VIRTUAL VOICES ON HANDS: PROMINENT APPLICATIONS ON THE SYNTHESIS AND CONTROL OF THE SINGING VOICE .

Anastasia Georgaki, Lecturer
Music Department, School of Philosophy
National and Kapodistrian University of Athens, Greece
georgaki@music.uoa.gr

ABSTRACT

The on-going research of the last thirty years on the synthesis of the singing voice highlights different aspects of this implicative field which involves the interdisciplinary area of musical acoustics, signal processing, linguistics, artificial intelligence, music perception and cognition, music information retrieval and performance systems. Recent work shows that the musical and natural quality of singing voice synthesis has evolved enough for high fidelity commercial applications to be realistically envisioned.

In the first paragraph of this paper we are going to highlight briefly the different aspects of the on-going research (synthesis models, performance by rules, text-to- speech synthesis, controllers) through a taxonomy of these approaches. In the second part we are going to emphasize on the utility and the different applications of this research area (including the recent commercial ones) as a tool for the music creativity by presenting audio and video excerpts of various approaches through a MIDI accordion. Finally, we are going to present future and related work on Greek singing, outlining a new research project named AOIDOS /Virtual Greek singer which is under development at the University of Athens.

By this article we want to highlight the prominent applications of this research domain in the field of musicology and music creation and music education.

1.INTRODUCTION

The last thirty years, there has been a special research interest on the synthesis of the singing voice; the conception of synthesizers has been quite fruitful, due to the exploitation of the data extracted from the restricted analysis of the singing voice, and due to a big effort by scientists to separate the speaking voice from the singing voice by focusing their interest on their acoustical and cultural differences: frequency, displacement of the formants, vibrato, attack, spectral envelope, etc. Since 1980 various projects have been carried out all over the world having as principal point the synthesis of the singing voice [1],[3],[4],[5],[6],[25],[26],[28],[29].

In fact, every project has its own goals and directions. Since our last research [14] where we present the most important projects on the synthesis of the singing voice, multiple research programs have being arising all over the world through different optical views, languages and methodologies,focusing on the mystery of the *synthetic singing voice*. [2], [15], [16], [19], [21], [22], [33].

2. MODELS AND RESEARCH ASPECTS

Among the various projects which use a multitude of techniques and rules, concerning the analysis and synthesis of the singing voice, we have selected as a vehicle of our discussion, the research projects which tend to have a complete point of view about the synthesis of the singing voice (in order to speak about 'models' which fulfil the expectations of a synthesizer not only from the acoustical point of view but also from the phonetic one). These different optical views extend from the development of a proper technique for the *naturalness* of the sound quality (which is of great importance for the singing synthesis, whereas *intelligibility* is more important for the speech synthesis) to the designing of the rules that determine the adjunction of phonemes or diphones into phrases and their expression.

2.1.Synthesizer models

The three synthesizers which are already established in the world of computer music research and have been used for research purposes are MUSSE/RULSUS [28] CHANT [25],[26] and SPASM/SINGER [5]. In our days new synthesis systems as FLINGER[1], LYRICOS[2] [21], VOCALWRITER[3],VOCALOID [33], CANTOR[31], - extend the idea of usability and performability of the computers. These models which have been developed through the last seven years bring the laboratory research

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[1] Festival Speech synthesis system uses diphones for synthesis: http://cslu.cse.ogi.edu/cgi-bin/flinger

[2] An innovative score to singing synthesis program. http://clu.cse.cgi.edu/tts/research/sing/sing.html

[3] A commercial program for singing synthesis which starts form a score and offers 90 different preset voices.http://kaelabs.com

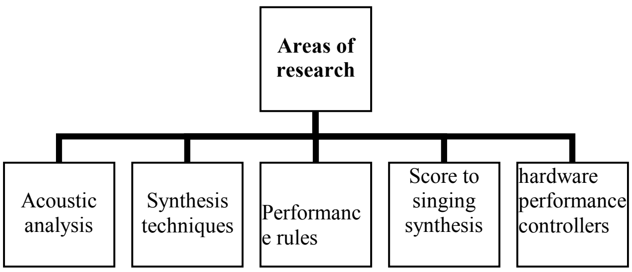
outdoors and excite more and more the interest of musicians and composers to use these prominent tools for creative applications as they give the user the immediate contact with the environment as we will see in the next paragraph.

2.2. Research Areas : From synthesis to control

In any case, all these projects and especially the models in which we have been referring to, differ not only in their synthesis technique, the implemented rules but also in the control interface and the resulting sound (every model has its own particular voice signature). They differ also in the performability of the model and its applications in the computer music field (composition, psychoacoustics, vocal training and education and performance)[4].

The research of the last twenty years has been focused especially on the development of flexible synthesis techniques (as a product of a fruitful acoustic analysis) in order to solve the code of *naturalness and vivacity* of the singing voice in the lower or higher frequencies during singing. Techniques like FM synthesis[4], the formant model[1],[28], the FOF synthesis[25],[27], the physical modelling[5], the synthesis by concatenation of sampled sounds[2],[21],[26] are the most popular in the computer music world.

Other approaches on the synthesis of the singing voice include the development of performance rules[5]during singing [1],[3],[28],the development of the score-to-sing synthesis which can also be decomposed to two subsystems[6]and the development of hardware performance controllers [7].



1.Research areas on the synthesis of the singing voice

2.3. The complexity of the singing voice signal

Attempting an evaluation to the research models we have mentioned above, the technical problems are related with the complexity of the vocal signal and more specifically to:

a) the huge quantity of parameters and data, describing the complex voice singing model, related to the incapacity of the machines to elaborate these satisfactorily (for example in order to have an entire command of the Greek language we must sample about 2300 sound units , just for one type of voice only). This is one of the major cues for differentiating the vocal signal from an ordinary instrumental signal, as the voice is closely connected to the human being, not only from the physiological point of view but also from the acoustic one. In other acoustic signals, it is not necessary, in the same detailed manner to describe the formant trajectories or the microvariations of the signal (which, in the case of voice, are related very closely with the biological function of the vocal apparatus).

b) the specifity of the voice concerning biological functions of the human body (organic and psychological) which affect the timbre , the intensity and articulation of the voice. For example, any aleatoric microvariations due to stress or other factors, influences the periodicity of the vocal signal.

c) the fact that every language has its proper phonetic rules and phonemes renders the creation of an international phonetic database very difficult (a big vocabulary of phonemes and diphones in several languages and an interdisciplinary connection between them), and for evident reasons prevents the commercialisation of a universal vocal synthesizer.

2.3. The control of parameters

Researchers are still preoccupied with problems concerning the control of a synthesized singing phrase[12];

a) on a first level, the most important element that they try to assume by manipulating parameters in the frequency domain (frequencies, bandwidths, amplitudes of formants) is that the control must be coherent with the direct perception.[2],[3],[16],[34].

b) on a second level researchers are preoccupied with rules of evolution of the formants, rules of interactions between the parameters or questions concerning the reception of control signals from physical peripherals, in order to introduce them into the synthesizer.[27],[22],[15].

c) on a third level they try to ameliorate the control of the oscillation of the glottis, of respiration muscles and other acoustic mechanisms. Researchers must also construct rules related to the vocal cords' tension during singing, as also rules which describe the interaction between vocal effort (muscles, cords etc.) and vocal result (articulators).[23],

In brief, the problem of the control can be treated not only by the physiological point of view but also from the biological one, which in collaboration with the researchers of the cognitive sciences will give the proper

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[4] Some acoustic examples will give evidence for these observations : Singing phrases from MUSSE, SPASM, CHANT, LYRICOS, CANTOR, etc.

[5] Rules for Music Performance: http://www.speech.kth.se/music/performance/

[6] The first subsystem is score analysis which converts the score into abstract representations(e.g. MIDI like representation) including the phoneme and prosody contour. The second subsystem is sound rendering which converts these abstract representations to the acoustic output.

informations about the influence of psychological situations on singing interpretation and the importance ofthe body anatomy on singing (resonators, tongue, vocal cords etc..).

2.4.Perception related problems

The voice, more than any other instrument, is related very closely to the ear and the ear has the capacity to recognise whether a sound is artificial or not. These perceptive problems come forward because of:
a) the lack of *naturalness* in the dynamic evolution of the vocal signal due to the lack of rules needed to describe the complexity of the human activities during singing . Among the most perfect sound examples that we have in our archive, and concerning of course voices which are conceived in abstracto, we can conclude that: *the synthetic singing voices lack naturalness* (apart from some exceptions[7]which don't make use of consonnants and are sung in high frequencies, where normally the intelligibility of voice is altered).In this case we must avoid to confuse the sampled-based synthesis of voices in some programs (like in VOCALOID) and the pure formant synthesis of other programs. In the first case we slightly understand that this voice is synthetic (sample based) and in the second case, even if the concatenation of the diphones is excellent we can perceive the robotic character of the words.
b) the sensibility of the ear which can discriminate the most subtle differences between the spectre of a real and synthetic voice (critical bands, feedback system between voice and ear.)

3. PROMINENT APPLICATIONS

Until now existing technology prevented composers from achieving the same success when their compositions involved vocals. Though systems and software that synthesize singing voices exist, the work entailed in making them sound real was complicated and onerous. First, the popularization of sound samplers containing a wide range of pre-recorded sounds has led some producers to try creating music with vocals using samples of human-voice snippets and the development of score to singing techniques . Second, the design of new controllers (e.x. accordion–type) bring the research of this complicated domain closer to the performance-driven music. Third, the design of new synthesis interfaces open a new window to the comprehension of the acoustic function of the vocal tract during singing, by giving the opportunity to professional singers to control better their voices and explain better to their students the art of singing.

3.1.Score to singing synthesis

Last year, music technology industry has presented two promising new singing voice synthesis programs which open new horizons in the score- to singing-synthesis of the voice: CANTOR(VirSYn) [8]and VOCALOID (Yamaha).[9]

Apart from the fastidious and sophisticated research which has been referred in previous paragraphs on the *naturalness* , *accuracy and parameters control of the singing voice synthesis* these new commercial products focus on the automatic reproduction of singing phrases via lyrics and score, partly neglecting the large amount of control nuances which is needed to sound “real”. Although the embryon-version sound quality is medium, some enthusiastic composers and amateurs of pop and classical music that were waiting many years for such a product have welcomed them. Testing vocal compositions (where the lyrics accompanied by a score can be converted to voice through different approaches) and create virtual singers or artificial songs of a great singer[10] seems to be of great importance for a techno-composer and artist.

Yamaha’s *Vocaloid* is in fact a special synthesizer with much more complicated control parameters, different from these of ordinary synthesizers. *Vocaloid* parameters can be regarded as purely acoustic and are not meant to be user friendly. So by increasing *amplitude of resonance* the program will get output overload while that could be avoided if a change in one parameter was automatically compensated by the change in another. *Vibrato, Attack* and other *"expressive elements"* are needed in order to sound more naturally. In fact, without introducing "expressive elements" it only provides

[7] Rodet x. and his research group .*Synthesis of the Aria The Queen of the Night from Mozart's Opera The Magic Flute* http://www.ircam.fr/anasyn/reine.html

[8]Virsyn presented in the Frankfurt Musikmesse Prolight+sound2004a new 8-part vocal synthesizer, Cantor (Mac/Win)- *(http://www.kvr-vst.com/get/984.html*) - which lets users enter words in English and play them melodically from a MIDI keyboard in real-time. According to the manufacturer, Cantor's Voice editor lets you edit the character of the virtual singer by defining the base spectrum for vowels and consonants. The application also includes a Phoneme editor and offers real-time control over vibrato rate and depth as well as the gender of the singing voice.

[9] VOCALOID (www.vocaloid.org) uses Frequency-Domain Singing Articulation Splicing and Shaping, a vocal (singing-voice) synthesizing system developed by YAMAHA. With this system, the "singing articulations" (collections of voice snippets, such as of phrases, and snippets of vocal expression variations like vibrato) needed to reproduce vocals are collected from custom-produced recordings of accomplished singers and put into a database after conversion into frequency domains. To synthesize vocal parts, the system retrieves data consisting of voice snippets, applies pitch conversion, and splices and shapes them to form the words of a song as input by the user. As this processing is done at the frequency-domain level, pitch can be easily changed according to the specified melody, and the voice snippets can be spliced in a way that reproduces smooth-flowing words. VOCALOID itself consists of a score editor, which does the scale, song-word, and expression processing; the Vocal Sound Generator, the engine that synthesizes the vocals; and libraries (each comprised of a pronunciation database and a timbre database) for each vocal. New vocal libraries can be created by recording real voices pronouncing basic vocabulary and reproducing variation effects (such as vibrato) according to templates.

[10] The composers who use music notation programs or sequencers can test their compositions by different voice timbres and decide which one fits to be interpreted during the real performance

"correct static synthesis of vocal speech", i.e. correct melody and correct speech.

Virsyn's *Cantor* synthesizes the human voice entirely in software - using no samples and as a result is able to offer real-time playability from a MIDI input. A kind of an additive oscillator, Cube style, with a certain amount of partials, affords a very good quality of the vowels a, e, o…. but the consonant quality especially for the dentals (b, d), the nasals and other is still medium. *Cantor* gives the chance to composers to interpolate easily from instrumental sounds to vocal ones (change a vowel to a gong) and finally it can easily be emerged as a powerful tool for electroacoustic composition.

These new programs have different synthesis techniques but similar interfaces. *Vocaloid* seems to haven more perspectives in the pop music industry than Cantor, which can be an excellent tool for both electroacoustic and computer music composers.[11]

3.2. Music Creation : from simulation to abstraction

Since now, some composers of contemporary and electroacoustic music have used the synthesis of the singing voice in order to create ambiguous timbers and interesting interpolations between them. [13]. The timbral metamorphosis and processing of the vocal character is in the cue of their experimentations than the phonetic aspects and the text-to speech concatenation of the voice. The techniques that have been used are:

a) voice in abstracto, where the vocal material is entirely produced by the computer by the aid of a program synthesis and is restricted in timbral transformations of vowels by the techniques of simulation, hybridisation, interpolation or extrapolation.

b) analysis-resynthesis of concrete pre-recorded voice which allows the processing and resynthesis not only of the vowels but also of entire sung phrases

c) processing of the voice by formant synthesis in real-time (interactive systems). The resynthesis of the voice occurs in real time by applying simple techniques like the processing of the formants, and broadens the horizons of electroacoustic performance by the computer

3.3. Performance-driven voice synthesis

Which should be the applications of the synthesis of the singing voice in the domain of performance? In line with the research of the "lost instrument" [Dufourt, 1996] our ambition here is to discuss the possible forms of a controller, which gives the liberty of expression and experimentation on voice.

All tools are extensions of human intention. The musical instrument that are in essence an extension of human voice and touch, are conceived in order to combine the emotion of the speaking voice and that of the singing voice, with the possibility of dexterity than can be achieved with the fingers and hands. Yet, the immediate musical expression is still the voice, the most difficult to master instrument.

As an accordion player I have imagined of a versatile instrument which "breaths" like the voice in order to give manually the time-variation transitions of the vowels and of diphones [14]. I have tested vocal sounds by my MIDI-accordion (Victoria) making expressive vocal-like sounds by manipulating the breath controller but it was very difficult to produce singing phrases . By *Vocaloid* and especially *Cantor*, which contains a 16 phonemes dictionary, I can manipulate singing voices more easily.

More promising in the control of the singing voice appear two controllers which have been designed in Princeton University by the team of Perry Cook : Squeezevox[12][7] and COWE[13] (even though it is yet under development and it is not a natural "fit" due to many parameters).

Another approach to the performance-driven synthesis of the voice is that of a given performance. In this case the data are given by the interaction between the performer and the computer. The performer can play an instrument like violin, flute, etc, which affords the computer with the accurate pitches, durations and amplitude in real-time and through a singing voice encoding system it transforms the given information to human-like voice [18] .

3.4.Vocal Pedagogy

The last years several synthesis models between them SPASM/SINGER and MUSSE/RULSUS have been proved as useful programs for the understanding of the singing voice production and the passage form one register to the other. They have been used not only as vehicle for the comprehension of the singing voice but also as tools for creating new strategies in the vocal pedagogy By the aid of the computer, the singer must learn to make use of the source/vocal tract coupling in improving voice quality, while avoiding or compensating for its undesirable effects looking through the "mirror" of the computer. Electronically, the singer may set the richness of the "voice" spectrum at any level desired and like that, the voice source of the electronic voice can be easily isolated from the vocal tract that drives it. Let us also add to these "advantages" of the electronic voice the ability to select the proper voice fundamental frequency to any desired accuracy,

[11] We will make a presentation of our esthetical approach on the synthesis of singing voice by MIDI accordion using both programs (CANTOR, VOCALOID).

[12] Squeezebox allows a sophisticated control of the vocal synthesis in real-time which is an accordion device controller for controlling synthesized singing voices. With the right hand, pitch is controlled by the keyboard, vibrato with aftertouch, fine pitch and vibrato with a linear strip. Breathing is controlled by the bellows, and the left hand controls vowels and constants via buttons (presets), or continuous controllers such as a touch pad, plungers, or squeeze interface. (http://soundlab.cs.princeton.edu/research/controllers/squeezevox)

[13] How can a player perform and interact between different vocal techniques? The COWE model goes further the idea of accordion and treats the control of vocal models, including BelCanto singers, crying babies, Tibetan and Tuvan singers.

including the characteristics of pitch change and vibrato (many consonnants cannot be accurately synthesized by physical modelling as yet). Last by visualising the positions of the formants (especially in the Spasm/SINGER model[5], [6]) the synthesis of singing voice should be a promising assistant for the future academic singing courses.

3.5. Meta-processing, resurrection of forgotten voices, ethnomusicology and musical aesthetics

The synthesis of a singing voice can also be a useful tool to post-processing to a music studio when corrections to a singing recording voice are required and the singer can not perform another recording. According to X.Rodet [21], for instance, restoration of singing archives could be done by using a singing voice synthesis system. As another example, new scores or new interpretations could also be created by singing synthesis techniques as if performed by a singer of the past or at least with a great resemblance to such a singer, or to his style, like the resurrection of the voice of Farinelli[8]. In the field systematic musicology, singing voice synthesis can open new directions in the understanding and qualification of beautiful and rich voices [29] where we can reproduce and examine our occidental psychoacoustic preferences concerning the voice.

Last, in the area of ethnomusicology, isolated researches have been done [30]. In this case the analysis-synthesis of singing voice can open new directions in the study of the singing voice techniques in occidental music and investigate the relativity and transitions between the world vocal techniques. As a matter of fact, considerable differences can be found between European traditional or classical singing voice, such as bel canto and German lied, and the Asian traditional pressed singing voices, such as throat singing around the Altai mountains, Japanese Youkyoku, and Korean Pansori.

3.6. THE *AOIDOS* virtual Greek singer

Based on the conception of text-to speech vocal synthesizer developed in the Department of Computer science, University of Athens[32],[33] a research program named AOIDOS[14] is on evolution on the analysis and synthesis of Greek singing, aiming on the study between Byzantine singing and bel-canto, the synthesis by concatenation of Greek singing diphones and the study of performance rules in different vocal techniques of Greek music (in adjunction to their appropriated modal musical systems like ancient Greek modes, ecclesiastic modes, Greek traditional music modes, rebetiko modes, etc.)

In order to enrich this 'cognitif vocal singer' with elements concerning not only timbre, but also the technique and the language, we must extract the data by analysis, studying different vocal models (different modes of Greek singing etc..) and implement all these data in the computer[15] .

Our future expectation of this vocal synthesizer concerns the field of ethnomusicological and literature research : to which degree this synthesizer could be a pertinent tool for integrating several encoded vocal techniques aiming to study the transitions of vocal technique through the evolution of the Greek language.

4. CONCLUSION

Though systems and software that synthesize singing voices exist, the work entailed in making them sound real remains complicated and onerous. Even after much fine-tuning, synthesizing vocals to be indistinguishable to listeners from real singing was still virtually impossible.

In the last few years the promising applications of the synthesis of the singing voice are various: score to singing synthesis, music performance, voice pedagogy, music creation, post-processing of the voice which give the possibility to the composers, musicians and musicologist to investigate multiple aspects of the interchange of different vocal timbres and techniques.

Future challenges include synthesizer models improvements, automatic estimation of model parameter values from recordings, learning techniques for automatic rule construction and, last gaining a better understanding of the technical, acoustical and interpretive aspects of the singing voice in order to approach more to the design of a "cognitif" vocal synthesizer which should be a pertinent tool for systematic musicology, music education, music performance and creation.

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[14] The AOIDOS means the singer who composed in performance (the *aoidos*) in Homer's *Iliade.* Another methaphorical approach of AOIDOS is the expression of emotional states : it is known that the three primordial forms of the Muses represent three basic functions of the human intellect. *Melete:* Research., *Mneme :* Pattern storage and recognition mechanisms, *Aoidos*: Expression of emotional states.

[15] The singing synthesis system will be based on several recordings of different singers (rebetiko, Byzantine, traditional, etc.) which will be analyzed and stored in a database. In a first step of our development in this database will be stored his voice characteristics (phonetics) and his low-level expressivity (attacks, releases, note transitions and vibratos).

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