Formant Analysis of Altered Notes in a Diatonic Harmonica

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Professional diatonic harmonica players are able to play half-step notes which are not in the standard frequency settings using bending techniques. By changing the shape of the vocal tract, the timbre of the sound changes and the notes bend. This way, players are able to play a full chromatic scale by using altered notes. This paper tries to explain the altered notes phenomenon in terms of formants. Our experiments demonstrate that there is a relation between formants and pitch frequency while a note bends.

1 Introduction

In diatonic Harmonica, "bending" and "overblowing" techniques allow players to create a range of pitches beyond the fixed frequencies. These techniques were a question mark for researchers to find a scientifically based explanation. In addition, the reasons of bending and overblowing have never been investigated through formant analysis.

By adjusting the shape of the mouth, professional players learn by experience how to bend the pitch by a semitone. In [4], the movement of the harmonica reeds during bending is investigated. The theory of pitch control in harmonica is investigated in [5].

While playing the harmonica, all the techniques are happening inside the mouth of the player and is hidden from sight [2]. This issue makes the harmonica teaching harder. In [3] a MRI scanning is performed in order to identify the static and dynamic changes of the pitch.

Altered notes also appear in singing [8] as overtone singing. As a result, we can focus on the structure of the vocal tract to learn more about altered notes. Every configuration of the mouth gives the breath an absolute pitch and we can easily change the pitch of the breath by changing the shape of the mouth [6]. Speech sounds are produced by the position or the movement of structures within vocal tract [7]. The movement of the tongue, lips and other articulators creates patterns of energy in the acoustic signal that we can observe on the sound spectrogram [7]. Two frequency bands F_1 and F_2 are two formants associated with the sound produced in the mouth.

Formant is not only related to human vocal tract. Musical instruments also have their own formants [9]. Wind instrument sounds can be shown to be characterized by pitch-invariant spectral maxima or formants [10]. By playing the harmonica, there will be two different volumes: first, the mouth and vocal tract; second, the harmonica chamber. Due to the fact that the mouth and the harmonica together shape a new chamber, by studying the output signal we can investigate what is happening inside the inner area of this new chamber. Since the only adjustable part of this chamber is the mouth of the player, we can study the changes of the inner mouth by formant analysis.

In this paper, we provide formant analysis of altered notes and formant changes related to the vocal tract of the player. Two sets of recordings are used, then a formant analysis is applied for different groups of recordings. The results of the formant analysis and harmonics extraction are available to help harmonica teachers and learners have a better understanding of altered notes.

This paper is organized as follow: Section 2 gives a description of experiment setup. In Section 3, results and discussions are provided and in Section 4, conclusions and future work are presented.

2 Experiment setup

Two sets of recordings are prepared for two different experiment of setups. The first set, corresponds to "group experiments" and the second set is recorded for "transition experiments". In "group experiments", we are trying to show the differences between half-step and more bent notes in case of formants. In "transition experiments", we are going to track the transition of the formants from an unbent state to a bent state.

2.1 Group experiments

Three groups of notes described in Table 1 are used in this experiment. In each group, each note is played separately without any changes in frequency. The first note of each group is the fundamental as tuned in factory. The other notes in each set are the bent notes. The factory tuned notes need no correlation, and any shape can be inside the mouth. But for the bent notes, special shapes must be inside the mouth so the note can bend.

Table 1: Notes used for the group experiments.

Group #	Notes
Group 1	D (unbent), D_b
Group 2	G (unbent), G_b, F
Group 3	B (unbent), B_b, A, A_b

2.2 Transition experiments

Two different notes that can be found in Table 2 are recorded for section 2.2. Each note has a continuous transition from an unbent state to a bent state. Each note is bent to a half-step lower note.

Table 2: Notes used for the unbent-to-bent transition experiments.

Base Note	Description
D	from unbent D to bent D_b
G	from unbent G to bent G_b

2.3 Recordings and analysis method

A key of "C" ten hole diatonic of the "Hohner Marine Band" harmonica is used which is played by an experienced professional harmonica player for the recordings. [1] Formant analysis is used as the method of this paper which is based on the spectrum of the acoustic signal. The spectrum of the signal is calculated and formant analysis is done on this spectrum. A 10 ms hanning windowed LPC with 50% overlap is used to calculate the LPC spectrum of our 16-bit, mono, sampling frequency of 16 kHz PCM audio samples. A 40 ms hanning windowed spectrum with 50% overlap is used to calculate the spectrum. The LPC of order 30 helps to have a better observation of formants [1]. To calculate the harmonics, a peak detector [14] is used to detect the harmonic peaks in spectrum of each window. To show the harmonics of each note, the average of each harmonic in all windows is used. To calculate the formants of each note, each recording divided into 3 parts with an equal length. Then median of each part's formants for all windows is used as its formants.

Formants are found by observing the peaks in this LPC spectrum [12]. Pitches of the samples also are extracted using MIR toolbox [11].

3 Results and discussion

In this section, results of formant analysis is provided. In Figure 1, a spectrum of a frame and its related LPC is provided. The first peak in the LPC represents the first formant (F_1) and the second peak shows the second formant (F_2). To calculate the formant of each recorded note, we used median of the formants of all the frames in our recording. Pitch is also calculated using the MIR Toolbox [11].

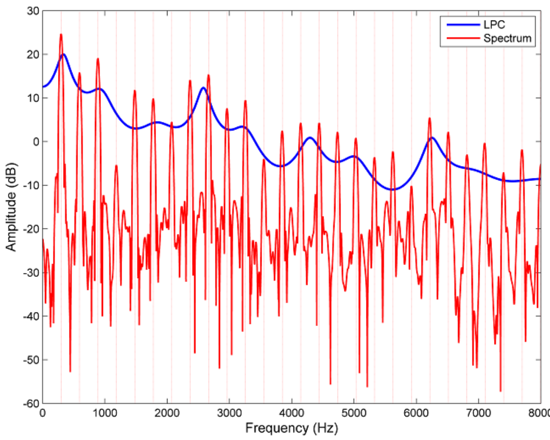

Figure 1: Spectrum and LPC of a frame from an unbent D note.

As mentioned in Section 2, two sets of experiments are conducted in this paper. In the first set, 3 different groups of notes are analyzed. In the second set, 2 notes are analyzed from an unbend state transferring to a bending state.

3.1 Group experiments

In Table 3, Table 4, and Table 5, pitch, F_1 and F_2 of the 3 groups are reported, respectively.

[1] Our recordings will be available online at http://www.cp.jku.at/.

Table 3 shows when D note bends to D_b, the fundamental frequency decreases. By decreasing the pitch, F_1 and F_2 decrease simultaneously.

In Table 4, second group shows when G bents to G_b and G_b bends to F, F_1 decreases with pitch. F_2 also shows a drop from G bending to G_b and from G_b to F.

In Table 5, the third group results demonstrates when B bends to B_b and then A, formants decrease by pitch at the same time. When A bends to A_b, formants decrease. According to group results, when we bend a note and its frequency decreases, the first and second formants also decrease with it.

Table 3: Pitch and formants of group 1 (D and D_b).

Hz	f_0	F_1	F_2
D	295.76	297.0	798.0
D_b	286.34	286.0	574.75

Table 4: Pitch and formants of group 2 (G, G_b and F).

Hz	f_0	F_1	F_2
G	394.9	384.0	574.0
G_b	371.53	371.0	573.0
F	350.15	348.0	571.0

Table 5: Pitch and formants of group 3 (B, B_b, A and A_b).

Hz	f_0	F_1	F_2
B	488.34	479.0	505.0
B_b	466.03	452.0	481.0
A	432.58	417.6	443.0
A_b	411.83	394.0	422.0

3.1.1 Harmonics

In Figure 2 and Figure 3, two different frames are selected; the first one from the unbent note and the second one from bent note. For the unbent notes, all the harmonics appear in a multiple of pitch frequency and the distance between harmonics are the same. Hence harmonic frequencies appear in a multiple of fundamental frequency. In the other words, harmonic frequencies are directly related with pitch frequency.

In bent notes, the first harmonic appears at the pitch frequency, but the other harmonics appear closer. Figure 4 shows the gaps between harmonics change while the note bends. A gap, is a distance of one harmonic peak from its adjacent harmonic peak in the frequency axis. It forces the harmonics to move and this way, a shift in harmonics will appear. The harmonics are not close to a multiple of fundamental frequency anymore. In Table 6, the first 5 harmonics of group 1 are shown. Usually, the harmonics should appear in a multiple of fundamental frequency according to Figure 3. The harmonics appear closer together than usual when the note bends as it is shown in Figure 2. The distance between harmonics also decreases when the note bends. Another observation is that the distance between harmonics are less than the pitch frequency. Table 7 and Table 8 also support this phenomena. Considering Figure 2 and Figure 3, a shift in harmonics happens when the note bends.

Table 6: First 5 harmonics of group 1 (D and D_b).

	1st	2nd	3rd	4th	5th
D	291.13	588.88	884.46	1180.95	1476.85
D_b	281.74	568.85	856.07	1143.26	1430.70

Table 7: First 5 harmonics of group 2 (G, G_b and F).

	1st	2nd	3rd	4th	5th
G	310.21	625.65	940.87	1256.87	1572.75
G_b	309.12	623.09	937.20	1251.92	1566.28
F	303.41	612.02	920.65	1226.11	1531.70

Table 8: First 5 harmonics of group 3 (B, B_b, A and A_b).

	1st	2nd	3rd	4th	5th
B	472.29	950.29	1435.5	1723.55	1907.58
B_b	441.0	932.0	1296.0	1611.0	1891.0
A	419.0	912.0	1218.0	1531.0	1883.0
A_b	404.0	801.0	1133.0	1502.0	1609.0

3.2 Transition experiments

In this section, we will use a set of recordings mentioned in Table 2 to show how formants changes together from an unbent position to a bent position. To show the changes, we use a formants-pitch map for our samples. We use 3 points in each sample to show the transitions of formants from unbent to bent; starting point from the unbent state, transition state from unbent-to-bent in the middle, and finally bent state at the end. Numbers from 1 to 3 the plot, indicate to the time order of the recording. The first point (1) shows the starting time of the recording, while it is still unbent, the second point (2) points to the transition part of the note in the middle of

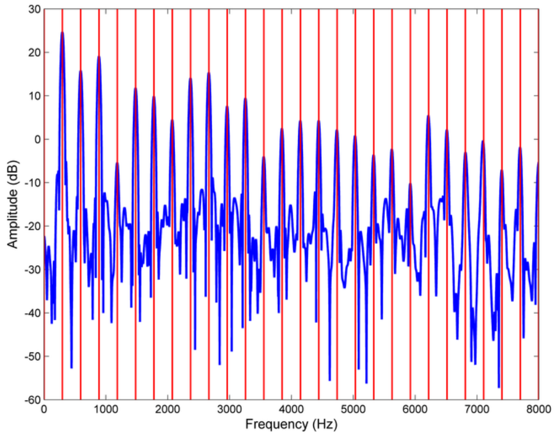

Figure 2: Spectrum and harmonics of an unbent D note.

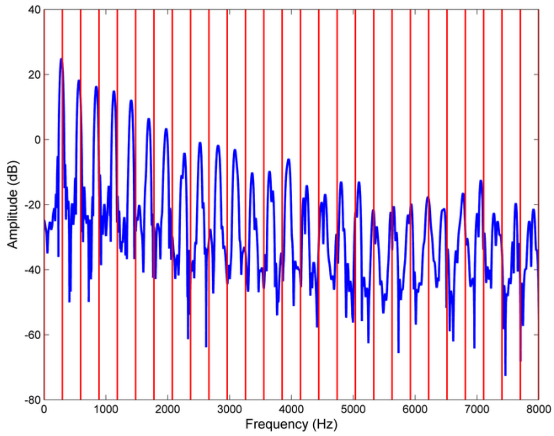

Figure 3: Spectrum and harmonics of a bent D note.

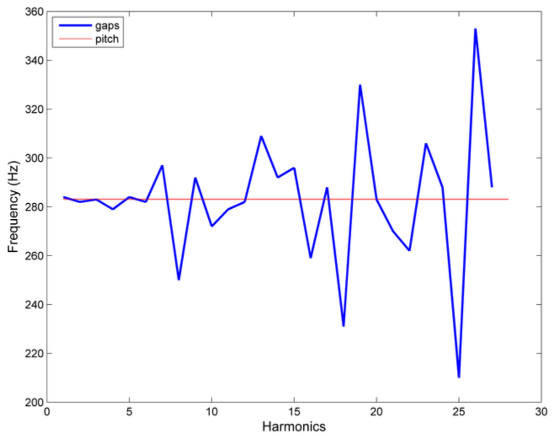

Figure 4: Gap distances between harmonics in a bent D note and the pitch frequency (f_0).

the recording time, while it is bending from unbent to bent, and the third (3) indicates to the bent note at the end of the time of recording. These 3 points divide each recording to 3 parts. From starting point to transition point, from transition point to bending point and from bending point to the end. In the other words, whole frames divided into 3 equal smaller segments. Then median of the frames in each segment, is calculated to represent the formant of that part. Figure 5 shows the formants space of the notes while they change from unbent to bent. It shows when a note bends, both F_1 and F_2 decrease. Figure 6 shows a similar decrease in F_1 and f_0 in D and G notes. In Figure 7, a similar behavior is observed. All the results support the idea that when the pitch frequency decreases, the formants (F_1 and F_2) are decreasing. Figure 8 shows a 3 dimensional view of the change of the formants and the pitch together for a better understanding.

In Figure 9, the vowel space shows that the formants of all notes from our samples, including D and G notes; are in the green rectangle area which marked in the figure. Two back vowels of U and O vowels are also located in this area. Figure 10 indicates the tongue positions for back vowels. It shows the tongue for back vowels of U and O vowels, that are highest tongue positions of cardinal back vowels which means the tongue is positioned as far back as possible in the mouth without creating a constriction. This shape of the tongue, makes a small whole in the back of the mouth [13] and also an empty area after it which maybe is one of the reasons of altered notes phenomena. Support or rejection of this idea needs more experiments that will be a target for our future work.

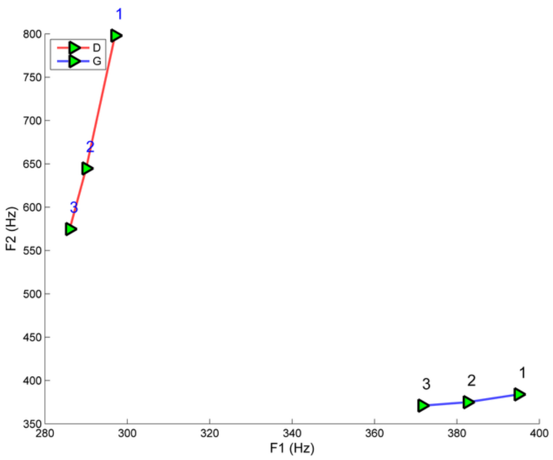

Figure 5: Formants change transition of D and G notes in formant space.

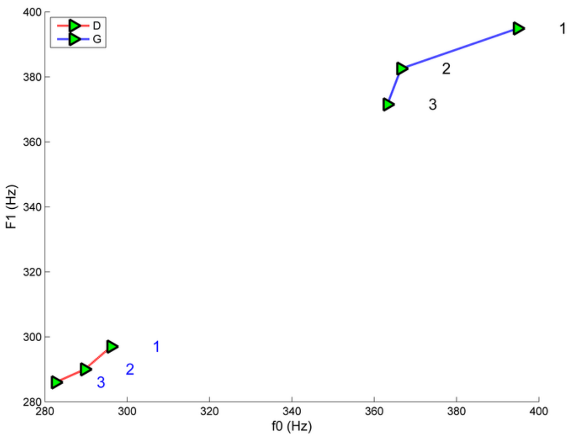

Figure 6: Pitch changes versus transition of F_1 in D and G notes.

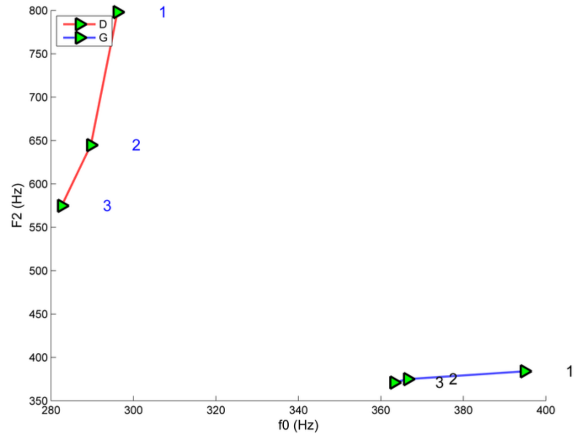

Figure 7: Pitch changes versus transition of F_2 in D and G notes.

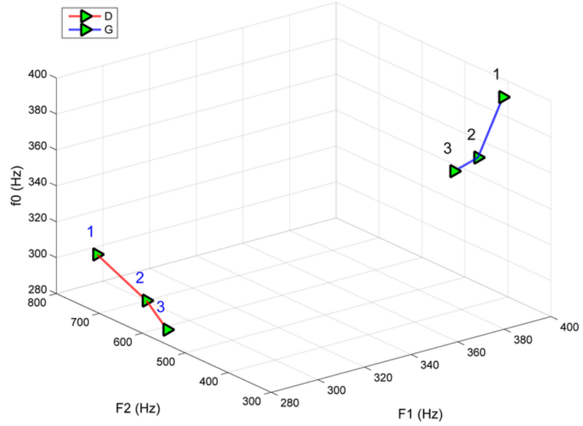

Figure 8: Pitch changes versus transition of vowel formants in D and G notes.

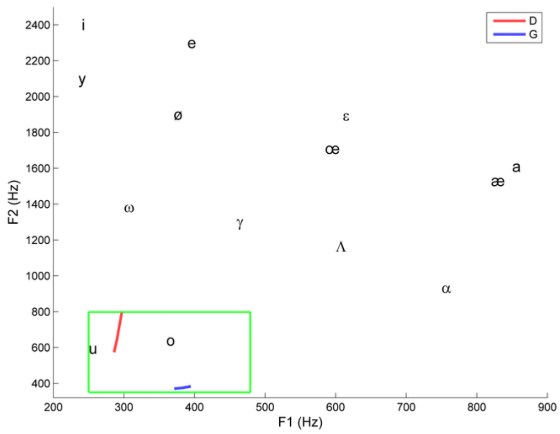

Figure 9: Formants change transition of D and G notes in vowel space.

4 Conclusions and future work

This paper investigates the altered notes phenomenon by doing a spectral formant analysis of recorded unbent and bent samples in harmonica. The results show a direct relation of the pitch with F_1 and F_2 in both bent and unbent

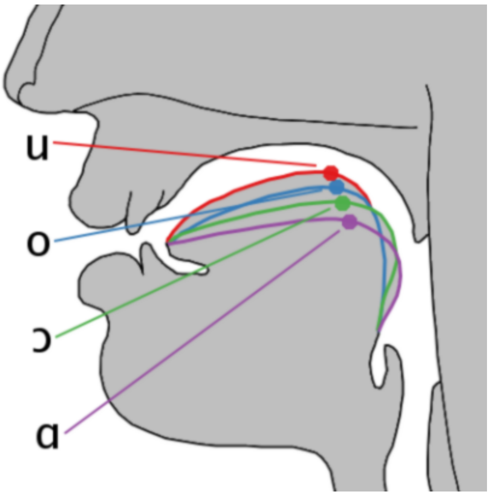

Figure 10: Tongue positions of Daniel Jones' cardinal back vowels [15].

notes. Also there is an area in vowel formants space, which the tongue position in this area, makes a small hole in the back of the mouth, and an empty space after it. Also we can conclude that the green area in Figure 9 is the area that bending phenomena happens and for example, it is not possible to bend a note while the formant space is somewhere close to the "A" vowel.

In future work we will investigate the relation of this shape with altered notes. There are more factors which can also effects the bending phenomena in harmonica like air flow and speed, which need to be studied in our future work.

5 Acknowledgment

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