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Brain Computer Interface - some technical remarks

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Abstract. We consider some grafic and computational aspects of BCI's - Brain Computer Interfaces, which could be of importance in the training of users and exploitation by uesrs, in the future system learning and acquisition and mapping of the important events and knowledge. The current systems transfer rates at the BCI are estimated, proposing potential accelerations by use of inner tones and melodies.

Keywords: Brain Computer Interface; 3D Brain Structured Graphics; Real Time Capacity; Inner Tones and Music; Neuro Acoustics;

1. Introduction

The fast development in the area of brain computer interfaces – BCI, which was either SF or heresy 15 -20 years ago, has become a technical field today. It is exciting reality that people can be easily trained to turn on/off variety of appliances and systems in their environment and maintain continuous control of complex systems by simply controlling brain inner mental states by their own will. With the new accelerated developments of all segments of technologies and research involved, the BCI is quickly growing with the hardly predictable limits. Reported exciting successes of a number of researchers [Babyloni et al., 2007; Cincotti et al., 2002; Kenedy et al., 2000; Donaghue, 2002; Schalk et al., 2004] is offering promises for substantial change in self support abilities for the people with hard handicaps, with hopes to build technical bridges over their functional problems and improve their life quality. On the other hand, this beginning is marking a shift for the whole culture, opening new hopes for the bidirectional BCI's that will enable brain to brain direct communication and hopefully cognitive function share by means like now days electronic conferencing; imagine future collective inner brain music performances and collective constructions of e.g. mathematical objects and proofs, using common mental screens like blackboards now days? We shortly discuss functional 3D graphics for BCI - brain structural real time presentation and BCI based on low and higher EEG frequency domains. All our methods and software were developed in conjunction with the needs of our colleagues, mainly from the Institute for biological research in Belgrade.

2. Real time 3D graphic interfaces in BCI

Real Time – RT graphics of BCI that will support both training of potential users with the monitoring of their activity when using the BCI and more precise functional mapping in the forthcoming research, beside monitoring of E/MEG signals, spectra, derivates, should include the RT brain model visualization as well, combining suitably the graphic presentation of all experimental data and related brain activity.

We have developed systems that combine diverse sensors inputs into user controlled functional color fusions. Originally developed for UV microscopy, it found a nice use in the astronomy, fusing data from radio telescopes, optical instruments and X-ray orbital observatory. Also it has a nice application in forensics. The system merges monochrome inputs, by allowing previous monochrome preprocessing, then input alignments, and generating the RT gallery by different color indices that could turn some invisible relations into perceptible. We illustrate its use on the example of fMRI, monochrome combinations, as shown on the Figure 1. This is a 2D situation, but the method would work on 3D structures equally well, if needed, with extra alignments. Beside translations, we could add rotations, zooming and even controlled inflations/deflations.

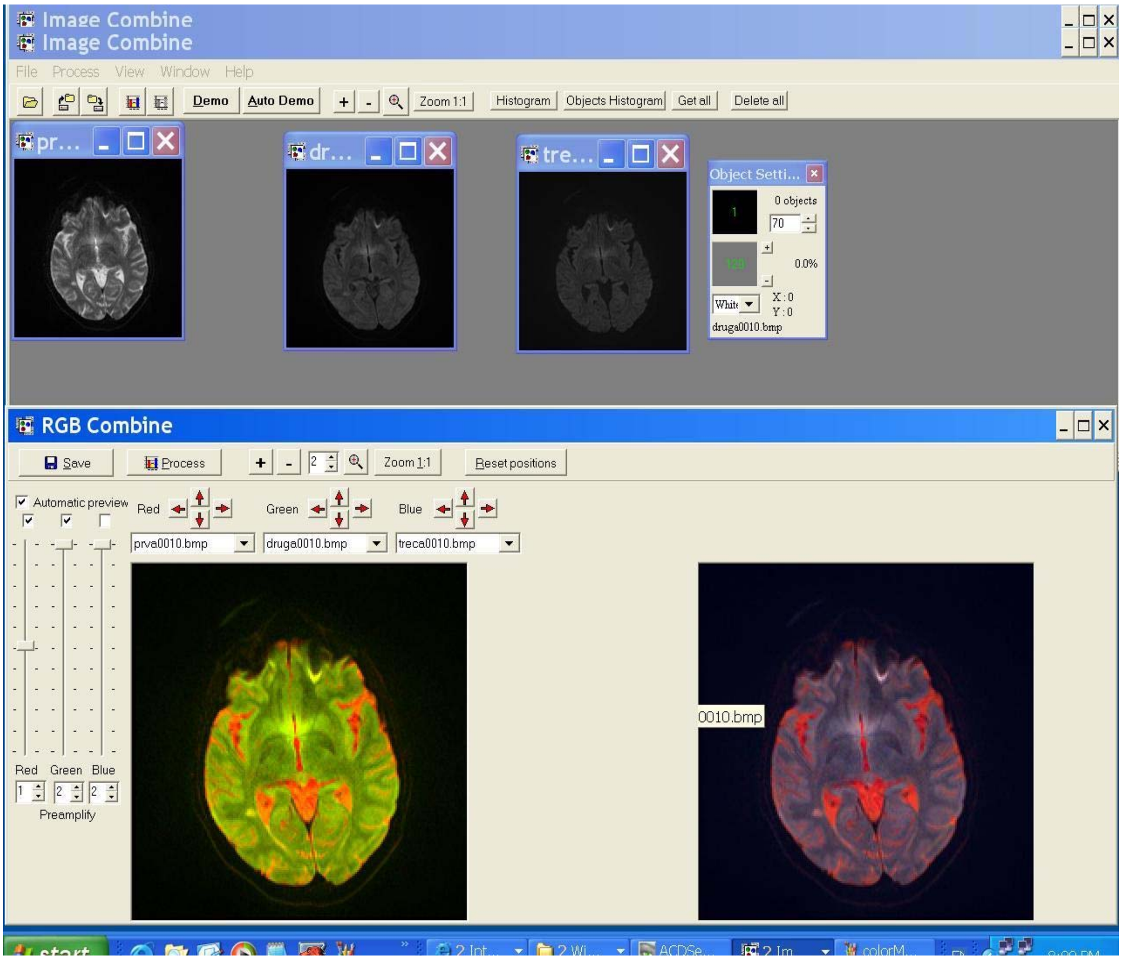


Figure 1. *Illustration of our color fusion method: here the initial fMRI monochromes are combined into a user controled color balance fusions that would provide additional structural information and insights. This method is applicable on 3D structures, with inputs of alternative origin.*

The 3D digital model of brain is becoming necessity. That would incorporate all digital brain morphologic and functional structuring. We believe the transparency and translucency should be used to support the comprehensive insights into the active areas, as it has been in broad use in the entertaining industry and building design. The coloring fantasy in the representations of brain structures should provide effects which are suitable to enhance the capacity to perceive relative geometries of involved structural components and subsystems. The 3D navigational commands and light sources controls with morpho metric tools should be completely real time – RT.

Digital 3D brain models should provide functions for automatic data acquisition and precise functional mapping - into the digital layers of brain physical and functional spaces, from the sensors used, with the individualization of acquired brain 3D image. That would open ability for automatized comparisons of physical characteristics and changes with the data based standards and classification of the deformations and malfunctions. We have developed methods for analysis and comparisons of CCD chromosome images, with automatic detection, extractions, normalizations, with detailed RT 3D fully navigable, high resolution, photomorphology, some of which is shown on the right part of the Figure 2.

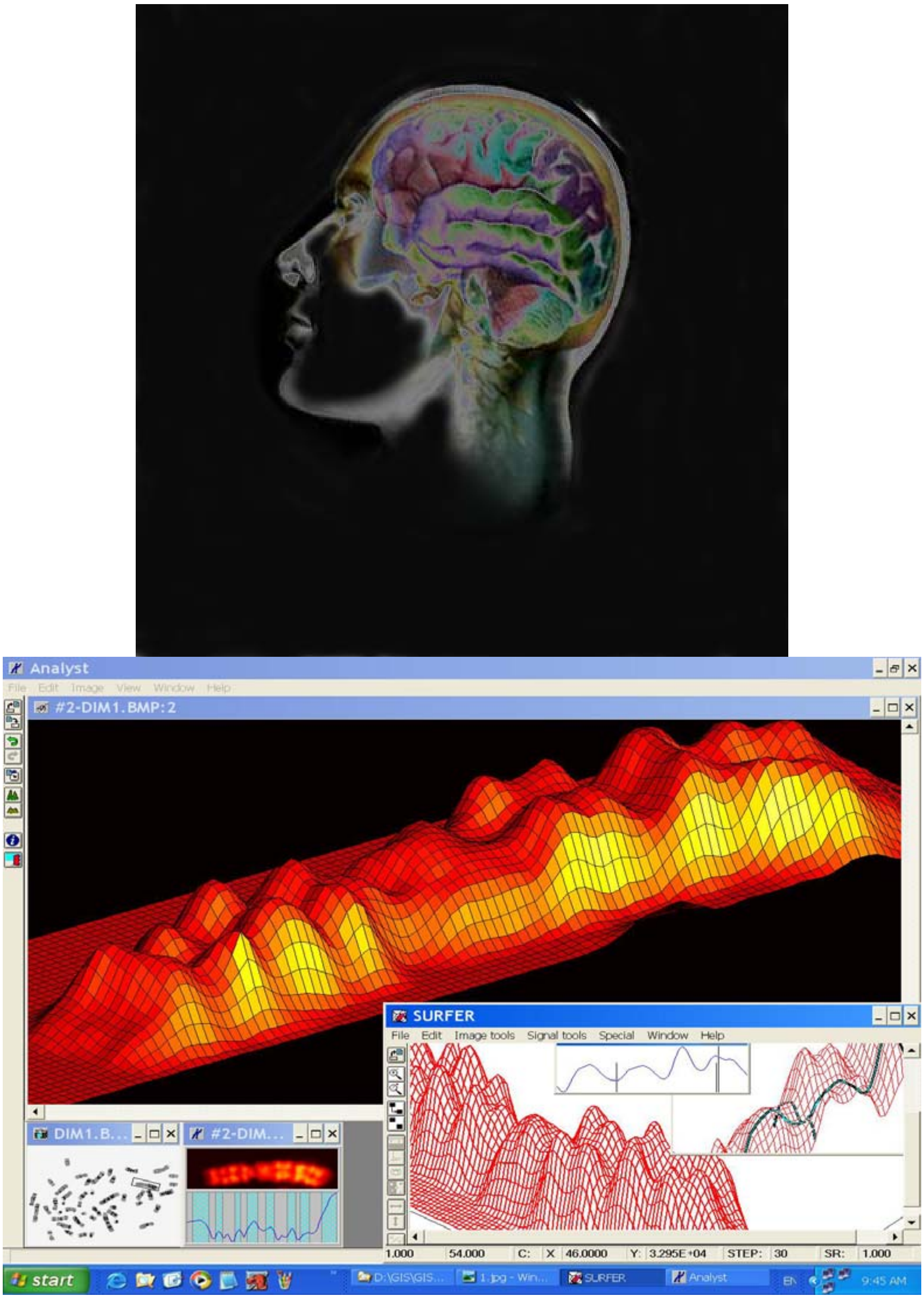


Figure 2*. A nice brain model, which should expand into a 3D digital model, like our developed 3D fully 3D RT navigable photo morphology analyzer for chromosome analysis and gene addressing.*

Working with the 3D laser scanner, we developed solutions for the detection and reconstruction of 3D objects and manifolds and their optimized visualizations. We believe the examples of jelly fish in the Figure 3. offer the idea how reach the real time visualizations of brain activities might be.

Figure 3*. These jelly fish models give idea of how to implement a 3D digital brain model, which should support digital structural layers, RT controlled transparency of visualizations, 3D navigation.*

3. BCI – some DSP aspects

When $B = \{ x_i \mid i \in I\}$ is an ortho normal base of the Hilbert space *X*, then the Fourier coefficients of the vector $x \in X$ are calculated with $\hat{x}_i = (x, x_i)$, $i \in I$, where (*x*,*y*) is the inner product of vectors *x* and *y*. The $\hat{x}_i$ are projections of *x* to the base vectors x_i, $i \in I$. The Fourier development of the vector *x* with respect to the base B, is given with the formula

$$x = \sum_{i \in I} \hat{x}_i x_i \, .$$

The sums are always at most countable, no matter of the size of I and all orthogonal bases are of the same size, the orthogonal dimension of the space *X* is in practice countable. When the elements of B are the well known trigonometric functions, the above is usually referred to as the classic development. Mostly experiments are in some sort of controlled conditions, e.g. filtering, when the support becomes compact and then B is finite. In recent decades quite popular became various wavelet developments, which use different types of functions in the base. However, the base elements ortho normality is quite crucial for the semantics. Why all this is of any importance and what are the criteria for the base selection? The answer is in the potential ability to de convolute mixes of functions in experimental phenomena and the resonance of the components of the signal with some element of the chosen basis B. If the obtained spectra have no distinguished spectral lines/bands, then the applied development with certain base hardly provides for any better insight into the phenomena complexity, e.g., if the signals contain some usual wave components, then they should be discerned in the Fourier spectrum, if a component is more square like, then the square-like wavelets should do better. However, if in the signal there are mixes of the components of the both or more kinds that could hardly fit into one ortho normal base, then it is harder to discover the selection criteria and the method might fail to be informative. The noninvasive EEG signals from the scalp are to some measure linearly dependent [Babyloni et al. 2007; Jovanovic 1998, 2001], which makes some difficulties, but which can also be rather useful: if some frequency component is present in more than one signal, then this fact could be very useful to relatively amplify it and produce signal-composites that could eliminate a lot of noise and form the features which are easier to recognize and become useful for the BCI. Currently BCI use lower parts of EEG spectrum. People learn how to generate certain mental states, which we called somewhat earlier WCBP (Will Controlled Brain Physiology), correlated to the EEG signal changes, which could be automatically recognized. That could define the simple command set language, which is used for the control of the exterior connected to the computer. In our experiments described earlier in [Jovanovic 1998, 2001], we had some success in learning to switch on and off the frequency pulses in the range ≤ 6Hz and at 10 to 12Hz, shown on the Figure 4. and some success in a kind of the Morse code modulation of the frequencies in the range 12 – 14 Hz.

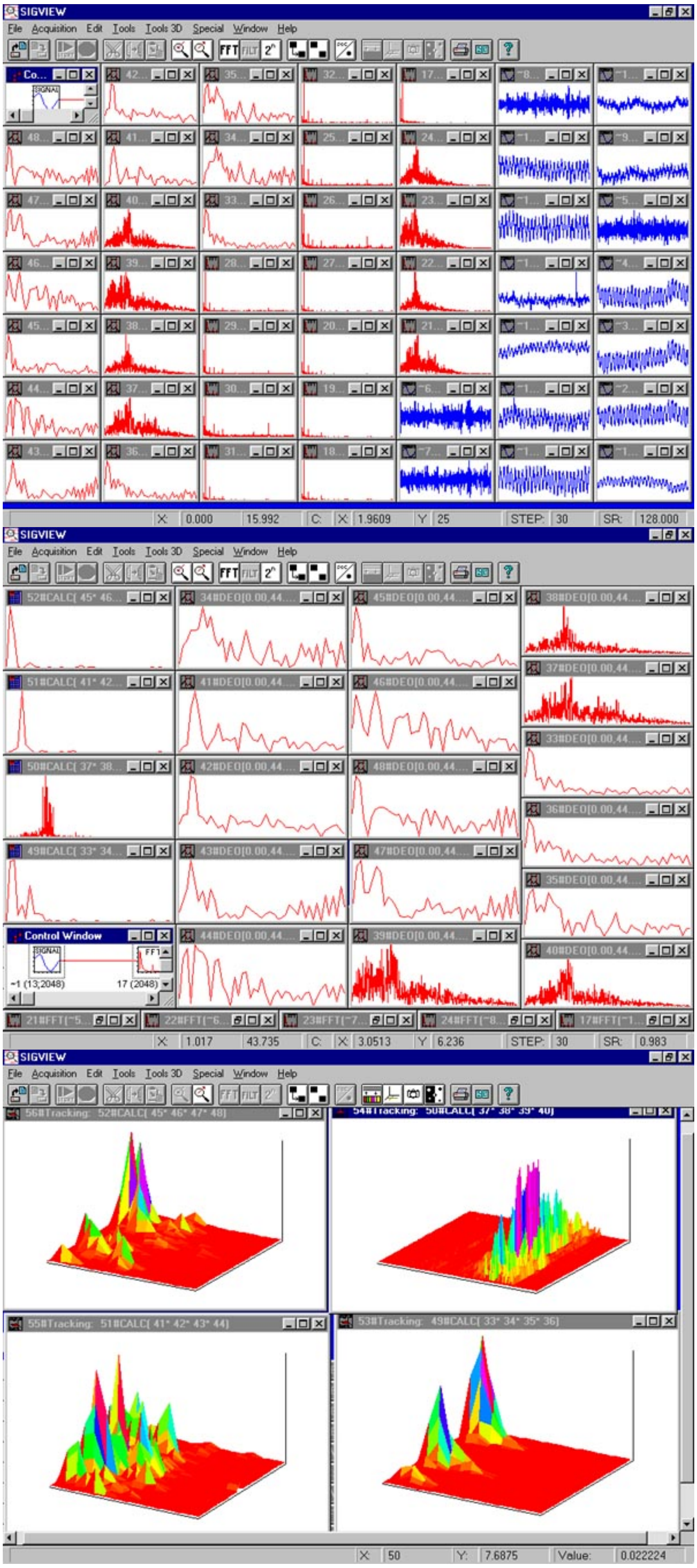


Figure 4. *WCBP: signals from the four short experiments with their spectra and initial parts, dot products of related spectra, in the middle, their composite-spectrograms exhibiting features that are easily automatically extracted in real time, to the right.*

This approach might be useful when it is easier for user to learn to generate, switch on and off some frequencies. From our experience and it seems to be similar with the described BCIs, they suffer of highly reduced set of reliably recognizable mental states representations. The nature of signals – low frequencies demands quite a lot of time for certain command recognition, no matter how fast computers are used. Both currently determine limits to the BCI inner language expression power and the speed of the command realization in the external world - BCI reaction time, to somewhere between 0.5 and 1 second at best, bounding the BCI to simpler and slow action applications. Recently, these problems attracted attention towards higher frequencies in EEG [Kroger et al., 2006; Watkins at al., 2006] that might be highly promising.

4. Neuro acoustic BMI's - towards WCCC

WCCC stays for the Will Controlled Chidakash (Sanskrit: mental screen) Content. The needs for BCI which would support faster action and fast control in more complex dynamic systems are older than the first BCI. That means the larger class of faster switching controllable states, with the RT recognition, which would form the basis for a formalized system, like a natural language or operating system command language, with the fast sequences of command action-strings. Independently and related to such possibilities, since long ago, we have been thinking of a potential solution of earlier listed demands for BCI for a rather large population. A lot of people discern well music details. Some sing inside - voiceless, even generate inside some preferable instrumental music. This we call Inner music for a long time, but it seems to have become a common term and a notion. In presence of Inner Music, a lot of processing at different locations in the brain happen, opening the chance of increased multiple occurrences of components in EEG signals, with increased linear dependence. Music consists of individual tones and if we can detect them, then we might open a chance for BCI to switch from older pulse dialing to the tone dialing, using tone sequences – melodies in the expressively rich hierarchical command language, with the fastest and highly reliable will controlled switching. This desires motivated our ties with biology research. We contributed developing a lot of software for our researchers, but the origin was rather poorly satisfied. We computerized one old EEG with 8 input bipolar channels in the lab working with implants in rats in 1993, upgrading it four times in subsequent four years. Lifting acquisition rates, from less than 500Hz -2 channel, to beyond 50KHz per channel -16 channel, we made our chance for initial acoustic experimentation with rats, discovering the stimulated frequencies in the rat brain spectra. However, the whole lab, our equipment and the whole building reverberated in noise, which was very discouraging. Trying experiments with humans confirmed we were overwhelmed with the noise. Not expecting to be able to approach inner tone representations with our improvised system that suffered of all incurable noise, we said 'lets just try it' and our very first experimental subject Dr Katarina Tomaševic from Musicology Institute brought the change. We performed simple experiments using the calibration tones for 2-3 seconds, then pause, while the experimental subject started singing inner tone, then we had 5 seconds lasting acquisitions with unfiltered 8 channel EEG mount, which, after some searches was earlier tested as better promising. In the post processing analysis in the following days, in the thousands of forest like spectra, we found the first inner played C2 first harmonic traces at 522Hz, where it was supposed to be, on some electrode outputs, but missing on some other (Fig. 5 to Fig. 9).

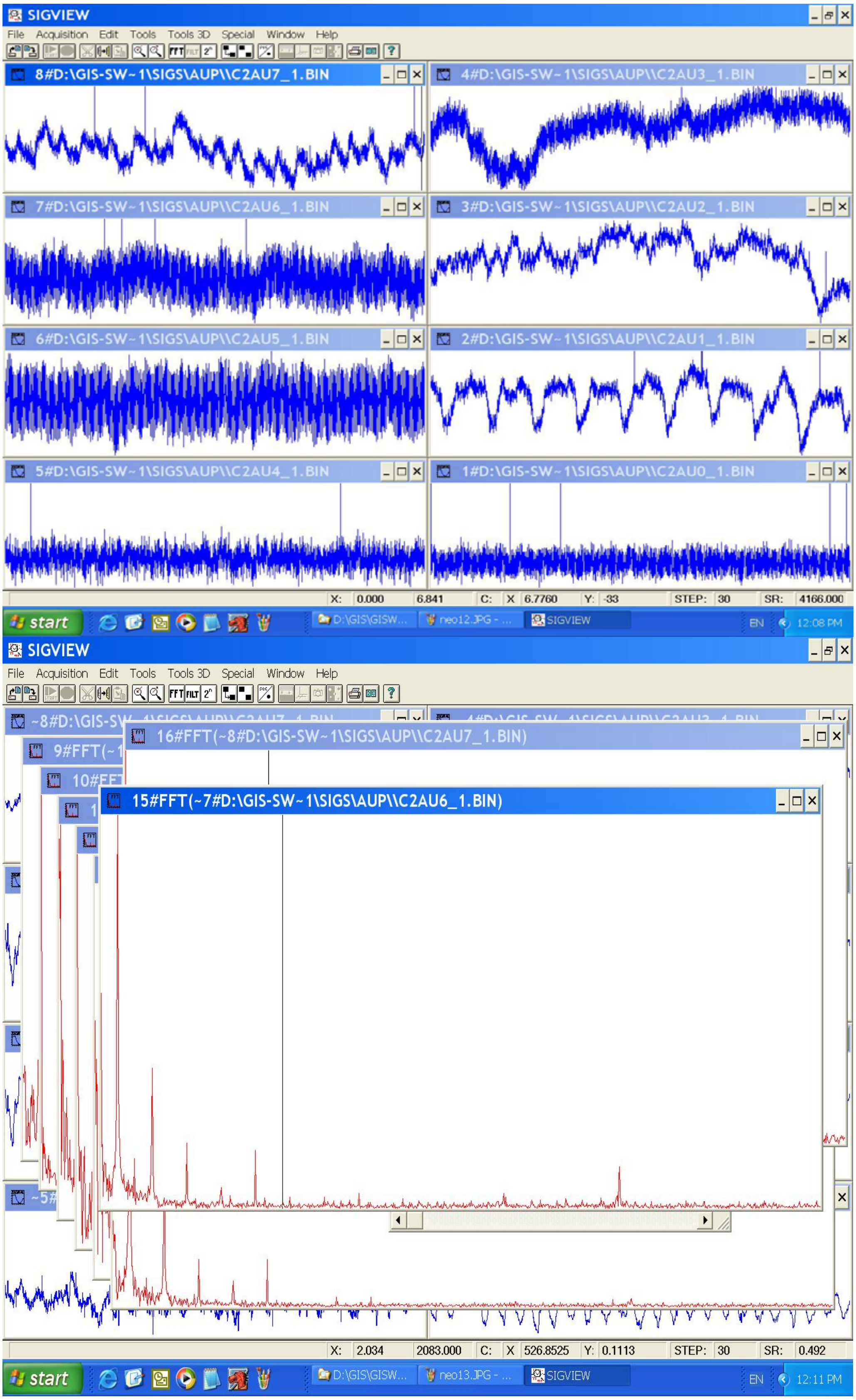
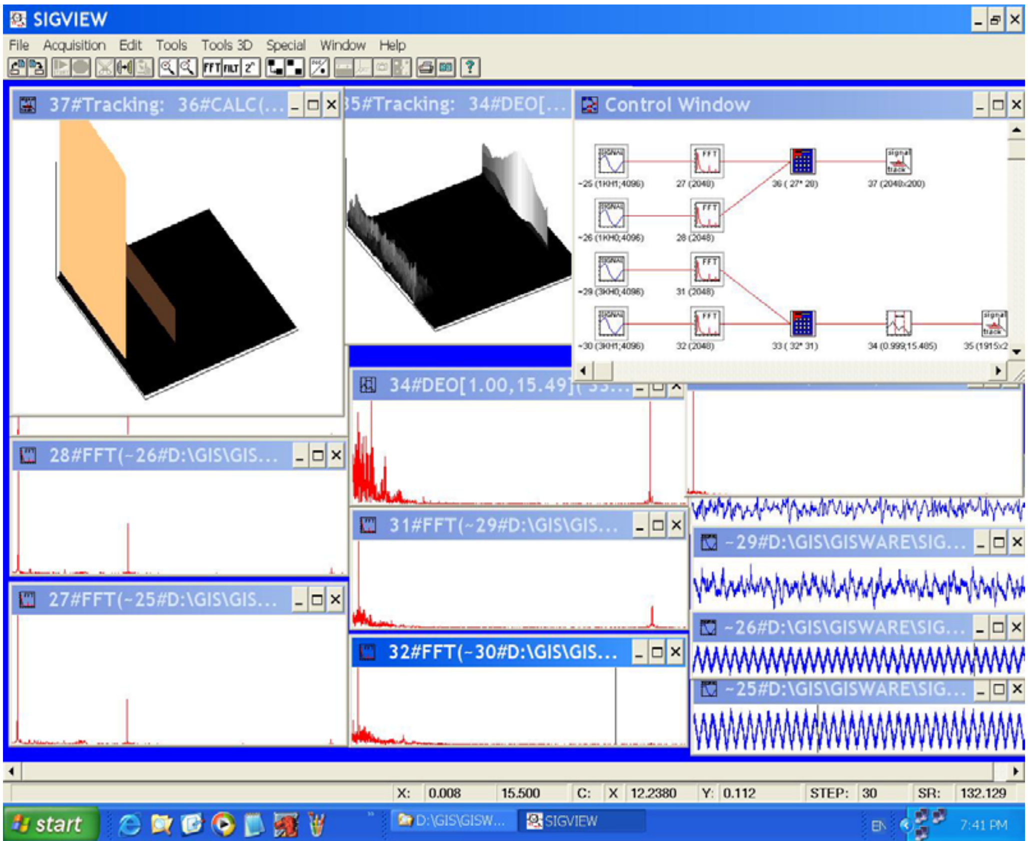


Figure 5a. *8 channel unfiltered EEG recording of inner tone C2, power spectra with marked position of C2 at 525Hz*



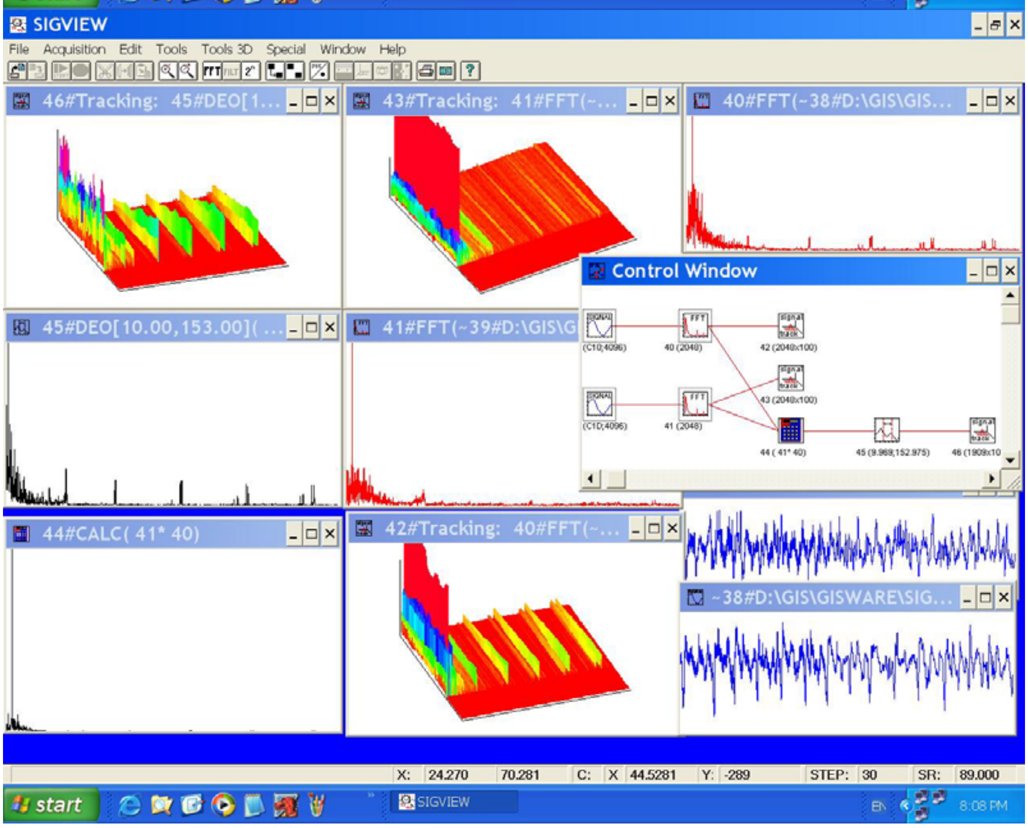


Figure 5b. *top: calibration 1&3KHz; lower: external-played trumpet at C1.*

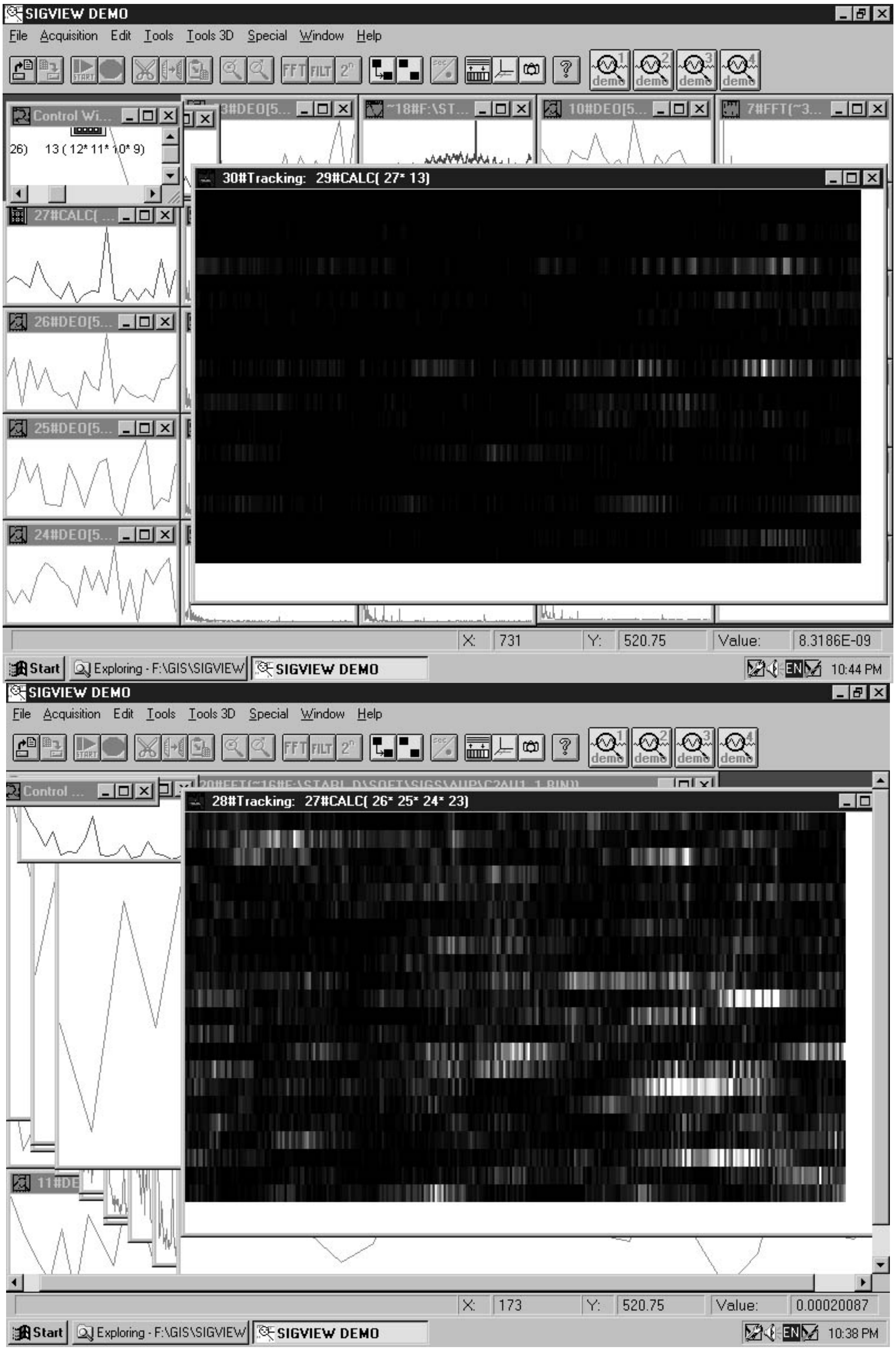


Figure 6. *top: spectra intervals 500-545Hz, dot product of all 8inputs, emerging 525Hz, corresponding to inner C2; low: dot product of the same spectral intervals for 2 frontal and 2 low lateral inputs, 525Hz line present with other masking details.*

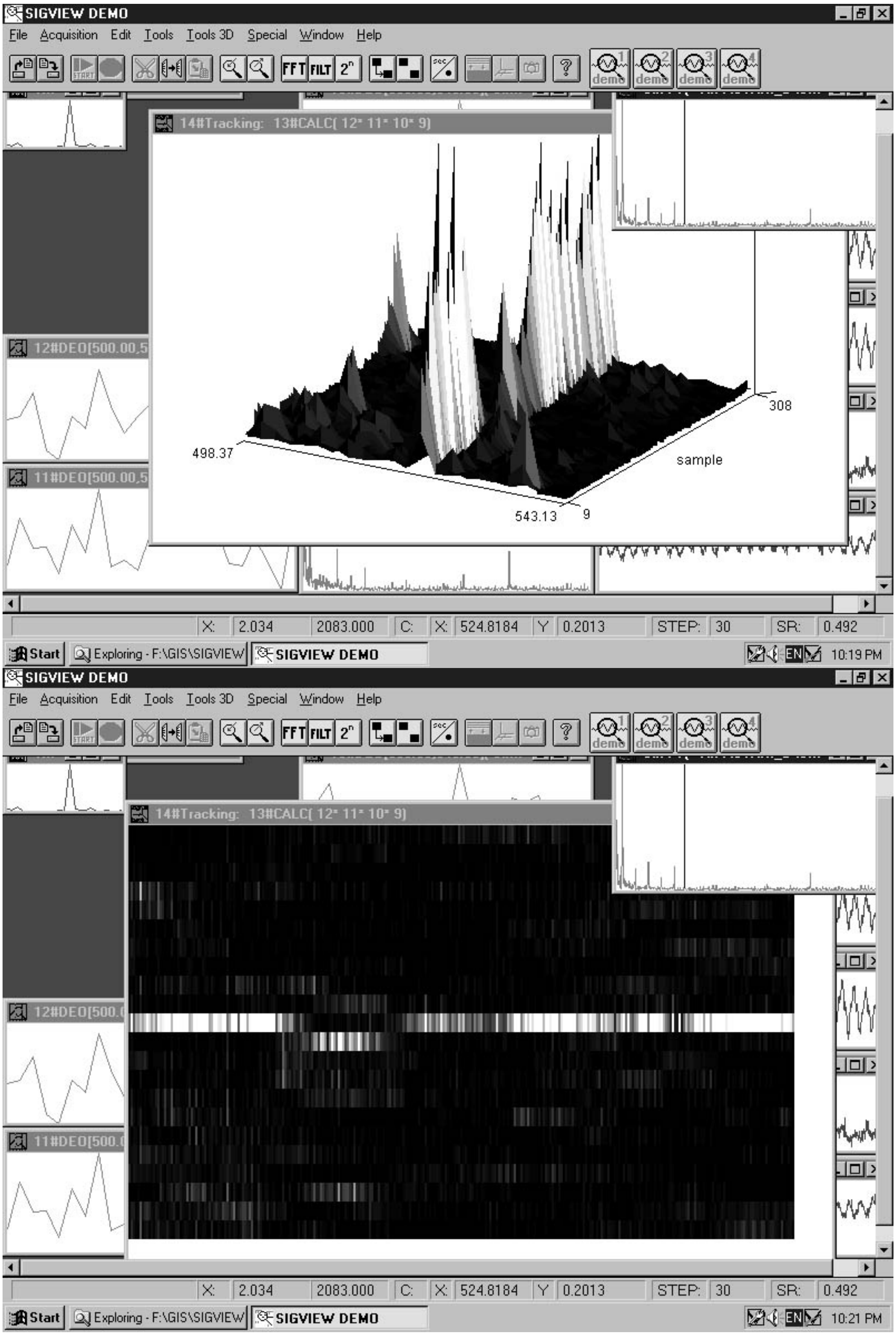


Figure 7. *Inner C2, better responding channel selection: coordinate vise product of 3D spectra, lateral and the top lateral electrodes, frequency interval 500-545Hz showing extracted Inner C2 tone.*

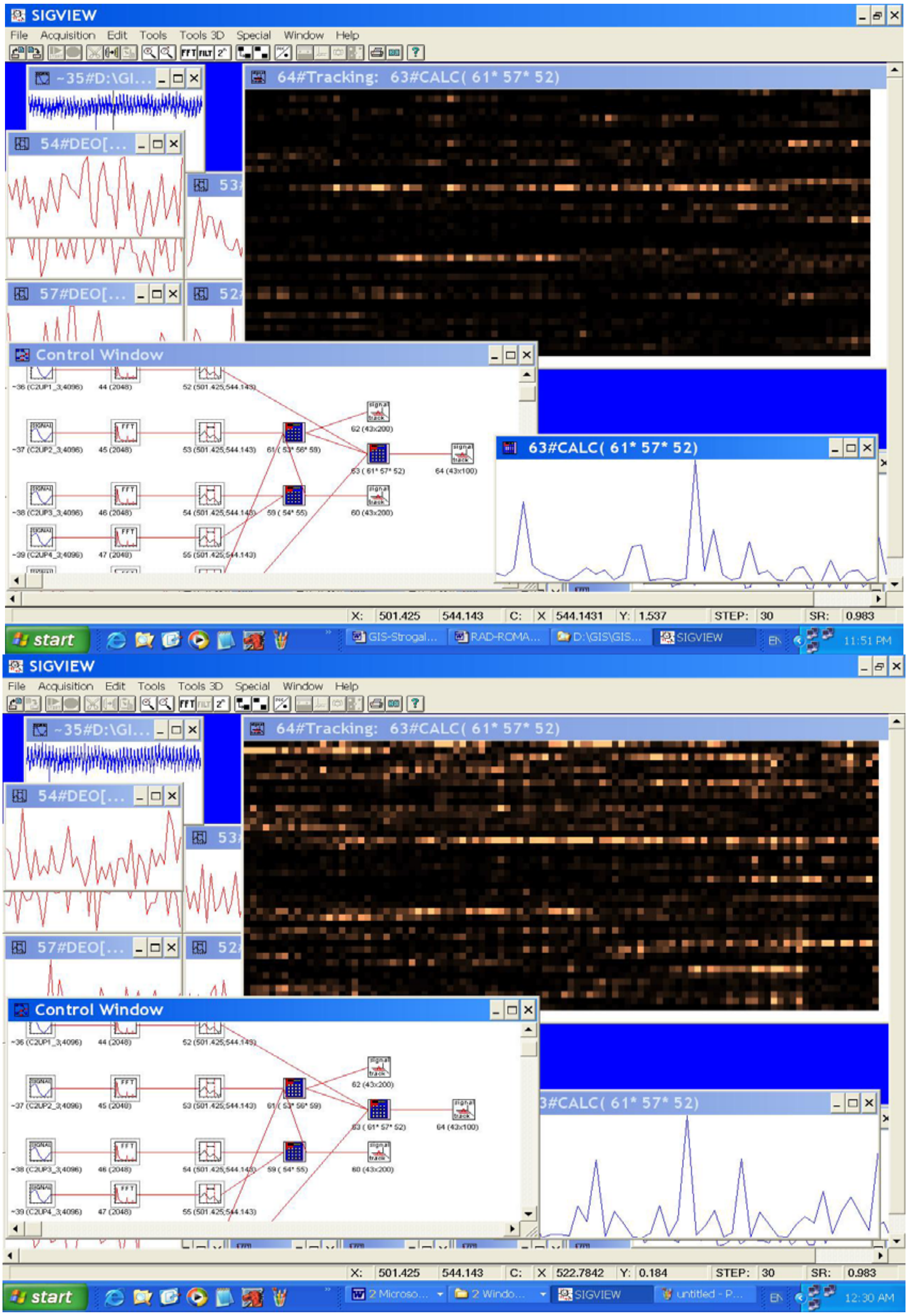


Figure 8. *Another experiment with the Inner C2; Inner C2, here with other features, but well placed and not without a chance to be better filtered.*

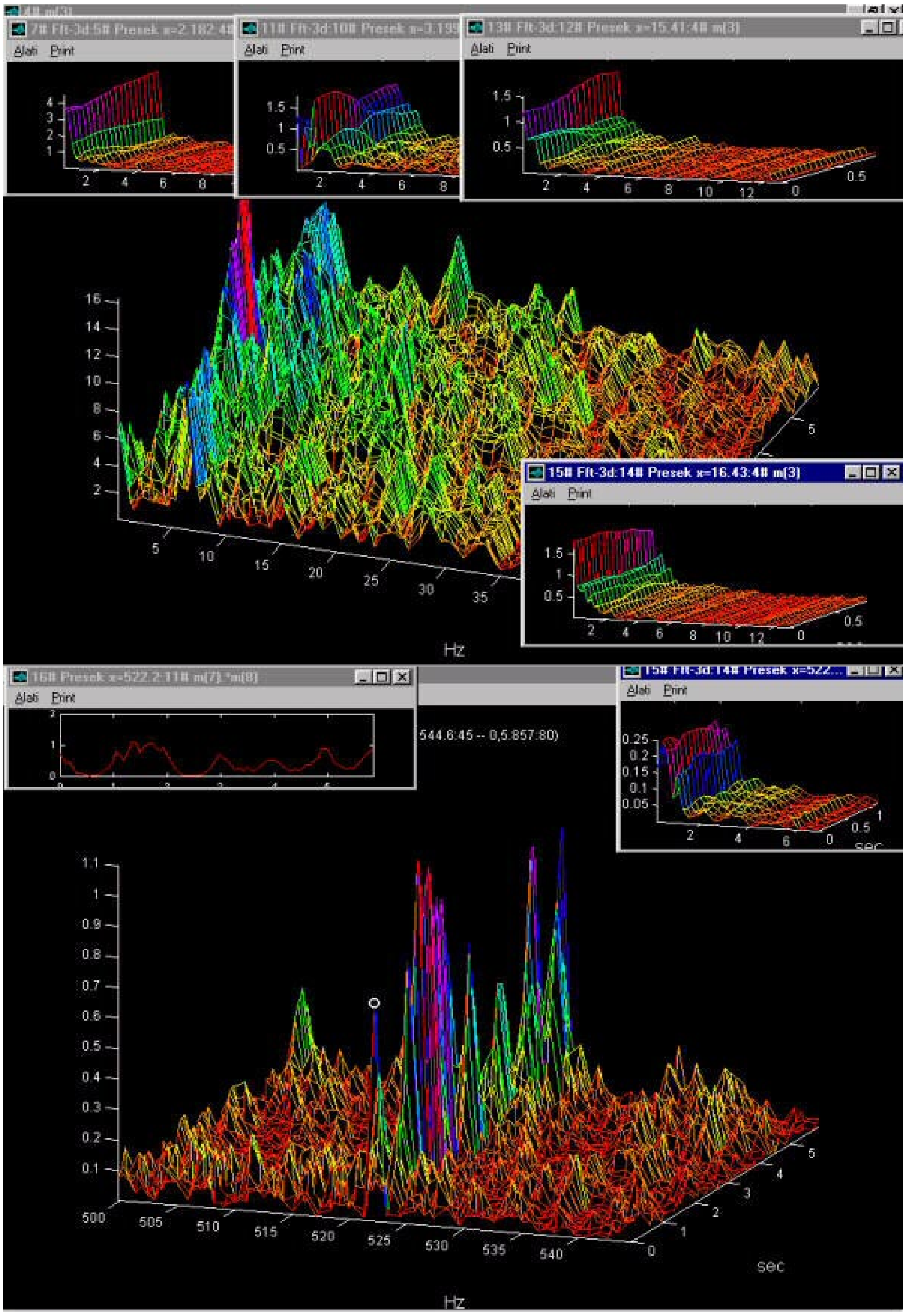


Figure 9*. Energy distribution: left the low composite spectrum 0-45Hz, with relative magnitudes up to 16 and low formations-green with relative magnitudes > 6; right, well cleaned inner C2 at 522Hz, maximal magnitudes reaching 1.1, with energy roughly 1% of the left part, but locally well discerned and detectable.*

Repeating the same sort of experiment with the few musically trained subjects and a few non talented colleagues, we recorded a collection of signals while thinking-playing inside inner tones. With those without the talent, we were not able to detect any frequency trace near the calibrating pre playing tones, the same with first few harmonics. However, with trained people, we had serious positive statistics with the tones whose frequencies were away from other dominant spectral features, noise or whatever. We reached positive conclusions of possible spectral separation of different inner tones. When, e.g. playing D2, there was no affirmative answer at C2 and vicinity, thus supporting the evidence that we could have tones with disjoint first few harmonics representations. More details of these experiments are available in our earlier reports [Jovanovic, 1997, 1998, 2001, 2004, 2006].

5. Discussion

After our experiments with inner tones – music, encountering huge complexity in the search and potential automatic recognition of the simplest tones, we are certain that this is just a small beginning, but that more profound and more systematic research, with the new much more sophisticated equipment and methods could bring much better results. Especially, the fusion with fMRI might assist in the inner music active zones inventory expansion and precise addressing in the brain, that could follow with better electrode-mounts selection and positioning, which is especially important now with the high resolution EEG in BCI as in [Babyloni et al., 2007]. We do not expect that the current successful BCIs could be competed soon with the inner-tones based BCI, but those based on higher spectral frequencies are emerging [Kroger et al., 2006; Watkins et al., 2006]. Our experimenting lab collapsed in 1997, another, where we also had limited access and integrated our upgrade on the existing EEG, was heavily used by patients and became inaccessible for our experiments. Our high rate signal acquisition and analysis systems and software were installed in other labs where they became very useful, of which we mention the Neurophysiology unit of the Institute for Biological Research and polygraphy at Pharmacology Institute, School of Medicine, as shown in [Culic et al., 2001; Japundzic-Zigon, 2001]. We continued our efforts towards the better chance for the experimentation with inner music, developing the environment, based on embedded DSP systems and network processing, including powerful parallel processor boards, capable of acquisition of up to 256 channels per PC in acoustic range, LAN and Internet broadcasting, parallelizing all numerics, spectral calculations and linear algebra, with all channel multiple monitor graphics, thus achieving serious RT ability. All our references, library with the discussed experimental signals and software for analysis and viewing and all other biomedical software are available at our sight www.matf.bg.ac.yu/~aljosha.

References

Babyloni F, Cincotti F, Marciani M, Salinari S, Astolfi L, Tocci A, Aloise F, De Vico Fallani F, Bufalari S, Mattia D. The estimation of cortical activity for brain-computer interface: appliactions indomotic context. *Computational Intelligence and Neuroscience,* Volume 2007, Article ID 91651, 7 pages, 2007.

Cincotti F, Mattia D, Babyloni C, et al. Classification of EEG mental patterns by using two scalp electrodes and Mahalanobis distance-based classifiers. *Method of Information in Medicine,* 41(4): 337-341, 2002.

Culic M, Saponjic J, Jankovic B, Kalauzi A, Jovanovic A. Slow oscillation of Purkinje cell firing rate induced by locus coeruleus stimulation in rats. *Neurophysiology,* 33, 55-59, 2001.

Donoghue JP. Connecting cortex to machines: recent advances in brain interfaces, *Nature Neuroscience,* 5(supplement), 1085-1088, 2002.

Japundzic-Zigon N. Effects of nonpeptide V1a and V2 antagonists on blood pressure fast oscillations in conscious rats, *Clinical and Experimental Hypertension,* 23(4), 277-292, 2001.

Jovanovic A. Mathematics in biology (Serbian: Matematika u biologiji) with CD-ROM: CCD microscopy, image & signal processing, School of Mathematics, Un. of Belgrade, 1997.

Jovanovic A. Brain signals in computer interface, (Russian: Kompjuterni interfeis s ispolzovaniem elektronnih signalov mozga), *Intelektualnie Sistemi,* 3(1-2): 109-117, 1998, (Lomonosov, Russ. Ac. of Sc.)

Jovanovic A. Research in the Group for intelligent systems at Belgrade University, problems and results (Russian: Isledovania v oblasti intelektualnih system v Belgradskom Universitete, problemi i rezultati), *Intelektualnie Sistemi* 6(1-4): 163-182, 2001, (Lomonosov, Russ. Ac. of Sc.)

Jovanovic A. Biomedical image and signal processing, School of Mathematics, Un. of Belgrade, E-book, 2004.

Jovanovic A, Jovanovic M, Perovic A, Maric M. A System for neural acoustics analysis. In proceedings of the 4th Annual Serbian – Hungarian joint symposium on Intelligent Systems, SISY 2006, 275-283.

Kenedy PR, Bakay RAE, Moore MM, Adams K, Goldwaithe J. Direct control of a computer from the human central nervous system. *IEEE Transactions on Rehabilitation Engineering,* 8(2): 198-202, 2000.

Kroger JK, Elliott L, Wong TN, Lakey J, Dang H, George J. Detecting mental commands in high-frequency EEG: faster brain-machine interfaces. In proceedings of the 2006 Biomedical Engineering Society Annual Meeting, Chicago, 2006.

Schalk G, McFarland DJ, Hinterberger T, Birbaumer N, Wolpaw JR. BCI2000: a general purpose brain-computer interface (BCI) system. *IEEE Transactions on Biomedical Engineering,* 51(6): 1034-1043, 2004.

Watkins C, Kroger J, Kwong N, Elliott L, George J. Exploring high-frequency EEG as a faster medium of brain-machine communication. In Proceedings Institute of Biological Engineering 2006 Annual Meeting, Tucson, 2006.