A Synopsis of Hardware and Software Implementations of Byzantine Music Delta Systems

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Abstract: **-** Our work presents the most recent developments in instrumental and DSP melodic reproduction of Byzantine music. This specific musical system is a Delta musical structure with a “thinner” microtonal scale partition of the well-known European scale and therefore new notes are involved. Apart from the tonality distribution, in Byzantine music Delta notation, transitional patterns appear stating qualitative ways for the ascent or descent of prosodic pitch. This paper describes apart from a hardware piano-like implementation of the exact tonal distribution, software protocols and interfaces of this complex musical surface that enable DSP systems to reproduce with synthetic voice realizations the pitch, timbre and prosody of a real Byzantine singer.

Key-Words: - Delta Musical Systems, Byzantine Music, Musical Synthesizers, MIDI Protocol, Formant Synthesizers, Physical Modeling.

1 Introduction

Our work presents the most recent developments in instrumental and DSP musical reproduction of Byzantine music. When we use the term Byzantine music, we mean the music that was used by the people of the Byzantine empire (4^{th} to 15^{th} century), composed to Greek texts as ceremonial festival or church music. Elements were derived from Syrian, Hebrew and Greek sources [1]. This musical system was not confined only to ecclesiastical music; it was a generalized musical system originating directly from ancient Greek music and was used as the usual music surface by all the people living in the vast areas of the empire, from Southern Italy and the Balkans up to Russia and down to Middle East and Egypt. The nations of Middle East were accustomed to the Greek language and (musical) civilization throughout the conquests of Alexander the Great and its successors [2].

Although Greek instruments were used, the *organ* was the main one. The organ was a musical wind instrument in which sound is produced by one or more sets of pipes, each producing a single pitch by means of a mechanically or electrically controlled wind supply. Several keyboards (manuals) are played with the hands. Projecting knobs (stops) to the sides of the keyboard operate wooden sliders that pass under the mouths of a rank of pipes to stop a particular rank [1]. The pedals of the organ are like another keyboard, played with the feet. The prevailing organ for several centuries from the 3^{rd} century B.C. was the Greek hydraulos or hydraulis [3]. Although secular Byzantine music used instruments, ecclesiastical music was vocal. It is reported however that the organ was used for tuning or ear training, but not for the formal vocal performance [4].

Two major characteristics of Byzantine music are its *modal* character and its *homophonic* performance [2, 4, 5, 6]. By the term mode we do not merely imply the ways of ordering the notes of a scale [6], but a *tropos*, a way, a guideline of performance including various side effects like pitch bendings (“ελξεις”) and accompanying prosodic transient phenomena.

After the Arab/Muslim conquest of Egypt and Syria, the nature of the state and culture was transformed. Byzantium became much more a Greek state [5]. This is the divergent point for Western and Eastern music: while in the West the heritage of antiquity was transformed gradually to the Ambrosian chant, later to the Gregorian chant and finally to the polyphonic Western music orchestration, in the East prevailed the Byzantine music scheme. Although it resembles the plainsong character of the Gregorian chant, it is rather homophonic [6] than monophonic.

After the collapse of the Byzantine Empire and the Ottoman occupation, almost all surviving Byzantine music is sacred and its major form was the hymn. Byzantine chant is monodic, in free rhythm. Notation was first a series of symbols to remind the singer of a melody he already knew (Fig. 1(a)); later a staffless notation indicating starting note and subsequent intervals of a melody was used (Fig. 1(b)) [1]. The symbols used for the musical encoding of Byzantine music are called *parasimantiki* (“*pa ra shmant ikh*”). Parasimantiki is a set of symbols that transcribe analytically the correct way for the interpretation and articulation of musical phrases [1, 2, 7, 8, 9]. In this notation are written the hymns of the Orthodox Church and the Greek folk songs. Parasimantiki had prevailed in the East as the dominant musical notation and was reformed in 1814 and 1881 from committees of the Ecumenical Patriarchate of Constaninople to an analytical notation system whose symbols came out of the numerous symbols of the earlier shorthand-like notations [2, 4, 8].

Byzantine music is basically modal. Eight modes are used currently: four authentic (modes A, B, C and D) and their plagal ones (modes Plagal A, Plagal B, “Varys” and Plagal D) [2, 4, 6]. These came from a pool of about 15 modes used in Byzantine era. The ones that were not suitable for the solemnity of ecclesiastical music were diminished [2] and have survived sporadically in Eastern musical traditions. Since Byzantine music is a direct descendant of Ancient Greek music, Ancient Greek modes like Dorian, Lydian, Mixolydian etc are rehashed. However, although the names of modes are taken from ancient Greek names, there is an ambiguity on the exact correspondence of Ancient Greek modes, Byzantine modes and the re-use of the Ancient Greek mode names in contemporary music forms like Jazz [2, 6, 9].

It should be noted at this point that although Byzantine music survives as a relic of glorious past in the music of the Greek Orthodox Church it is not a musical phenomenon deteriorated in mainland Greece.

The following should be taken into account:

a) Byzantine music is characterized by “orientalization”, i.e. influence of Arabic or even Turkish music microtonal scale divisions. This is predominantly obvious in the modes that use chromatic scales. In its long history Byzantine music had stages of “orientalization” and “de-orientalization”, but primarily it is the precursor of all these oriental musical systems originating directly from Ancient Greek music [2]. Influences and similarities exist between these musical traditions and there is affinity in hearings, scales and modes.
b) Byzantine music was spread as ecclesiastical music to all Eastern Slavonic, Syrian and Arab Orthodox churches. Although especially the Slavonic churches underwent extensive “de-orientalization” and shifted to polyphonic Western music, they still use Byzantine music melodies; recently, there is an explosion of Byzantine hymns worldwide through the *diaspora* of the these nations [10].
c) The musical patterns of Traditional Greek music and current Greek popular music have been shaped and categorized through practice according to the Byzantine music tradition and theoretical models and they are described in terms of this musical idiom. These patterns are not only vocal, but they have been also detected in instrumental performance, having a significantly different structure when compared with equivalent patterns of the typical western equal tempered tradition [11, 12].

The crucial issue in the Byzantine music surface is the melodic and harmonic information signified by parasimantiki. The Byzantine music notation can be perceived as a combination of special symbols that have musical information (pitch intervals, timing and quality conduct). These symbols form sequences according to the rules and the behavior of a morphogenetic field in the sense of Markov chains (Fig. 1). A thorough study of these structures by Spyridis and Politis has resulted in the composition by a computer of Byzantine hymnlike melodies according to the statistical and entropic content of the analyzed melodies. By this method it has been outlined that “the musical holons are composed by the influence of strong morphogenetic fields in all structural levels of the Byzantine hymns musical language” [7]. In other words, Byzantine music has a strong cohesive structure. However, parasimantiki does not describe notes explicitly, but as an increment or decrement from the previous level, *as a phonetic transition from the current state to the next one.* Thus, when musical reproduction is taken into account, we need a new frame for the interpretation and interfacing of the musical notation, since parasimantiki is a Delta musical

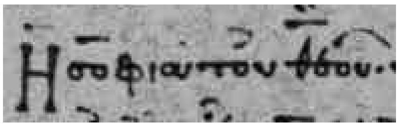
(a)

(b)


Fig. 1. Byzantine Manuscipts. (a) Detail of the so-called 'Chartres fragment' with musical notation, beginning of the sticheron "Η σοφια του Θεου, Mode plagal D", Monumenta Musicae Byzantinae, University of Copenhagen [9]. (b) "Doxastarion" of Iakovos Protpsaltes, Panteleimon Monastery of Mount Athos, cod. 1013, 1805 AD. Paper, 17.7x 11 cm, ff. 258.

system with melismatic bonds deriving from the underlying prosodic surface of the lyrics (Fig. 1).

2 Delta Characteristics, Statistical Analysis, Interpretation of Byzantine Music Notation and Synthetic Speech Reproduction

The Byzantine music system is a Delta musical system. Having an uninterrupted evolutionary course of about 15 centuries, it was reformed to an analytical system by two committees of the Ecumenical Patriarchate of Constantinople in 1814 and in 1881 [2, 4, 13]. These committees did not create a new musical system; they gave a more systematic approach to the underlying surface of the Byzantine musical tradition and founded the theoretical values of contemporary Byzantine music. Although their approach was focused on vocal ecclesiastical music, it engulfed the whole structure of Byzantine music. As a result, the Greek musical heritage, whether ecclesiastical or secular [14] has been transcribed to Byzantine music notation, its inherent notation. The symbols of this notation came out of the numerous symbols of the earlier shorthand-like notations, like those exhibited in Fig. 1. These symbols comprise the musical alphabet of Byzantine music, and as a whole they are described by the term *parasimantiki*. It should be noted at this point that references to Byzantine music are directed to the theoretical musical system of 1881 and its parasimantiki and not to the previous forms which in their overall majority have been compiled to parasimantiki. So, parasimantiki is a set of symbols that transcribe analytically the correct way for the interpretation and articulation of musical phrases [2, 13].

From what has been presented thus far, it is obvious that the Byzantine music scheme is a complex musical structure comprised of several music surfaces. Since its elements are idiomatic and do not correspond seemingly with Western music categories, its structure cannot be directly classified and interpreted with computational theories that have been applied to Western music sources. This has lead to empirical and heuristic approaches of its musical surfaces according to the technological status quo of the implementation period.

2.1 Statistical analysis of parasimantiki

This approach was historically the first that attempted to decipher the not easily penetrated world of Byzantine music. Pioneers in this field were Spyridis [7, 13] and Politis [7, 15]. These researchers used Hidden Markov Models in order to estimate the morphogenetic characteristics of the musical source they examined. The analytical

method they used was based on the computation of *entropy* over a zero memory source.
Entropy H was defined as [7]

$$H(p_i) = -\sum_{i=1}^{N} p_i \log_2 p_i \quad \text{in bits/symbol} \qquad (1)$$

where p_i stands for the appearance probability of the i-th symbol. Entropy is related to the mean value of the uncertainty, which characterizes the informative environment of the observer.

According to this method, estimating the entropic content of a melody is equivalent to seeking for the possibility of a note to appear after a given sequence of prevailing notes.

This approach had been applied successfully in Western music where the basic notion was musical surface(0), i.e. succession of notes. However, the adaptation of this method in parasimantiki had some serious problems that had to do with the modeling of the musical surfaces of parasimantiki. While in Western music analysis the predicate involved, the note, has by itself information concerning pitch and duration, in Byzantine music the symbols of parasimantiki form a Delta system denoting increment or decrement from the note implied by the previous symbol. The approach of Spyridis and Politis used three musical surfaces (Fig. 2) instead of the one used for Western music analysis.

They presumed that in parasimantiki there are three most important kinds of musical signs:

i. The quantity signs,
ii. The time signs,
iii. The quality or expression signs.

The *quantity signs* do not indicate a note of a definite frequency, but rather they indicate the number of steps that should be ascended or descended in the musical scale. This means that there is a definite starting note in each hymn, and all quantity characters show the development of the melody with respect to the 'basis', the starting note.

The simplest voice fluctuations are expressed by only ten quantity characters. By combining the above simple quantity characters about a hundred of complexions result. Consequently, with quantity signs all intervals can be formed, even the *compound* ones (the ones above an octave), although they are rare.

It must be noted that each simple quantity character or any complexion of characters lasts for only one musical time unit. This is not always the case, but it is the rule.

The *time signs* are placed above the various simple or compound complexions of quantity characters and operate on them altering their musical duration. However, there are cases where certain time signs can influence the time duration of the preceding or succeeding quantity signs.

The *quality* or *expression characters* are placed under the various quantity characters, they operate on one or two complexions or simple quantity signs and they indicate a manner of recitation, i.e. if the note implied by the quantity character will be recited emphatically, vividly or with voice trembling.

The analysis of Spyridis and Politis was confined to the dimension or surface of melody. For this surface, the three categories of signs were adequate enough. However, in parasimantiki there is a great variety of signs, the roles of which are various, aiming at the description of the precise development of melody. For example, there are many signs of alteration (sharps and flats) which increase or decrease the pitch of notes in an even number of Byzantine commas. (One Byzantine comma = $2^{1/72}$) [13]. Moreover, for the other dimensions or surfaces of Byzantine music, i.e. rhythm and harmony, there are specific signs which were not encountered at all since morphogenetic analysis is confined to the surface of melody.

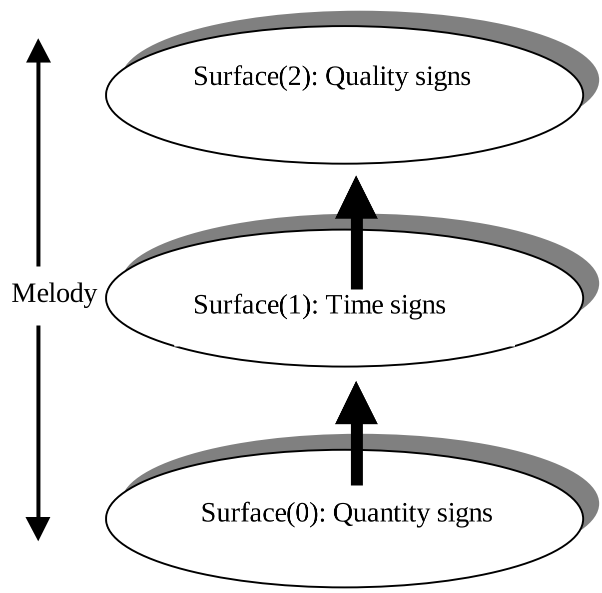


Fig. 2. Melodic surfaces of parasimantiki

The difficulty with the proposed methodology for the statistical analysis of Byzantine melodies was that an encoding scheme had to be devised that would serve as a human computer interface and in parallel it would be able to separate the three melodic surfaces. This encoding scheme was proposed by Politis [15] and has been the basis for all successive encoding approaches.

Implementing the Hidden Markov Model statistical method the statistical nature of Byzantine melodies was explored. However, the symbols of parasimantiki were perceived as statistical symbols and not as symbols that can produce music. More specifically: Byzantine music notation had been perceived as a combination of special symbols that have musical information (pitch intervals, timing and quality conduct). These symbols form sequences according to the rules and the behavior of a morphogenetic field. The rules of this field on parasimantiki were examined by analyzing the statistical behavior of sequences of Byzantine music symbols, and therefore *syntax rules* were deduced. The correctness of these rules was examined by a composition stage that produced synthetic hymn-like melodies. These melodies were acceptable according to the Modal behavior rules of Byzantine music [13].

2.2 Interpretation of Byzantine Music Notation as a Delta System

In the approach described in the previous section, the analysis scheme resembles the linguistic analysis performed on a certain language alphabet: grammar and syntax rules can be deduced but no accent or intonation information is encountered. Consequently, there was a need for a new frame for the interpretation and interfacing of the musical notation that could take into account the implied prosodic and musical information of parasimantiki.

In 1996 Politis, Tsoukalas and Linardis [16] proposed a new model: they took into account the human computer interface (HCI) context of Byzantine music notation and proposed an interpretation scheme that deciphers the melodic and harmonic context of parasimantiki to computer music predicates: scales, notes, alterations, exact frequencies, duration, and rhythm (temporal behavior).

The proposed model was formed taking into account the cognitive and psychoacoustic fermentation of a singer when he performs a Byzantine melody. Since parasimantiki is a Delta system, Politis et al. [16] used a Delta computational scheme which was a variation of an adaptive pulse code modulations system (ADPCM), the Delta modulation system. Based on this approach, the relation of Delta modulation and Byzantine music notation was designated and an encoding scheme was set up as a follow – up of the previous one [7]. This interpretation methodology lead to a simulation environment that has the following stages:

I. A *transformation* stage comprised of an *encoder* which transcribes Byzantine music melodies from parasimantiki to ASCII numerics, i.e. a computational model that transforms manuscripts like those of Fig. 1 to computer archives.
II. A *parser* that performs lexical, grammar and syntactical auditions over the computer archives in order to verify the correctness of the transformation stage.
III. An *interpretation* stage that incorporates a musical *compiler* which analyzes the computer archives of stage I and produces melodic information in the form of an ASCII file describing the mode, the implied note, the alterations, the exact pitch and the time duration.
IV. A *generation* stage that performs Byzantine music melodies.

The whole simulation environment was programmed in C++ and stipulated the transformation and interpretation stages according to the principles of pulse code modulation. The utmost part of the generation stage lead to an instrumental like reproduction of the melodic content using the PC speaker by computer programs acting as Byzantine music synthesizers. This is the goal of this approach: *to encode parasimantiki in a MIDI-like form and then execute Byzantine music scores in synthesizer mode.*

More specifically: the musical notation is considered as sequence of encoded symbols. The interpreter (whether he or she is a singer, a *psalt* or a synthesizer) has to decode them before he or she can perform them. So, the interpreter acts like the *decoding part* of the receiver in a PCM transmission system. Noisy transmission and loss of symbols is destructive in most cases and affects the *parsing* stage. In the simulation environment the equivalent of noisy transmission is the existence of erroneous Delta sequences.

This interpretation procedure of this method is described in Fig. 3.

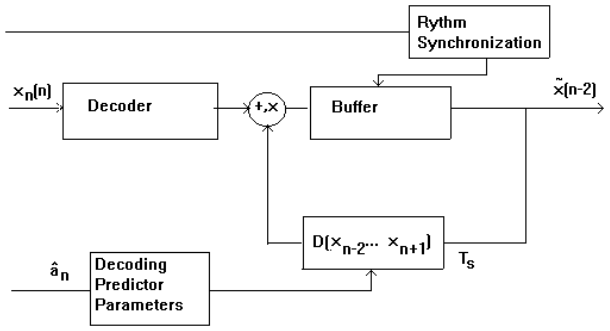


Fig. 3. Schematic description of the decoding process of Byzantine musical notation as a receiver of a Delta pulse coded and modulated signal.

The mathematical expression of the decoding process of the Δ modulator is described by (2). This relation describes the interpretation procedure for the n-th note of a Byzantine melody exported by the parser module and imported in the compiler module. As it has been explained in §2.1, since there are operators that expand their backward action up to two characters, when the n-th symbol arrives, the output of the receiver is actually the (n-2)-th interpreted symbol

$$\tilde{x}(n) = [\ \tilde{x}_n(n-3) + \text{sign}\,(x_n(n-2)) \cdot \Delta\,(x_n(n-2)) + \hat{a}_n\,] \cdot \mathbf{D}(x_{n-2},\dots x_{n+1}) \cdot \mathrm{Ts} \qquad (2)$$

and the n-th symbol is kept in a buffer until its time will come to be processed in the real time compiler. The evaluation of $\tilde{x}(n)$ is based on the adjustment Δ that the (n-2)-th symbol imposes on the note $\tilde{x}_n(n-3)$. $\tilde{x}_n(n-3)$ is the note indicated by the decoded sequence of signals that have arrived at the receiver 3 instances before the arrival of the n-th symbol. Δ is the increment or decrement of quantizer levels that the $x_n(n-2)$ symbol imposes on our quantizer. The increment at this interpretation stage is fixed in the sense that it merely implies an interval within a Byzantine music scale: a third, a fifth etc. However, in the generation stage, the distance of notes is variable, depending on the arrangement of notes within an octave of that scale.

The hold memory of the receiver will keep the deciphered information $\tilde{x}(n)$ of n-th symbol until the next two notes arrive in order to evaluate any possible operation of them on it.

For each symbol a duration T_s is perceived, unless this timing is altered by the timing operators. So, unless otherwise specified, the tempo or rhythm is T_s^{-1}.

With $\hat{a}_n$ are encompassed prediction coefficients inserted by symbols previously decoded and with

$$\mathbf{D}(x_{n-2},\dots x_{n+1}) \qquad (3)$$

a multiplication or cumulative vector operator operating on the residual memory (hold buffer) of the two previous notes is described. Also, in some circumstances time operators alter the timing of the notes that are bound to arrive. In such cases, operator $\mathbf{D}(x_{n-2},\dots x_{n+1})$ serves as a prediction coefficient.

The methodology of Politis et al. [16] proposed a robust and flexible musical interface schema for Byzantine music. Its impact can be parallelized with the introduction of MIDI protocol to the computer music society. The crucial point in this schema is the fidelity of the code in transcribing the Byzantine melodies (stages I-III). The stability of the synthesizer modules (stage IV) is related with the completeness and universality of the code. Since Byzantine music relies strongly on the oral tradition and on vocal performance there are many implied phenomena that the encoding scheme has to encapsulate and transcribe. Any incompetence of the code to describe lateral phenomena and side effects would lead to redesigning the interpreter part of the synthesizer. This is extremely laborious.

Another advantage of the proposed methodology is the disjunction of the interfacing stages (I → III) and the generation stage (IV) as is the case with the MIDI protocol. In this sense, the schema of Politis et al. [16] is a specification that describes a generalized encoding-decoding method rather than a concrete code. The intriguing point of this specification is its Delta nature.

2.3 The Voice Instrument Digital Interface of Byzantine Music

By having established an interpretation scheme for Byzantine music, the interfacing part with computers and digital instruments was drastically solved. However, since the Byzantine music paradigm is predominantly vocal, there was need for a voice add-on to the existing interfaces that would incorporate accent and intonation models for vocal reproduction. Such an extension was proposed by Politis Tsoukalas, Linardis and Bakalakos in 1997 [17]. The proposed system used the Δ modulation interpretation scheme [16] in conjunction with the SKINI (Synthesis toolKit Instrument Network

Interface) [18] physical model specification, a state of the art real-time synthetic voice program running on a Silicon Graphics SGI O2 workstation. Although a previous effort [19, 20] had modeled adequately well the Greek female singer attributes in a NEXTStep environment, the SKINI interface was able to offer male voice synthetic reproduction in an ample programming environment, that of SGIs and Windows.

More specifically:

The VIDI module is an end to end software system that had enabled for the first time a computer user to compose a melody with lyrics in Greek and then to hear it using an SGI O2 real-time synthetic singer. In order to do this, the VIDI implementation that was presented in the 1997 International Music Conference had the following modules:

A. A visual editor, the first of its kind, that enabled the composition of Byzantine music melodies in drag and drop mode (Fig. 4). The editor was equipped with a rule based engine that enabled the formation only of meaningless complexions. This enabled computer users with no previous knowledge of Byzantine music to compose syntactically acceptable melodies. In the bottom line of the composition canvas for each complexion lyrics could be added. The version of the editor presented in ICMC accepted only Greek morphemes.
   When the melody was composed, the editor saved it according to the encoding methodology of Δ modulation, in augmented form in order to take into account the intonation assertions of the quality symbols [17].
   The whole module was programmed using Visual Basic and was running on Windows thin client PCs.

B. A Byzantine music compiler, programmed in C++. This command line module could be invoked either by the visual editor or standalone and parsed and interpreted encoded Byzantine music melodies materializing a Δ modulation receiver-decoder. The deciphered information was saved in ASCII file format. Although the compiler relied on the previous version [16], new features were added improving its robustness in handling time and quantity events, in parsing lyrics and in transcribing morphemes to SKINI notation.

C. The interconnection between the SGI server and the Windows client was done via TCP/IP sockets. A small client program opened a socket on the server, binded it on a local IP address and 'listened' for connection on a predefined port. Via this client/server network the compiled information could be transferred to the synthetic singer.

D. A real-time synthetic singer running on an SGI O2 workstation. The singer module was comprised of a main control program which accepts the SKINI code, parses it and feeds it in the main synthesizer routine. This routine used a physical modeling approach [18] to synthesize the corresponding phrases using the data coming from the server and a set of glottis and shape files created by the SPASM software [19]. The glottis and shape files were created beforehand in such a way that they preserve the articulation and phonation parameters of the Greek language. Additional sets of these files were created extending the work of the IGDIS project [20]. The control parameters of the physical model synthesizer routine were carefully chosen to reflect the case of a male Byzantine speaker/singer by extending the length of the vocal tract since the original model used in IGDIS was that of female singer/speaker.

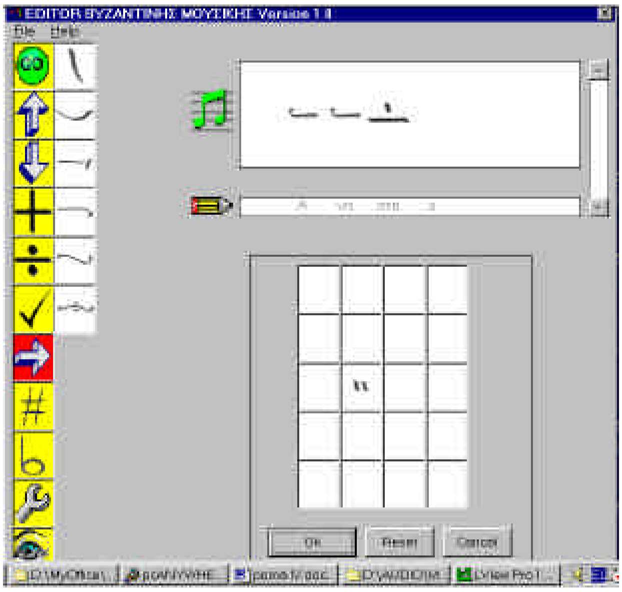


Fig. 4. The visual editor for the VIDI synthetic singer.

2.4 Synopsis of the D interpretation schemes for Byzantine Music

In all the computer processed features of Byzantine music surfaces, an encoding methodology was necessary. Although the proposed encoding schemes were based on the simulation of parasimantiki with a Delta modulation method, nevertheless they did not have the same depth. By depth we define rather an *arity*, an ability to engulf musical surfaces than merely a complexity of the implemented code. This means in simple words that when analyzing, when parsing or when performing with synthetic voice realizations the success of the method does not depend only on the performance of the tool that will be used but on the dimensions or surfaces of the Byzantine music paradigm that will be superenciphered.

In the previous subparagraphs two schemes with different arity were used. Both produced very good results and have smoothed the ground for a future universal specification, perhaps in conjunction with the widespread MIDI protocol.

3 Hardware Implementations

In parallel with the efforts to produce a synthetic singer that can perform adequately Byzantine music melodies, efforts were made to design instruments that can exactly perform the intervals of Byzantine scales. In this field pioneer is the work of Mastorakis et al. [21] which have produced a piano-like electronic instrument that can be tuned up according to the microtonal distribution of Byzantine music. The flexibility of this approach was that not only Byzantine music but all relative musical forms could also be performed, provided that the piano-like keyboard interface of the instrument is suitable.

3.1 Microtonal scale distribution

In all musical systems, the concept of scale is based on the distribution of specific notes within the space of an *octave*. An octave is the space from f to 2f, where f is an arbitrary frequency. The human ear perceives not the exact frequency of a note itself but the logarithm of f. Therefore the octave is the space from $\log_2 f$ to $(\log_2 f)+1$. The placing of the intermediate musical sounds from f to 2f or equivalently in the logarithmic scale from $\log_2 f$ to $(\log_2 f)+1$ yields the so-called musical partition.

The European Music System accepts the partition of the space $[\log_2 f, (\log_2 f)+1]$ into twelve equal parts: $\log_2 f$, $(\log_2 f)+1/12$, $(\log_2 f)+2/12$, ..., $(\log_2 f)+12/12$. Each space has a “logaritmic” range of 1/12 or equivalently it corresponds to a frequency ratio of $2^{1/12}$. In music this space is known as a semitone. Two successive spaces constitute a tone. Such a division of an octave forms the chromatic scale of the usual Western or European Music System. The chromatic scale is the most discrete in intervals partition of an octave pertaining more intervals than the diatonic (major, minor) scales that are usually used. If we refer to the modern fixed-pitch musical instruments that are tuned according to *equal temperament*, the scale distribution of Western music consists of the domain [C, $C^\#$ or D^b, D, $D^\#$ or E^b, E, F, $F^\#$ or G^b, G, $G^\#$ or A^b, A, $A^\#$ or B^b, B].

The music system, which Byzantine music follows since 1881, accepts the partition of the octave into seven notes, like Western music, but their alterations can create a variety of intervals between two successive notes. Furthermore, the positions of the notes within the space of an octave are not fixed, but they depend on which music mode is used. According to the 1881 Patriarchic Music Committee, the octave space $[\log_2 f, (\log_2 f)+1]$ is portioned into 72 equal parts $\log_2 f$, $(\log_2 f)+1/72$, $(\log_2 f)+2/72$, ..., $(\log_2 f)+72/72$. Each space has a “logarithmic” range of 1/72 or equivalently it corresponds to a frequency ratio of $2^{1/72}$. In Byzantine music this space is known as a “particle” (“morio”). Therefore six successive particles constitute a semitone. However, it is known that the Patriarchic Music Committee of 1881 defined as a minimum audible space the space of two successive particles. Therefore, the partition of the space $[\log_2 f, (\log_2 f)+1]$ is a partition into 36 equal parts: $\log_2 f$, $(\log_2 f)+1/36$, $(\log_2 f)+2/36$, ..., $(\log_2 f)+36/36$. Each space has a “logarithmic” range of 2/72 (i.e. 1/36) or equivalently it corresponds to a frequency ratio of $2^{1/36}$. This space is equivalent to two particles. The music of other Oriental Civilizations follows more or less the Byzantine music system [22].

According to what is mentioned above it is obvious that the European Music System interposes 12 notes in an octave space, while the Byzantine one interposes 36 notes. Therefore a usual Western musical instrument has to divide its semitone into three equal parts (in the logarithmic scale) in order to produce the fundamental space of the Byzantine music which is equivalent to two particles. It is obvious that the thinner partition of the octave does not set the European system aside but it expands it in a simple manner. Actually, this was the principle of the construction of the Electronic Instrument of the Byzantine Music (EIBM).

3.2 Implementation: the Electronic musical Instrument that accurately produces the spaces of Byzantine Music (EIBM)

EIBM implementation is described schematically in Fig. 5. The musical interface adopted is that of keyboard instrument, therefore the first block of the instrument is a keyboard controller.

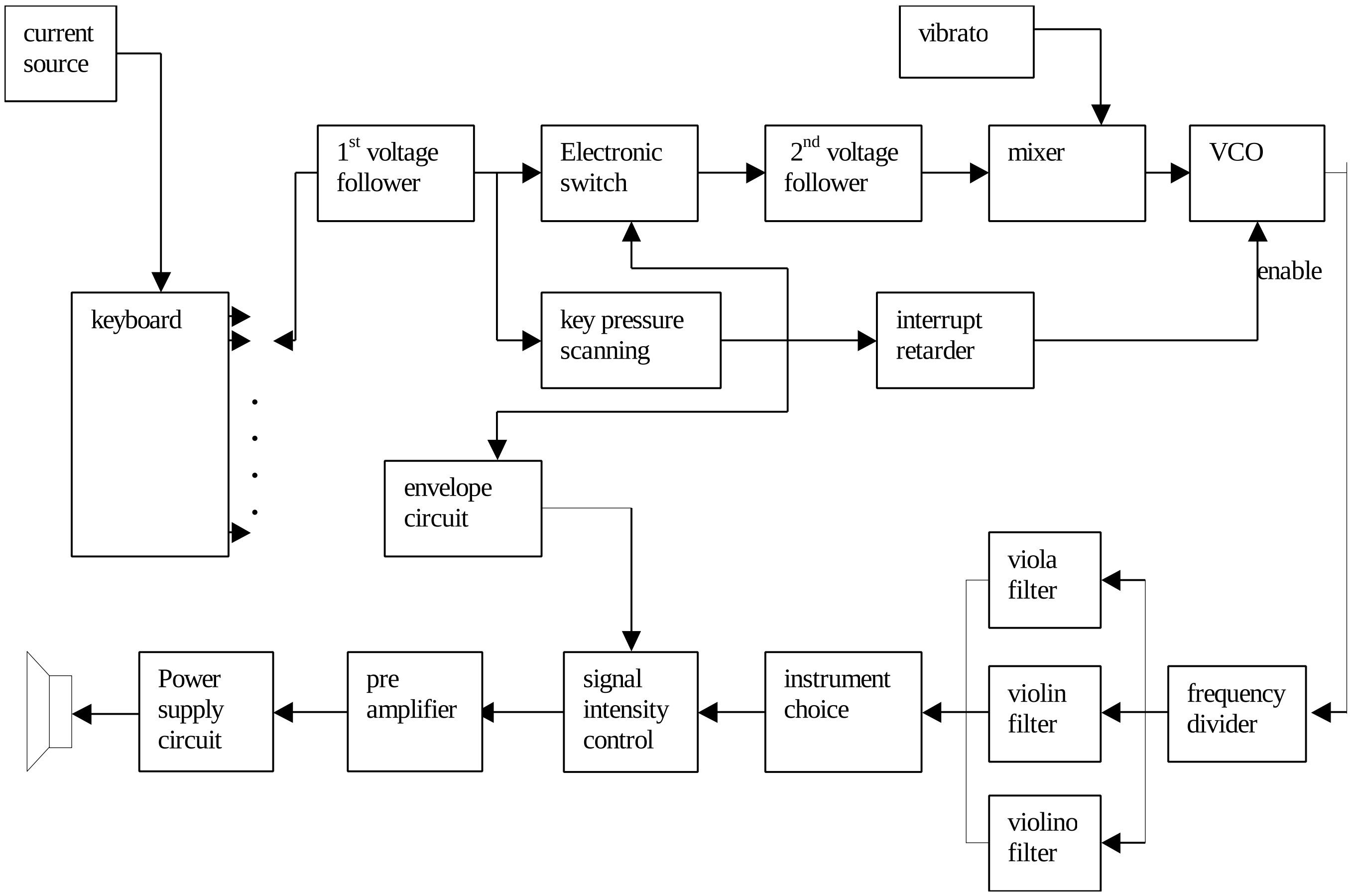


Fig. 5. EIBM schematic diagram

By pressing each key of the keyboard unit, the desired frequency is produced by the Voltage Control Oscillator (VCO) unit. This is done as follows: A current source supplies the successive keyboard trimmers of constant current. When a key is pressed the first voltage follower receives the voltage of the corresponding key as input. The output of the voltage follower is connected with an electronic switch and with the key pressure scanning. Therefore, when the pressure of a key is scanned, the electronic switch turns off and the keyboard voltage is directed to the second voltage follower. But at the same time, the output of the key scanning stage enters the input of the interrupt retarder unit. This signal activates the unit to send an "Enable" signal to the VCO. Then the Voltage Controlled Oscillator stage starts working.

The key pressure scanning unit acts as a co-ordinator unit:

- it signals the press of a key. This prevents the instrument from functioning due to false or noisy signals,
- it prolongs the function of VCO via the interrupt retarder unit,
- it enables the envelope circuit stage, which will operate before the VCO.

The envelope circuit will produce an "attack" stage in the signal intensity control unit that will feed in the pre-amplifying unit gradually. This means that the signal in the input of the pre-amplifier is not directly transmitted to the output but the waveform begins from a zero range and a linear increase (up to the level set by the regulation of the preamplifier) is observed. In this level it stays as long as the pressing of the key lasts (the "sustain" stage). When the key is released, the signal is not immediately cut off but shows a linear decrease again till its final elimination (the "release" stage).

The heart of the instrument is the VCO. In this unit, a key pressing is equivalent to a voltage, the precise value of which defines the oscillator frequency.

A frequency divider is also needed for the division of the frequency of the oscillator in order to produce lower octaves for the production of the notes of various instruments. This is achieved by the suitable composing of the fundamental frequency of the oscillator and its subtwice.

Since the VCO produces square waveforms, the output of the oscillator should be modulated with proper filters. The modulation is needed since sound of different instruments (of suitable timbre) should be produced and the tones should become melodious.

However, a specific frequency and an assigned instrument timbre are not enough in order to produce a note. The acoustic signal has to be enriched by a "vibrato" effect, i.e. a rapid regular fluctuation in pitch.

For example, the "vibrato" effect can be heard in cello by making the suitable move of the finger around the pressure point of the string, for the production of the desirable sound. Then the string oscillates in quite similar frequencies to the one which has to be produced. In this way a pleasant acoustic impression is achieved and this is the reason for which the present instrument was given the capability of producing the "vibrato" effect. As far as the frequency is concerned, vibrato is its variation round a central frequency (the one that corresponds to the produced note). In other words it is the modulation of the oscillator frequency by a very low frequency. For this effect there exists a different oscillator of regulated amplitude and regulated frequency. The amplitude of this oscillation defines the "depth" of the vibrato, while the frequency defines its "velocity".

In order to achieve the modulation of the oscillator's frequency, a mixing of the continuous voltage (which is determined by pressing a key) with the low frequency of the "vibrato" takes place. For this reason there exists a mixer, which is, in this case, a common resistance divider. The vibrato fluctuation itself is produced by IC LM555 which produces triangular voltage of low frequency, the range and frequency of which can be altered in order to achieve the desirable velocity and depth of the vibrato.

For the driving of the modulated output signal there exists a pre-amplifier, which is a voltage amplifier having a high input resistance, so that the previous circuit is not charged. There is also a power amplifier which further amplifies the signal and has a low output resistance for the driving of a speaker.

3.3 Synopsis of the hardware implementations of Byzantine music

The hardware implementation of EIBM is an attempt to fill in the gap that has been created since the collapse of the instrumental heritage in Byzantine music and can be considered as the successor of *organ* of Byzantine era. In recent times, various industrial electronics kits have been produced in Greece aiming in adding *homophony* to a solo singer. They achieve this by producing a vocal like timbre in the pitch of basic Byzantine music notes. However, they cannot produce melody with the intervals of parasimantiki. Within this framework, the EIBM is a brilliant instrumental standpoint for the proper production of Byzantine music melodies.

4 Conclusions

Until some years ago the world of Byzantine music was impenetrable for those but the few that were trained in this esoteric musical scheme. The only channel in presenting Byzantine music was by transcribing Byzantine melodies to European music notation and using software and hardware tools like editors, composers and synthesizers for its diffusion. But this would lead to loss of information due to the different approach in coding musical phenomena. Furthermore, Byzantine music focuses more on vocal performance and articulation and not on instrumental execution. As a result, its engineering strategy has adopted language engineering methodologies and possesses a more thorough inscription mechanism for the correct vocal performance. In this direction, the software and hardware systems presented in this paper constitute a colossal leap for the propagation of Byzantine music in the evolving information society.

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