direction of increasing brightness. This vector is parallel to the steepest slope line of the plane (equation (1)), and the perpendiculars to the vectors are the "iso-brightness lines".

The higher Q_8 and $|Z_8|$, and to a lesser extend Q_4, the brighter the sound (brightness is greatly correlated with Q_8 and $|Z_8|$, weakly with Q_4, see figure1). This result conforms to the physicist's intuition, because the characteristic of the impedance at the 8th resonance is supposed to have a great influence on the 2nd harmonic of the tone Bb4. And the relation between the brightness and the amplitude of the high frequency components of the spectrum is clearly demonstrated. The lower $f_8/2f_4$ and $|Z_4|$, the brighter the sound (brightness is negatively correlated with $f_8/2f_4$ and $|Z_4|$). This result could appear to be counterintuitive, but by examining table 2, one can see that the range of variation of $f_8/2f_4$ and $|Z_4|$ is very weak, so the influence of these variables is masked by the influence of Q_8 and $|Z_8|$.

Conclusions

In this paper, we proposed an interpretation of the brightness of a trumpet note (Bb4) by data extracted from the impedance curve. An artificial mouth and a variable depth mouthpiece have been used to produce the sounds, and to generate a set of instruments. The results show that changing the mouthpiece depth modifies characteristics of the impedance mainly for the high frequencies (high rank resonances). The influence of the characteristics of the 8th resonance frequency dominate on the brightness score: thye higher the quality factor Q8 and amplitude $|Z_8|$, the brighter the sound.

References

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