Real-Time Control of Greek Chant Synthesis

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ABSTRACT

This paper we report on an interdisciplinary project for modeling Greek chant with real-time vocal synthesis. Building on previous research, we employ a hybrid musical instrument: *Phonodeon* (Georgaki et al. 2005), consisting of a MIDI-accordeon coupled to a real-time algorithmic interaction and vocal synthesis engine. The synthesis is based on data provided by the AOIDOS program developed in the Department of the Computer science of the University of Athens, investigating Greek liturgical chant compared to *bel canto* singing. Phonodeon controls expressive vocal synthesis models based on formant synthesis and concatenated filtered samples. Its bellows serve as hardware control device that is physically analogous to the human breathing mechanism [georgaki, 1998a], while the buttons of the right hand can serve multiple functions. On the level of pitch structure, this paper focuses on a particular aspect of control, namely that of playing in the traditional non-tempered and flexible interval structure of Greek modes (ήχοι: *echoi*) while using the 12-semitone piano-type keyboard of the left hand. This enables the musical exploration of the relationship between the spectral structure of the vocal timbre of Greek chant and characteristic intervals occuring in the modal structure of the chant. To implement that, we developed techniques for superimposing interval patterns of the modes on the keyboard of the phonodeon. The work is the first comprehensive interactive model of antique, medieval and modern near-eastern tunings. The techniques developed can be combined with techniques for other control aspects, such as timbre and vocal expression control, phoneme or (expressive/ornamental/melodic pattern, inflection) sequence recall and combination, data record on/off, or others, which form part of the phonodeon project. On the level of timbre and expression, we make use of data obtained by analysis from audio samples of chanting as control sources for synthesis by concatenation of control data, thereby providing an example of realtime application of Diphone techniques (Rodet and Levevre). This research can find applications in many computer music fields such as algorithmically controlled improvisation, microtonal music, music theory and notation of (algorithmic/computerized) real-time performance, and computer modeling of experimental or non-western musical styles.

Keywords

Vocal synthesis, expressive synthesis, microtonal tunings, real-time control interfaces, algorithmic improvisation, music notation, music theory, ethnomusicology.

1. INTRODUCTION

Synthesis of the human voice has been a favorite topic in machine automation since the early days of the Automatophones. In 1678, Marin Mersenne dreams in his *Harmonia Universalis* of an organ which could reproduce basic vowel phonemes such as a, e, o, and u[1]. Von Kempelen achieved reproduction of these vowels in 1791, using a control mechanism for motorized bellows. Research on the synthesis of the singing voice has a history of over 35 years [Rodet, 2002] while that on the real-time control of synthetic voice is a relatively new field [Cook, 2000, 2005], [Yonezawa and al, 2005].

The overall objective of the phonodeon project is to create a novel hybrid musical instrument by combining the control capabilities

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[1] *" Je m'occupe maintenant à trouver la manière de faire prononcer les syllabes aux tuyaux d'orgue. J'ai desja rencontré les voyelles a, e, o et u mais i me fait bien de la peine, et puis j'ay treuvé la syllabe vê et fê. Je ne sçay si je paourray prendre le losir de trouver les autres consonnes, à raison des différentes experiences qu'il faut faire sur ce sujet , lesquels estant de coust, je laisseray le reste à ceux qui voudront passer outre." (Marin Mersenne)*[1]

of the accordeon with programmable real-time algorithmic generation and sound synthesis techniques. At this initial phase, we are developing a "grammar" for using the phonodeon as controller of synthesized singing by any accordeonist equipped with an accordeon-to-MIDI interface. We also want to enable composers of contemporary electroacoustic music to write for this kind of controller in order to explore and extend the capabilities of synthetic voice models and beyond and to experiment with the extrapolation and interpolation between different singing techniques of vocal styles from various parts of the world.

In previous stages of our research, we employed the Phonodeon for the control of voice-like timbres, mapping the bellows to expressive characteristics such as amplitude, virbarto and others and the left -hand buttons for changing vowel qualities [Georgaki et al. 2005].

The work described in the present paper aims to expand the musical capabilities of the phonodeon, enabling it to "sing" in the style of greek orthodox liturgical chant. Greek chant (often called "Byzantine Music") refers to the liturgical music and recitation tradition that is still practiced in Greek Orthodox churches. It is a strictly vocal tradition with more than 1000 years of history. As such, it has developed its own modal system, which is related to other contemporary and older systems of the eastern Mediterannean and Near East. The theory of the system is unique because it relies heavily on *relative pitch structures*, that is, the transposition of intervallic structures to different regions relative to a transposeable reference pitch, rather than on a fixed repertoire of absolute pitches or pitch classes. Implementing this principle on a freely programmable synthesis system with hardware controller is one of our research tasks. The solutions developed may be useful in exploring microtonal tuning techniques in other genres, including experimental computer music in general.

2. A VIRTUAL GREEK CHANTER

The present work is part of a research program named AOIDOS[2], studying the analysis and synthesis of Greek singing Based on a text-to speech vocal synthesizer developed in the Department of Computer science, University of Athens [Georgaki, 2004] [18]. aiming on, the synthesis by concatenation of Greek singing diphones and the study of performance rules in different vocal techniques of Greek music.

The long-term goal is to develop a 'cognitive chanter model' with elements concerning not only timbre, but all levels of chant structure. Layers of elements beyond timbre and phonemes are: Interval structure of the modes, generative phrase and melody structure models of the modes, micro-ornamentation (ornaments added by voice fluctuation in the range of 1-3 notes, lasting about 1 second or shorter), macro-ornamentation (ornamentation and expansion of melodic skeletons). In order to achieve this, a model is being developed based on data obtained by analysis of recordings of chanters and singers in a number of related genres (rebetiko, liturgical chant, traditional folk music, etc.). As a first step data has been collected regarding voice timbre, formant structure and inflection or ornamentation details including note transitions and vibrato. An important issue arising in this context is the relationship of the intervals and tunings of the Greek modal system to the vocal timbre of Greek chant. Since Greek chant has existed as a strictly vocal genre for more than 1000 years, it is interesting to examine whether and how the intervals that it employs concur with spectral characteristics of its particular voice technique.

The implementation of a playable system based on recorded data and on the MIDI-accordeon serves as a practical test for the validity of the mentioned cognitive chanter model.

3. DATA AND ANALYSIS

3.1 Sample Recordings

Data for the analysis were obtained by recordings and measurements from an experienced male professional Greek chant performer, 50 years old. The recordings were made in an anechoic studio using a Rode K2 microphone and digitizing at 44.100 Hz with a resolution of 16 bits using model Yamaha AW16G professional audio workstation.

The initial sample consists of the isolated vowels *a*, *e*, *i*, *o*, *u* in an ascending scale of the eight notes C3 up to C4.

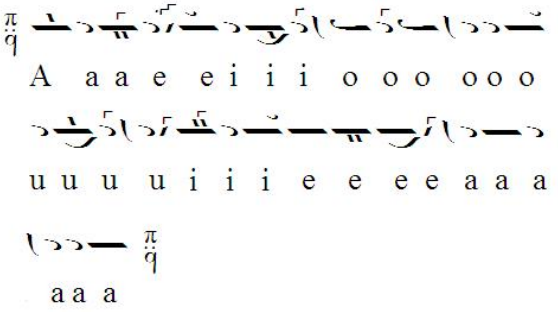

Fig. 1 Neo-byzantine notation of the music phrase used for formant trajectories extraction.

The second sample consists of a sample music phrase that uses all five basic Greek vowel phonemes (*a*, *e*, *i*, *o*, *u*). This was recorded under the same conditions as the initial sample above. Fig. 1 describes this music phrase in Byzantine notation. This is a characteristic phrase in the first mode, displaying the most common diatonic intervals of the fundamental scale of the modal system. These are non-tempered intervals built on the basis of three distinct types of seconds: major second (μείζων τόνος, approx. 203 cents), minor second (ελάσσων τόνος, ca 170-150 cents) and minimal second (ελάχιστος τόνος, ca 140-120 cents). As indicated by the cents value ranges, the size of the two latter types of seconds varies according to the direction of the melodic movement and their position in the scale or phrase. The conditions and the apparatus for the recording of this phrase were identical to the one described above for the case of the isolated vowels.

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[2] AOIDOS refers to the singer-reciter who composed during performance in Homer's *Iliad.* Furthermore, it it is part of a triad of concepts relating to the study of the arts in Greek antiquity, reflected in three primordial forms of the Muses that represent central aspects of the human artistic-intellectual pursuit: *Melete:* Research, Study, *Mneme :* Pattern storage and recognition mechanisms, *Aoidos*: Expression of emotional states.

3.2 Analysis and Meta-Data

Formant frequencies F_i (i=1,…,5) (Hz), formant bandwidths B_i (Hz) and formant relevant to the signal gain (*third column*) amplitude A_i (dB) were derived from the above data using Linear Prediction Coding (LPC) digital signal analysis my means of PRAAT software environment [19]. Table 1 (at the end of the paper) presents the results of the formant analysis at the steady-state regions of each vowel for the first recording.

Using the same methodology for the analysis of the data, formant trajectories (F_i, B_i, A_i, i=1, ..,5) were extracted for the whole duration (36,4 sec) of the musical phrase. In addition to the format data, the trajectories also include the frequency and gain of the fundamental of the vocal cords acting as excitation signal. A window of 20 msec was used for the analysis with a step of 10 msec, giving a time resolution of 10 msec. The data were stored in a file for experiments in resynthesis.

In order to use the data for resynthesis during performance, it was necessary to identify single subphrase and note elements in the recording based on the analysis data. These data correspond to single "Diphone" units in the control and synthesis method proposed by Rodet and Lefevre [15], as explained further in section 6 below.

4. SYSTEM AND CONSTRAINTS

Our performance system consists of an accordion coupled to a programmable synthesis environment via MIDI. A MIDI Accordion has up to 4 categories of controls which are usually transmitted via MIDI to external devices. The type of MIDI messages sent and their resolution may vary depending on the type of MIDI-conversion device that is attached to the accordion. For the present experiments, we used an Accordion of the type "Victoria" with a MIDI unit of type Q-Select. This system is capable of sending the following messages:

a. The pressure of the bellows, which is controlled by pressing together or pulling apart the two parts of the accordion with the help of the upper left and right arms held between straps and the accordion parts, is sent as MIDI-control no. 11.

b. The control parameters of the piano-type choromatic keyboard played by the right hand are sent,in the form of MIDI note-on and note-off messages. In our case, the keyboard had 38 keys, covering 3 octaves and 1 major second.

c. The control parameters or the left hand playing on several parallel rows of buttons are sent as MIDI note-on and off messages, on a different MIDI channel than those of the right-hand keyboard. In our case, the accordion was equipped with 120 buttons arranged in 20 rows of 6 buttons.

d. Other controllers such a footswitch or expression pedal can combined with the accordion as additional controllers. At this stage we did not make use of additional controllers.

In our system, the right-hand keyboard is used in the usual manner to play pitched notes. The buttons of the left hand serve multiple purposes: Phoneme formant choice, timbral inflection, ornament and expression indications and choice of melodic pitch interval patterns. The system as developed in [5] is a generic control model that can be adapted to needs of various control and synthesis techniques. It has an architecture comprised of 3 layers: *performance and control*, *mappping and drivers*, and *synthesis engine(s)*.

5. SYNTHESIS MODEL

The synthesis model used for this paper consists of five independently controllable formant filters that are applied to one shared source "excitation" signal modeling the vibration of the vocal chords. It is implemented in the SuperCollider 3 real-time programming and sound synthesis environment. The synthesis parameters are frequency and amplitude of the source signal frequency, bandwidth and amplitude for each of the five formant filters. Additionally, vibrato frequency and amplitude is provided for varying each of the frequency parameters, as means to add basic movement to the otherwise unnaturally static sound produced by synthesis.

A Graphic User Interface is provided for adjusting all synthesis parameters via sliders. This permits manual exploration of the properties of the synthesis model in order to gain a practical and intuitive grasp comparing to the data provided by the analysis of the vocal samples.

6. MODAL SYSTEM

6.1 Modal Structures

As modal structures we define here a number of scales composed of interval modules. It may include several variant modules. We assigned the most basic modal structures to 8 buttons of the right key.

6.2 Interval Modules

Interval modules can best be described as scale fragments composed of 2 or more adjoined musical intervals. There were in all 24 interval patterns comprised of 3, 4 or 5 notes, and corresponding to the main tetrachords of the 5 genera (soft and hard diatonic, soft and hard chromatic, and enharmonic). These can be applied to the modal structures as variants by pressing one of 24 further buttons.

6.3 Module Combinations

Module combinations are combinations of 2 or 3 interval modules and are used as parts of the modal structures.

6.4 Momentary Inflections

Momentary inflections are alterations of a single note upwards or downwards following the direction of the melody. 2 upward and 2 downward alterations were included, of 50 and 33 cents in each direction, triggered by 4 left-hand buttons.

6.5 Melodic Patterns

By melodic patterns we mean here segments of control data corresponding to entire phrases, and obtained by concatenating several note-events in the analysed and marked control data. These were assigned to left hand buttons as a second layer, triggered by pressing the bottom left button.

7. TIMBRE AND EXPRESSION

7.1 Phonemes

Phonemes were realized in 2 ways:

1. As static phonemes whose formant values were obtained by the mean values of phonemes from the analysis of the audio data.
2. As phonemes with moving inner microstructure obtained from the control data of single note events in the analysis.

These were organised in 2 sets, and switching between them enabled by a button.

7.2 Dynamics

Overal dynamics were controlled by signals received from the movement of the accordeons bellows. This means, while very simple produces convincing results and is easily mastered by the performer as it corresponds entirely to the usual acoustic way of using the accordeon.

7.3 Vibrato

Vibrato was essential in adding a live color to the synthesized voice. It can be either coupled to dynamics and its frequency and intensity can be modified in increments by 4 corresponding buttons.

7.4 Transitions

Transitions between notes are added by pressing 3 transition buttons and consist of envelopes bridging the control data for the fundamental pitch of the exciter-source.

7.5 Micro-inflections

Under Micro-inflections we mean types of small ornaments or specific shapes of control envelopes applied to the synthesis parameters of single notes. These were abstracted from the analysed control data.

8. EXPERIMENTS

We devised a series of performance experments to test the functionality of the various types of modulation of the virtual greek chanter model implemented on the phonodeon. These included interpretation of scales and of melodic phrases in different vowels, for testing a number of factors:

1. Change of vowels
2. Expressive change of volume within a note and within a phrase
3. Change of timbre
4. Change of tuning
5. Microtonal inflections
6. Vibrato
7. Ornaments
8. Transposition of modal intervallic structures
9. Manual interpretation of a whole melodic phrase
10. Concatenation of automated phrase parts into a new phrase while playing.

These experiments constitute a continuation of the experiments done in previous research [5]. As far as synthesis control is concerned, the main new technique explored in this paper is the resynthesis by concatenation of control data derived from analysis of recorded audio samples. This technique is closely related to that of Diphone control and synthesis presented by Rodet and Lefevre [15]. The innovative aspect here is that the concatenation of predefined control data units (in [15]: Diphone units) is done in real time.

The formant analysis data were analyzed with simple algorithms that placed marks at the points where the change of energy exceeded a specific threshold. The threshold was manualy adjusted until the markers corresponded most closely to the beginning of musical events recognizable as single “notes”. The results were compared to markers set by the IRCAM programs SVP (Audiosculpt) and Diphone applied on the original sample recordings.

9. DISCUSSION, FURTHER RESEARCH

In order to fully exploit the musical potential of developments in technology, musicians will need to be receptive to learning about the possibilities afforded by the new technologies, to make use of these as tools rather than as substitutes for creativity. Technological developments facilitating the transition from non-real-time to real-time [16] modes of operation in sound have also helped broaden the range of techniques available in live performance. In a way, music research is now entering a cyberspace-like situation, where the connections between traditional modes of interpreting music and musical styles and new technological tools are no longer evident. Thus musicians adapt their instruments and their performance and interpretations styles to entirely new modes which afford hitherto unknown capabilities of control on synthetic timbres. The resulting new “grammars” will have to be adapted and developed to match existing grammars that are mastered through traditional performance skills. Only then will the new instruments become accessible to traditionally trained musicians. As a summary, we mention here the imperatives or constraints formulated by the acoustician E. Leipp [6] with regard to models of acoustic musical instruments. These are:

1. Perceptual/cognitive constraints
2. Construction (hardware) constraints
3. Anatomic and physiological constraints
4. Commercial (cost etc.) constraints

These constraints are applied to the domains of parameters that govern the synthesis of pitch, intensity (dynamics), timbre, and other parameters of musical form. These must in turn conform to high-level cognitive constraints that govern the overall development of musical form.

In the domain of dynamics it was relatively easy to obtain results by coupling the quasi-continuous bellow pressure signal to the parameter for overall amplitude. In order to further refine this, we tried also to couple bellow pressure to other parameters related to intensity such as vibrato amplitude and speed as well as timbre.

In the domain of timbre, we assigned buttons of the left hand to vocal phonemes as well as to several different classes of timbre.

In the domain of pitch we also assigned buttons of the left hand to different tunings, intervallic structures and alterations in order to extend the melodic capabilities of the regular piano-type keyboard or the right hand.

The inner complexity of single events and phrases obtained from the analysis data and the sheer number of possible combinations amongst the different control aspects (phoneme, pitch, inflection, ornament, timbre etc.) suggest in the present experiments that control of all single aspects together is hardly possible to master by a single player. Three different approaches seem possible for future research:

1. Reduction of the control parameter space to simple essentials and / or combination with controlers that have high resolution of continuous control data and expressive capabilities.
2. Use of "intelligent performance models" that generate complex control parameters from simple commands and gestures from the performer by applying the model on the specific context at each moment of the current performance.
3. Live concatenation and modification of prerecorded or synthesized control patterns obtained by analysis from audio samples or by other means.

These approaches can be combined with each other. Given the fundamental differences between digital control means and vocal or other acoustic instrumental techniques, it is inevitable that new performance styles with their own characteristic sound will emerge from the attempts at modeling existing ones. Thus the present work can be understood as an exploration of future control techniques on the basis of an existing musical style.

10. CONCLUSION

This paper we presented ways of controlling a synthetic model of greek orthodox liturgical chant by *Phonodeon*, a MIDI accordion type controller. Our aim has been to develop a grammar that will enable the performer to manipulate vocal timbre, ornaments, melodic intervals and tunings. The work done has revealed some of the practical limitations of existing interfaces of acoustic instruments such as the accordion in the control of synthetic models of chanting. In sum, the two main factors that proved to be decisive in the nature of the control interface are:

1. The discrete nature of the particular interface in contrast to the continuous nature of some of the important aspects of the chant modeled.
2. The complexity of the melodic and expressive factors to be modeled in contrast to the need for relatively simple, easily learnable control schemes.

While both of these factors could not be fully addressed at this stage, the work done helped gain a clearer idea of the requirements that need to be met. With regard to the first factor, there is need for additional control interfaces for output of continuous parameter values (continuous gesture shapes) is needed. With regard to the second factor, there must be developed algorithms that map a smaller number of control parameters and values to the actual final parameter values required for synthesis. The question that arises for future research is whether such mapping algorithms are feasible and practical for live human performance with controller interfaces, or whether new types of abstractions can be developed based on just parts of a traditional performance model rather than the entire model itself. Such new algorithms or synthetic control models would then give rise to new types of musical styles in live performance.

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Table 1. Formant frequencies F_i (i=1,…,5) (Hz), formant bandwidths B_i (Hz) and formant relevant to the signal gain (*third column*) amplitude A_i (dB) for the signing of the five Greek vowels in eight different notes

		gain	F1	B1	A1	F2	B2	A2	F3	B3	A3	F4	B4	A4	F5	B5	A5
C3	/a/	59.2	494	47	59	922	109	46	2124	78	38	2700	282	28	3129	31	40
	/e/	64.8	468	44	63	1371	81	51	2169	22	63	2796	155	52	2977	43	57
	/i/	65.9	333	62	59	1577	24	58	2289	26	62	2876	66	59	3075	55	58
	/o/	65.4	552	46	66	663	277	56	2489	135	40	3077	139	57	3105	53	58
	/u/	60.9	410	59	60	2207	51	37	3009	51	47	3158	36	49	4180	74	20
D3	/a/	66.7	475	46	66	971	115	51	2387	28	60	2803	102	54	3063	35	58
	/e/	67.2	461	49	62	1363	44	56	2186	31	59	2850	73	60	2989	33	64
	/i/	66.9	333	70	59	1572	23	59	2245	81	53	2875	76	61	3019	48	62
	/o/	66.7	468	34	69	772	79	55	2397	89	41	2948	54	54	3135	35	56
	/u/	66.8	444	36	67	873	77	53	2322	92	41	3019	130	60	3044	26	63
E3	/a/	68.4	489	34	68	1066	146	48	2431	44	57	2849	64	59	3107	22	64
	/e/	66.2	484	61	60	1356	54	55	2171	42	57	2854	41	62	3049	36	60
	/i/	65.5	342	60	60	1542	33	56	2215	45	56	2894	108	56	3031	35	62
	/o/	67.4	527	50	66	2319	107	44	2926	163	52	3048	13	68	3995	164	23
	/u/	65.2	697	137	58	2210	269	42	2700	332	43	3068	6	70	3990	330	20
F3	/a/	68.9	514	45	67	1036	147	50	2423	59	56	2882	84	60	3057	38	63
	/e/	64.9	485	97	55	1496	203	44	2155	36	60	2877	88	57	3046	34	62
	/i/	67.6	360	77	59	1536	12	66	2232	48	57	2882	49	62	3082	24	65
	/o/	67.0	492	53	66	832	136	52	2348	105	43	3068	15	65	4026	172	22
	/u/	64.7	495	118	58	861	96	54	2270	74	44	3017	49	62	3055	87	60
G3	/a/	67.9	502	144	58	1020	245	47	2383	45	58	2955	84	63	3054	69	63
	/e/	67.2	505	187	53	1380	75	55	2158	28	63	2882	40	63	3108	34	62
	/i/	69.8	395	73	62	1566	21	66	2197	62	59	2871	71	62	3100	28	67
	/o/	69.4	554	220	60	823	154	57	2360	125	47	3030	201	66	3057	13	72
	/u/	65.8	455	98	61	933	128	51	2291	62	49	2933	96	53	3146	22	63
A3	/a/	66.0	506	70	63	975	115	52	2439	50	56	2750	239	48	3126	13	64
	/e/	68.6	482	79	62	1399	41	61	2203	51	59	2888	67	60	3144	30	64
	/i/	69.5	439	20	69	1557	13	68	2196	33	63	2863	77	59	3122	30	64
	/o/	70.2	495	99	65	901	61	62	2322	77	49	2995	18	69	3174	88	55
	/u/	70.0	481	58	68	973	56	61	2255	93	48	2967	31	64	3217	55	57
B3	/a/	71.1	546	116	64	1030	152	55	2341	51	60	2874	92	60	3143	14	71
	/e/	73.9	520	51	69	1597	254	53	2198	71	65	2870	44	70	3153	52	64
	/i/	71.9	442	56	64	1657	43	63	2203	70	62	2883	95	63	3131	32	69
	/o/	74.8	520	71	71	1005	49	67	2382	110	55	2955	110	62	3174	21	72
	/u/	72.9	505	87	66	1009	67	62	2260	82	53	3034	167	67	3077	21	73
C4	/a/	75.0	535	66	69	1073	67	62	2448	157	53	3021	213	72	3050	17	77
	/e/	74.8	534	30	73	1527	150	55	2274	61	66	2882	58	69	3177	49	66
	/i/	73.3	438	72	64	1610	26	68	2240	62	64	2894	56	68	3189	75	63
	/o/	75.0	538	67	70	1043	37	69	2123	132	50	2993	21	74	3173	63	64
	/u/	70.8	532	98	64	1078	126	56	2313	72	55	3000	104	60	3246	30	67