A System for Neural Acoustics Analysis

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Abstract: We are presenting details of a system for acquisition and analysis of neural signals, demonstrate it in operation and give nice application examples.

1   Introduction

Our **SMARTA** - systems for signal (acquisition), monitoring, archiving and real-time analysis of biomedical signals - consists of the following components: sensor / sensor devices, interfaces, analog-to-digital converters / devices, computers, and software that supports the functions of the entire system.

Variants of such systems are widely used in medicine. Their offer and applications are constantly growing all over the world thanks to advances in technology in the domain of digital signal processing (DSP), and thanks to software with a built-in powerful mathematical apparatus that enables analysis and insight inaccessible earlier. All that affects directly the expansion of medical knowledge and standards.

The result of our efforts were highly integrated, high performance SMARTA systems intended, first and foremost, for medical examination (computerized EEG system, ultra-fast neurologist system, cardio + (invasive) pressure analyzer, a system for acoustic examinations, an independent real-time spectroscope, CTG cardio-tokograph). They are also useful, with or without some add-ins or changes, for clinical work. The possibilities of our systems do not lag behind the possibilities of similar systems of renowned world manufacturers of medical equipment. Our clinical/research systems include:

> Integration of clinick DSP networks.

> Computerized EEG.

> Local neurological network obtained by linking all EEG and neurological testing and monitoring devices into a local area network of a clinic.

Computerized ECG.

Local cardiological network obtained by linking all cardiological monitors with the central computer and with a local computer network of a clinic. This provides the distribution of all signals to separate systems for archiving, monitoring and analysis (continuous archiving, monitoring of a patient's state - nurses, a copy of monitoring of a patient's state - a doctor on duty, analysis when required).

Computerized CTG cardio-toko-graph for gynecological-obstetric clinics:

all CTG devices are linked to the central computer, that provides local and remote monitoring, signal archiving and analysis.

A simpler architecture includes the following elements:

- a number of similar or different acquisition devices with analog

  (eventually digital) output,

- interfaces,

- AD converter,

- computer,

- software to support the required functions.

A simpler architecture may be extended into network applications where separate system functions are distributed to a network of computers.

A more complex architecture has embedded DSP computers in place of (elementary) AD converters in a simpler architecture; software is also split into several levels. By distributing processing in this way, a multi-channel entry is implemented (we have implemented a 256-channel input), with a transfer of greater capacity; numerics required for analysis is distributed to multiple processors; the possibility of using 3D graphics on the required number of monitors and real-time processing (using the methods for the real-time detection / prediction of significant states).

Side expansion of a more complex architecture provides cheap supercomputing and embracing an arbitrary number of acquisition channels, with monitoring, archiving, and real-time analysis and graphics. In complex architecture the most sophisticated part is software, which is distributed in the network of accessible processors of various applications. Systems of that kind of architecture are quite new, they have just come into existence, and cannot yet be found in the world market of medical equipment. In the immediate future we are likely to witness explosive expansion of this concept in all domains in general and in medicine in particular.

We work on systems with a simpler and a more complex architecture.

Presently we have 5 generations of signal processing systems. Their natural evolution mirrored the accelerated development of computer technology performances in recent years.

The significance of signal spectroscopy for the analysis of ECG + blood pressure signals and EEG signals is generally recognized, which is confirmed by recommendations of the American Medical Society in 1999.

Our software contains a great number of built-in tools that we have been developing for years. They enable the users to define the system according to their requirements, as well as to control all parameters in all available algorithms. Complete real-time visualization of all procedures is available, including top quality 3D graphics, which guarantees improved insight into all significant details and at the same time makes the work easier.

The system also contains a complex calculator that enables operations on signals, their derivatives, spectra, wavelets, as well as operations with 3D structures. Signals and all structures can be stored, or exported to some other software of an arbitrary origin, they can be printed or sent via the network. Ammong some interesting applications presented at our web http://www.gisss.com I will briefly discuss 'cardio'.
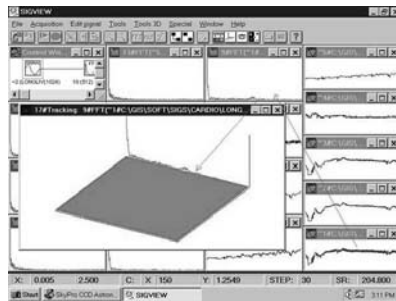

Figure 1   Figure 2

Fourier spectra and 3D spectra of the signals in the cardio experiment

Figures 1 and 2 present ECG and blood pressure signals of two participants of the experiment, signal spectra, and a 3D spectra of pressure signals of the participants. It can be observed that some spectra contain a noticeable line in the middle of the range, while others do not. By successive calculation of spectra in the course of 90 minute experiment we have observed that the characteristic spectrum line (the respiratory line) present in the blood pressure of one participant of the experiment, oscillates slowly in intensity and frequency (Figure 3 and left half of Figure 4), with the rhythm cca 2mHz, but it is not observed in the other participant's spectrum. In Figure 4 we can see spectral presentation of the entire 90 minute experiment: the left column contains signal spectra of the upper and lower blood pressure and of ECG of the participant with the spectrum formation in the middle

of the range; the right column contains the same signal parameters of the second participant. Time is presented from left to right, frequency from bottom to top, intensity is color-coded, from dark to bright.

The end of the experiment coincides with the death of the right participant, while the left participant continues to live. The experiment was carried out on rats with hemoragy, loosing 1/3 blood volume each, the left recieved injected vasopressin. It can be assumed that the presence/absence of certain spectrum structures points to the appearance of some vital crisis, that is why similar observations and early detection of characteristic spectral forms might be of special interest for humans.
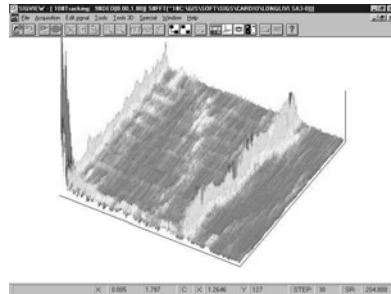
Figure 3

3D spectrum with a clearly expressed respiratory line that also oscillates around the main frequency in a very slow rhythm -- 2.5 mHz
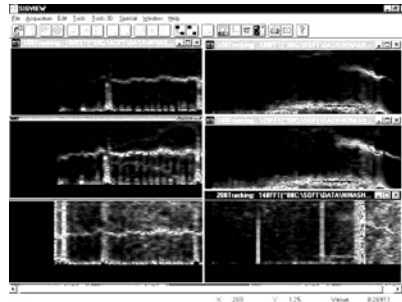

Figure 4

Left: spectra of the 'normal' participant of the experiment

Right: spectra of the dying participant

Horizontally: time

Vertically: frequency

Intensity is color-coded

2 EKMO -Eine Kleine Musikalisches Opffer -towards the Real Time Recognition of Brain Inner Music

EEG science is filtering everything beyond 30-40 Hz, claiming that EEG signals contain frequences in the 0-30 Hz range and that everything beyond should be attributed to muscular activity and 'artefacts'. Obviously, the filtered signals are simpler and thus 'nicer' and easier for classification and determination of neurophysiological pathologies. I wanted to identify music in the brain and very little of it is bellow 32 Hz, even more: nobody sings nor thinks music that low. Hence, no matter how nice the filtered signals might be, we know that after such filtering all music is filtered away too. Fortunately, the old EEG had switches for filters, so we could do the experiments with deactivated filters (switch 1993/1994). Obviously immediately we got all sorts of noise present in recorded

signals. Much worse than that, the target components – music part were by >= 2 orders of magnitude weaker than the energy part (=low frequences) of the brain signals. Still worse, after a sequence of tests of the equipement, it was clear that everything is in resonance, hardly leaving a chance that we could expose a subject to music and record the music from the brain, not just all artefacts. If that were our aim it would end in final dissapointment right at the beginning. Besides those transient aims, our main goal was still a little more subttle: to identify the inner music.

Inner music is the music in our spirit of rather inner origin. When we hear music in a dream or imagine it in all it's complexity, it is inner music. When singing/wistling aloud we first generate inner tone, then pass it to the peripheral device to generate it externaly. The most complex reasonable music is a sequence (array) of linear combinations of individual tones (harmonies), each of which is a linear combination of Fourier basis (harmonics for coloring). Hence, the identification of inner music is reduced to the identification of its atoms – individual inner tones. Inner tones are still more hidden by the brain than the externaly generated tones, being usualy weaker by at least an extra order of magnitude than the percieved tone representation. Beside being very weak and very hardly detectable, they have some nice properties:

- they could be easily will generated (WGCC – will generated Chidaksch contents),

- being properly inner they are not accompanied by all sorts of resonances and artefacts in the registration equipement,

- they are broadcasted to broader brain areas, thus offering better chance for extractions,

- tones being atoms of music: ability to record individual tones expands to the ability to record the most complex music in the brain; in this way very complex will generated mental contents become completely real tilme detectable and recordable, thus reproducable, opening room to investigate eg.

- music telepathy,

- a new class of 'brain-computer' interfaces.

The above list determined demands on the needed DSP system: multychannel, high resolution, (multy) 3D spectroscopy with complex numerics, all in RT (real time). Our expanded 5th DSP generation will quite satisfactorily satisfy the demands. Based on the advanced technology of Innovative Integration, the family of highly efficient embedded DSP computers, our 5th generation reached megasample acquisitions, distributed numerics, networking, high speed 3D multygraphs, expanding with paralell high resolution spectra.

Yet in early 1994 after replacing the rat in the music-tones experiments with a suitable musicologist (Katarina Tomašević from Musicology Institute of Serbian Academy od Sciences and Arts) we made first positive moves. Namely, after tremendous quantity of artefacts in the recordings of externaly originated tones, I sugested to the experimented lady to try to generate some inner tones, one by one, after external calibration and subsequent external sound silence. In her signals, after a thousand hour analysis with our primitive signal analysis software from that time, I discovered inner tones that were imaginated and not produced aloud. After that we repeated the tone imagining experiments with a partial success.

Here is a little of that experimentation. Inner calibration was performed first: for a fiew seconds the tone that was to be inner-repeated was played by electric organ. Then the organ stopped and after a short pause the experimental subject concentrated to the calibrated tone, was singing inside the same tone. Experiments with recordings were repeated for approximately .5 hour, then changing the subject. Some people had difficulties. Some were champions.

We give some relevant brief description of this work, showing the (later) working environment together with our experimental material. Figure 5 shows RT voice recording with the accompanied spectrum, the dark band selects a portion of spectrum 500-545 Hz, negligible. The inner tone D2 spectrum, with the 500-545 Hz band dark selected, Figure 6. Its 3D view (spectrum segment 500-545 Hz) on Figure 7 shows no interesting features. Channel #0 (out of 8) in the recording of the Inner C2, with marked 524 Hz frequency shown in Figure 8.
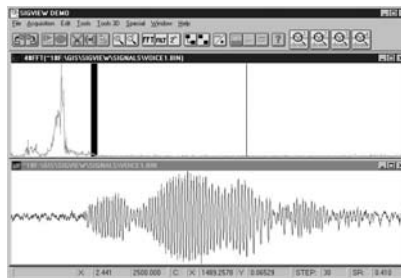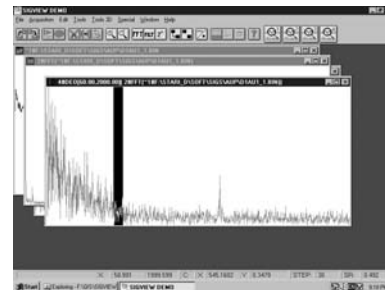

Figure 5
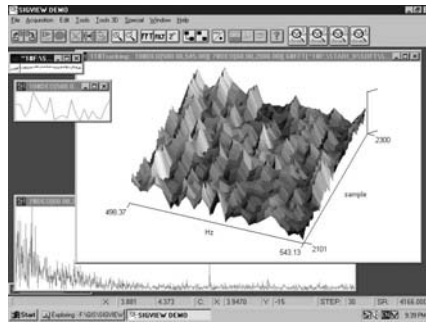Voice recording

Figure 6
Inner D2, marked 500-545Hz

Figure 7

Inner D2, 500-545 Hz region of it's 3D spectrum
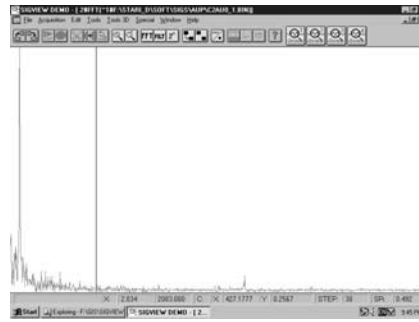

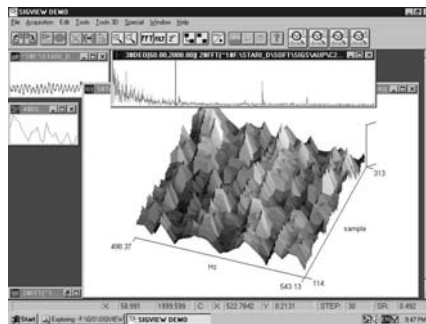
Figure 8

Channel #0 – Inner C2, marked 524 Hz

Figure 9

Channel #0 of Inner C2, 500-545 Hz

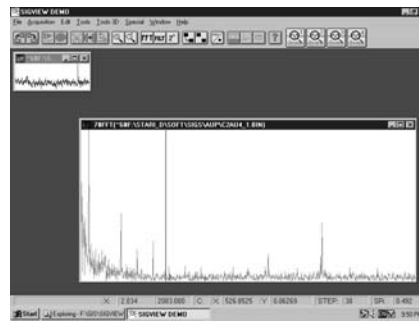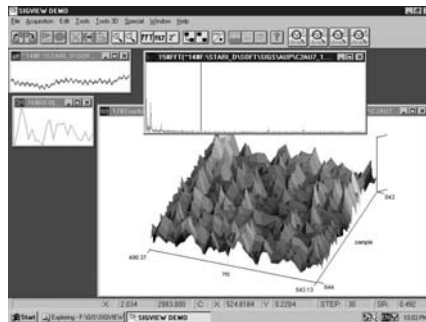
Figure 10

Channel #4 of Inner C2, marked 524 Hz

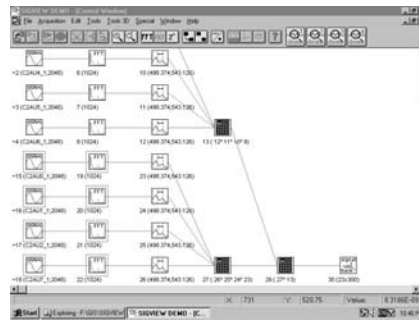

Figure 11

Channel#7 of Inner C2, 3D spectrum, 500-545 Hz
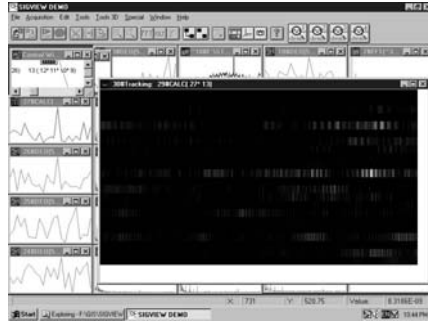

Figure 12

Inner C2, involved system components

Figure 13
Inner C2, coordinatevise 3D spectral product, all channels 500-545Hz showing almost no descernible feature, just one small ping
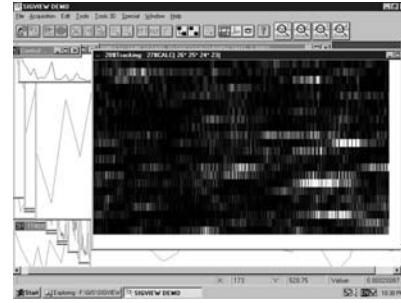

Figure 14
Inner C2 coordinatevise 3D spectral product of input channels corresponding to the 4 frontal and the top-frontal electrodes, showing C2 line together with other things
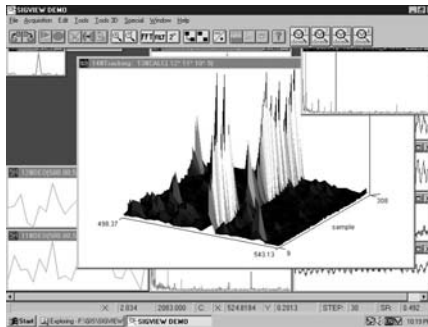

Figure 15
Inner C2, coordinatevise product of 3D spectra, 500-545 Hz of lateral and the top lateral channels, showing beautifuly extracted Inner C2 tone
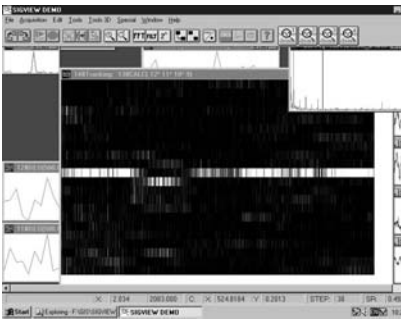

Figure 16
The same as on picture 25. composite 3D spectrum top view, close to being packed into musical scores (RT)

In this way with Chump we made historic recordings (here the Inner C2 of mine - early 1994), with the successful extraction of Inner tones, after inspecting thousands of thousands of brain signal spectra (thus involving calculations of billions of Fourier coefficients), with nice evidence of simple WGCC, in early 1994, all promising that more and highly complex (musical) WGCCRT recognition would be possible in early century, opening room for other sorts of WGCC. Some applications of these ideas and technics are clear. One more: children with distorted music hearing would have a chance to learn how to see/hear/sing the tones sharper when they see in RT what intervals they do not distinguish well.

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