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ORIGINAL ARTICLE

Design and simulation of virtual telephone keypad control based on brain computer interface (BCI) with very high transfer rates

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Abstract Brain Computer Interface (BCI) is a communication and control mechanism, which does not rely on any kind of muscular response to send a message to the external world. This technique is used to help the paralyzed people with spinal cord injury to have the ability to communicate with the external world. In this paper we emphasize to increase the BCI System bit rate for controlling a virtual telephone keypad. To achieve the proposed algorithm, a simulated virtual telephone keypad based on Steady State Visual Evoked Potential (SSVEP) BCI system is developed. Dynamic programming technique with specifically modified Longest Common Subsequence (LCS) algorithm is used. By comparing the paralyzed user selection with the recent, and then the rest, of the stored records in the file of the telephone, the user can save the rest of his choices for controlling the keypad and thence improving the overall performance of the BCI system. This axiomatic approach, which is used in searching the web pages for increasing the

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performance of the searching, is urgent to be used for the paralyzed people rather than the normal user.

1. Introduction

Brain Computer Interface (BCI) is a communication and control channel, that is based on direct measurement of brain activity rather than the physical movement by Interfacing brain signals to the computer and translating brain electrical activities into messages or commands, which can be used in several computer applications such as spelling, cursor control, games and virtual environment control, which will be useful and helpful for patients who are severely paralyzed [1–6].

2. Literature review

Current BCI systems are relatively low bandwidth devices, offering maximum information transfer rates of 5–25 bits/min at best, which may take several minutes to input simple word to computer. In addition BCI systems are error prone with rate 10% to 30% for either false positive error, which refers to selecting the incorrect choice or false negative error which refers to missing the correct choice. For both error types, BCI systems need error detection with error recovery and correction techniques to handle these errors [8–13].

In 2002, Ming Cheng, Xiaorong Gao, Shangkai Gao, and Dingfeng Xu presented a Brain Computer Interface based on Steady State Visual Evoked Potential (SSVEP). It was displayed as a virtual telephone keypad in the computer monitor with thirteen buttons represented as ten digits 0–9, BACKSPACE, ENTER and on/off, each button having different frequency. Users enter their required phone number putting their gaze at these buttons, and every time users need to call the phone number they have to choose all the digits of the desired number. They used SSVEP in the BCI since it is recording non-invasive signal, which eliminates the need for intensive training to use, and it has high information transfer rate which was 27.15 bits/min, an average for all subjects [13,14].

A. Materka and M. Byczuk demonstrated how to increase the speed and accuracy of brain computer interface by proper selection of the stimulus frequency in SSVEP BCI systems, and using COMB filtering of the EEG signal prior to performing the Discrete Fourier Transform (DFT) with substantial increase of the SSVEP signal to noise ratio [15]. They investigated that the benefits of using COMB filtering is to suppress noise and artifacts whose spectral components do not coincide with the stimulus fundamental frequency and its harmonics. COMB filtering is a well known technique for luminance and chrominance components separation in color TV decoders, and helps to separate the color signals from the black and white, providing a higher resolution or sharper picture. In this BCI they used the same idea of the virtual telephone key and they described five different layers, which are EEG acquisition, Pre-processing, Windowing FFT, Post processing and Analysis and SSVEP Detection.

In 2005, Luca Piccini, Sergio Parini, Luca Maggi and Giuseppe Andreoni presented a wearable BCI system, which consists of two parts: The first one is the hardware, which they called Kimera, that consists of two layers of hardware architecture, wireless acquisition and transmission board based on Bluetooth arm chip, and a low power miniaturized biosignal acquisition analog front end. The second part of the system is the software, which they called Bellerophonte for the graphical user interface management, protocol execution, data recording, transmission and processing [16]. The implementation of this BCI system is based on SSVEP applied to two state selections using standard monitor with a couple of high efficiency frequency LEDs. EEG signals are recorded from the O1 and O2 electrodes according to the 10–20 International System of electrodes placement. BCI system is based on supervised classifier implemented through a multi- class Conical Discriminate Analysis (CDA) with a continuous real time feedback and required a proper initial training period, which consists of nine phases of fifteen seconds equally distributed among three stimulus: Screen center fixation (NULL event), left stimulus (command A) and right stimulus fixation (command B).

In 2006, L. Maggi, S. Parini, G. Panfili and G. Andreoni presented a similar technology as previously presented by Kimera and Bellerophone system, but with four commands instead of two commands only (up, down, left and right). This BCI system algorithm was based on supervised multi class classifier implemented by combining different binary Reqularized Linear Discriminate Analysis (RLDA) classifiers [17]. It is also a system based on a supervised translation algorithm, and the protocol consisting of three main functioning modes, which are training mode, meta-training mode and testing mode. After testing the system on five healthy subjects, the system showed good robustness against false positive and achieved accuracy during meta-training between 80 and 100% and the average speed was 10–15 commands per minute. As a result of these findings, this BCI system provided a reliable, smart and low cost BCI system.

In 2006, Kim Dremstrup Nielsen, Alvaro Fuentes Cabrera, and Omar Feix do Nascimento described BCI system based on SSVEP, which studied seven healthy subjects using a 3×3 matrix flickering squares numbered from 1 to 9. Stimulation frequencies used were 5.0, 7.08, 7.73, 8.5, 10.63, 12.14, 14.16, 17.0 and 9.44 Hz in order for each box 1 to 9. They were displayed on a CRT computer screen with a refresh rate of 85 Hz. Subjects were instructed to enter their phone number, birth date and numbers from one to nine by focusing their gaze on the appropriate squares on the computer screen. Each phone number or birth date was selected three times, while number from one to nine selected four times [18]. Online extraction of SSVEP features classification was done using Fast Fourier Transform (FFT) based on non-averaged periodograms of 2048 samples. Symbol selection is based on first, second and third harmonics. If the amplitude is below a defined threshold, it means no symbol is selected. The result extracted from seven subjects showed 79.7% of the trials were correctly detected with a resulting signal rate of 9.3 characters per minute.

In 2007, Ola Friman, Thorsten Luth, Ivan Volosyak and Axel Graser presented online spelling BCI application based on SSVEP, which displayed to the user with two different layout raw column layout and rhombus lay out. Both layouts were tested on eleven healthy subjects to spell word BRAIN-COMPUTERINTERFACE, which in previous off line studies has shown significantly improved classification performance [19]. The average information rate of this on-line spelling application was 27 bits/minute and the probability of correctly classifying the user's attention was estimated to be 97.5%.

Gernot R. Muller-Purtz and Gert Pfurtscheller presented a 2-axis hand prosthesis, asynchronously (self-based) controlled with 4 class SSVEP based BCI. The hand prosthesis attach with four red lights (LED) at the fingers, index finger to turn right, fifth finger to turn left and at the forearm, there are two lights – first one to open the hand and the second one, to close it. All these lights flicker continuously with different frequencies 6, 7, 8 and 13 Hz [20]. The accuracy of the online classification for this BCI system was between 44% and 88%.

Zhonglin Lin, Chagshui Zhang, Wei Wu and Xiaorong Goe introduced canonical correlation analysis (CCA) to analyze the frequency component of the SSVEP in EEG. They employed CCA to extract frequency feature in EEG, as well as to select channels for analysis. After that, recognition strategy for SSVEP based BCI was proposed [21]. After testing this system, they concluded that the used signals in PSDA approach had a very high SNR and the area that generated the SSVEP was very small, while the use of signal within a broader area in the CCA approach can introduce more noise and negatively affect recognition accuracy.

Tilmann Kluge and Manfred Hartmann proposed a different estimator for the analysis of SSVEPs. In contrast to previously published Power Spectral Density (PSD) estimator, which is non-coherent measures for the signal power in narrow frequency band. In this study, they presented a phase coherent estimate that takes into account both amplitude and phase of Fourier series coefficients. The EEG signal was recorded from two electrodes and the used band-pass filter between 0.3 and 100 Hz and a notch filter at 50 Hz. Analog to digital conversion was performed using a data acquisition card with a sampling rate of 256 Hz and 6 bit resolution [22]. In this approach, three different experiments were performed, such as two stimuli flickered with two different reversal rates, two stimuli flickering both at 10 Hz but with different relative phase and Similar to the second one but stimuli flickered at 12 Hz and the phase difference was 180 degrees.

In 2007, Ola Friman, Ivan Volosyak and Axel Graser presented six different methods namely: Average Combination, Native Combination, Bipolar Combination, Laplacian Combination, Minimum Energy Combination and Maximum Contrast Combination for detecting steady state visual evoked potentials, using multiple EEG signals for achieving high information transfer rates with high detection accuracy by finding combinations of electrode signals that cancel strong interference signal in EEG data [23]. The best detection accuracy was achieved with the minimum energy method, which utilized an SSVEP model to produce uncorrelated channels containing minimal energy from nuisance signals [24–27].

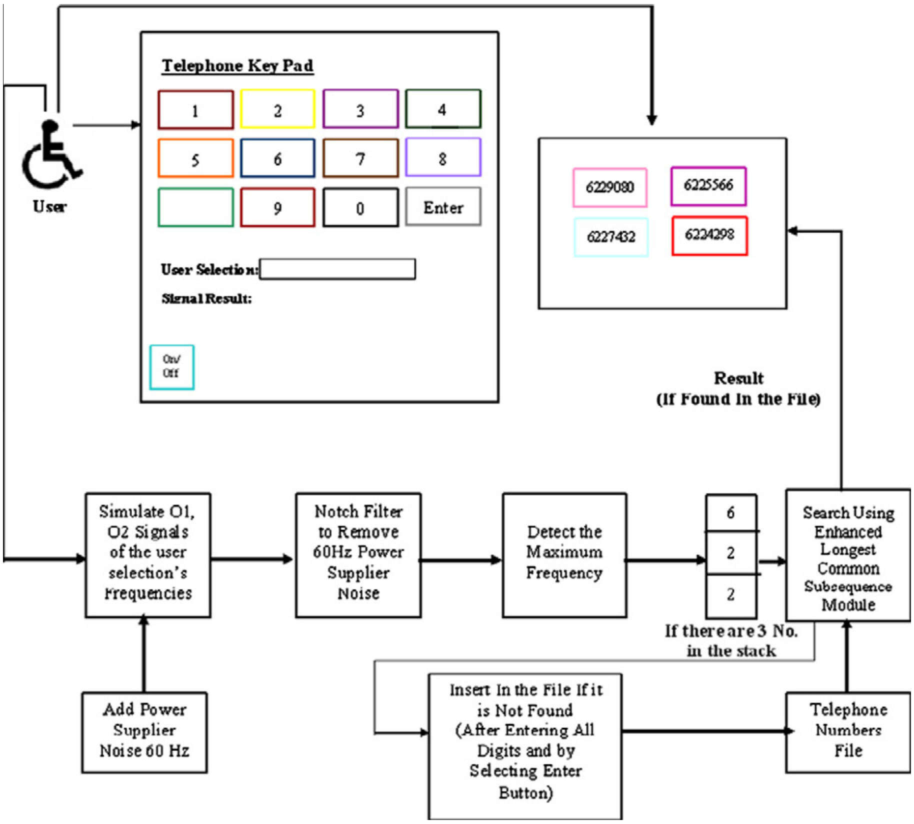


Figure 1 Proposed BCI System.

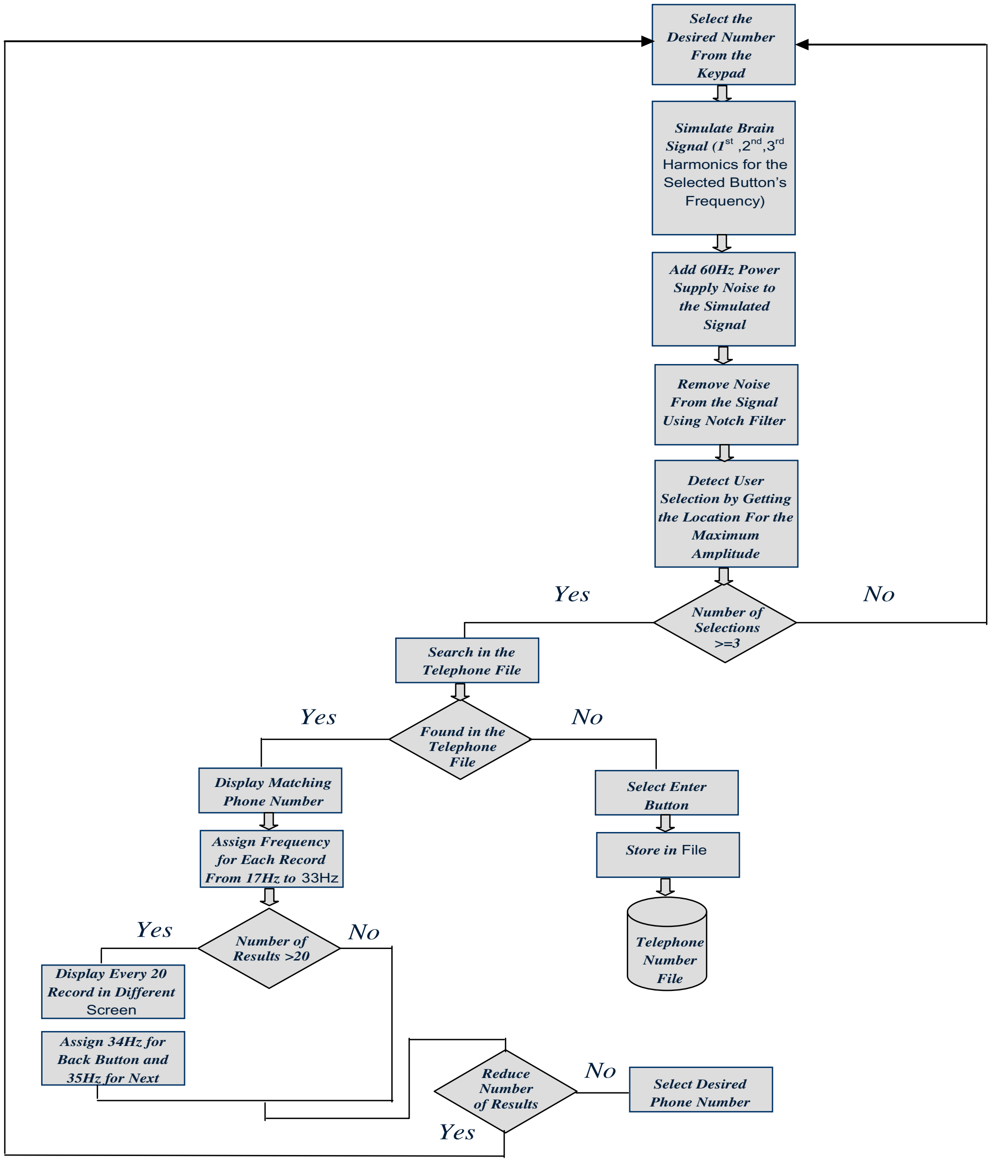


Figure 2 Presented BCI workflow.

In all of the above BCI SSVEP systems, the transfer rates do not increase 27 bit/s. In this paper, dynamic programming technique with specifically modified Longest Common Subsequence (LCS) algorithm is used to increase the bit rates of the systems, which are given above. By comparing the paralyzed user selection with the recent, and then the rest, of the stored records in the file of the telephone, the user can save the rest of his choices for controlling of the keypad and hence improving the overall performance of the BCI system. This axiomatic approach, which is used in searching of the web pages for increasing the performance of the searching, is urgent to be used for the paralyzed people rather than the normal user.

3. Proposed system

The block diagram of the BCI system, which is proposed and simulated in this paper, is shown in (see Fig. 1).

3.1. Software layout

There are thirteen buttons: 0–9 buttons, Back button to delete the wrong selection, Enter button to signal the end of the user selections which will be automatically added to the telephone file if it was not found in the stored file and on/off button that is to be selected as a start that user start dialing his/her telephone number. All of these thirteen buttons have different frequencies and colors based on the SSVEP frequencies limitation starting from 4 to 35 Hz. The user selection field in the layout is to display the selection for the user and there is a signal result field to display the result of the user selection after applying all methods and algorithms on the selected button's frequency.

3.2. System workflow

Presented BCI system worked as follows (See Fig. 2):

Table 1 Buttons frequency.

Button	Assigned frequency (Hz)
On/Off	5
0	4
1	6
2	7
3	8
4	9
5	10
6	11
7	12
8	13
9	14
Back space	15
Enter	16
Results (updated LCS)	16 < frequency < 36

- First, user has to select on/off button to start, and select his/her telephone number, this step will eliminate the false positive error (Selecting incorrect choice).
- Then, user starts to dial the telephone number by selecting his/her selections from the telephone keypad.
- After that, signal simulation takes place,
- which generating the first, second and third harmonics of the selected button frequency as a summation of the three sin waves for the three harmonics, add power supplier 60 Hz noise, then work with this signal as an EEG signal and clean that simulated signal from power noise by applying notch filter and transformed to the frequency domain using Fast Fourier Transform (FFT), then the correct frequency is extracted by getting the peak of the frequencies.
- Once user has selected three digits or more, the system starts searching in the stored telephone user file to find the telephone numbers matching the same user (starting) digits using.

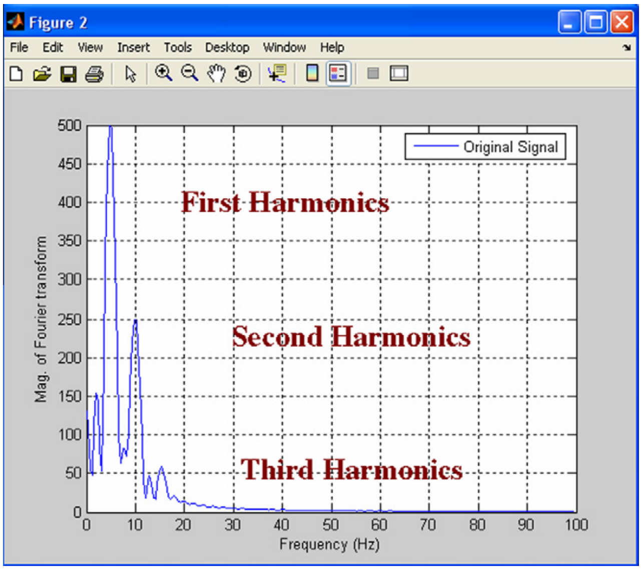


Figure 3 The original signal in the frequency domain obtained from EEG(O1&O2) due to a specific button.

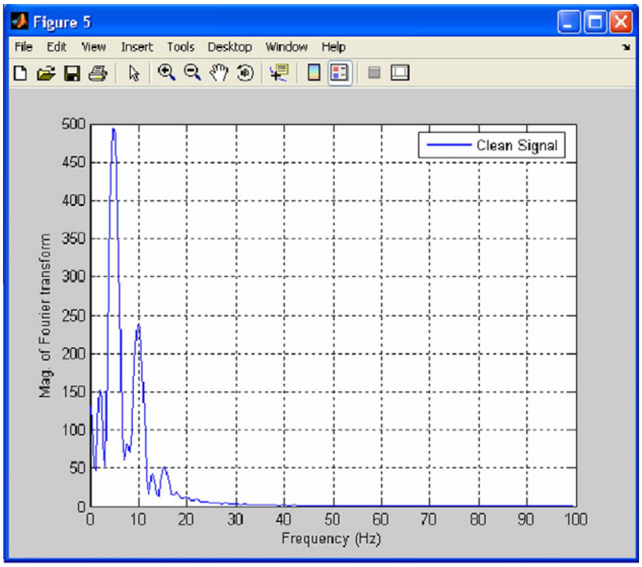


Figure 4 The original signal corrupted with 60 Hz power supply noise.

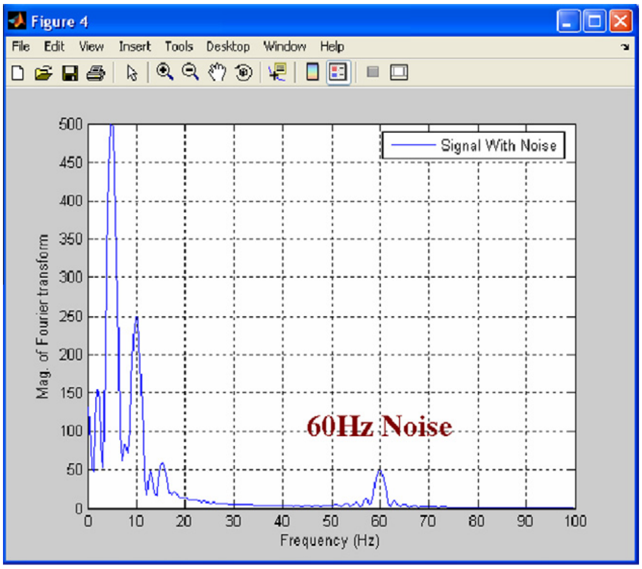
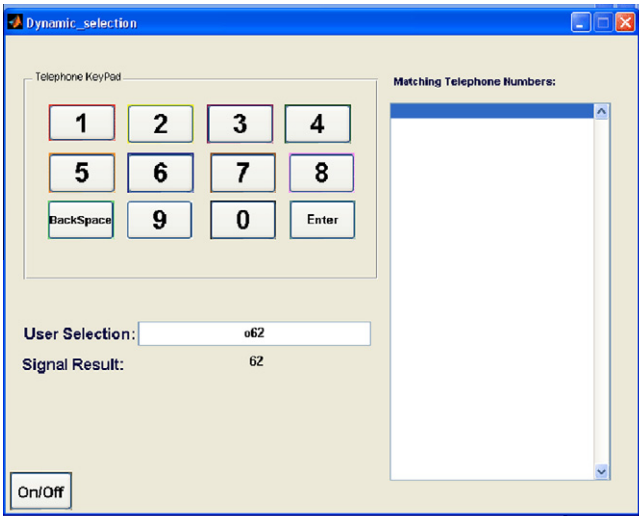


Figure 5 The signal after applying the Notch filter.

- Dynamic programming technique and specially updated Longest Common Subsequence algorithm and then display the results to the user which will help the user to reach their desired telephone number faster with less selection. User has a chance to eliminate number of matches from the file by selecting more digits from the telephone keypad.
- In case the user enters a wrong selection, he/she can select the Back button, which deletes the previous selection.
- Finally, if the user enters all the telephone number digits and system did not find it in the stored file, he/she can choose the Enter button and the telephone number will be stored in the file. This will then help the user to find the same number in a faster way. The next time the user search for it then dial it.



User Selection: o62

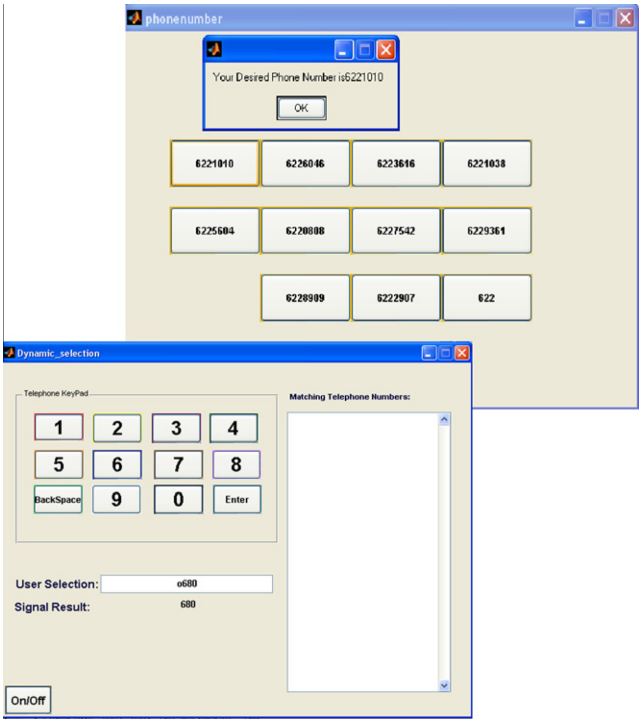
Signal Result: 62

Figure 6 User select 6, 2 and system recognize the selection 6 = 11 Hz, 2 = 7 Hz.

4. Results and discussion

The presented BCI system contains thirteen buttons with different frequencies assigned to each buttons from 4 to 35 Hz. It is based on SSVEP (see Table 1) and it displays to the user once he/she start the program.

Note that frequencies assigned to the thirteen buttons internally in the program within the range between 4 and 16 Hz. Matching phone numbers from the file assigned to randomly frequencies between 17 and 35 Hz excluding 34 and 35 Hz which assigned to back and next buttons if the matching phone numbers from the file more than 20 records.

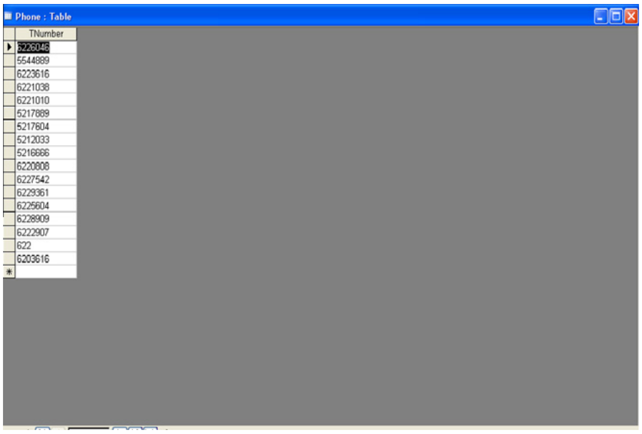


Your Desired Phone Number is6221010

User Selection: o680

Signal Result: 680

Figure 7 Matching phone number from the file.


Phone : Table

TNumber
6226046
5544889
6223616
6221038
6221010
5217889
5217604
5212033
5216666
6220808
6227542
6229361
6225604
6228909
6222907
622
6203616

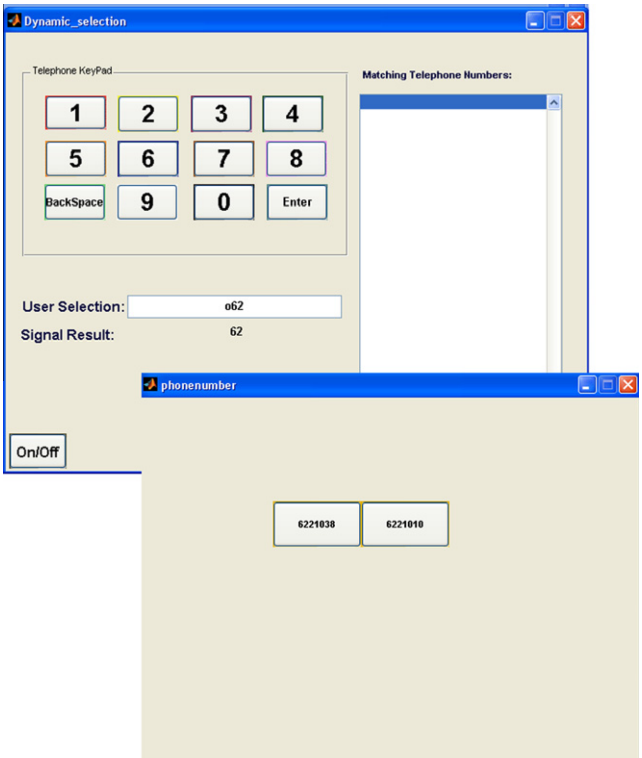
Figure 8 Matching phone number in microsoft access view.

From the hardware viewpoint, (see Figs. 3–5) simulate the EEG signals in the frequency Domain, as well as, the addition of power line artifacts with its Notch filter.

Figs. 3–6 show the simulated systems with the associated results.

4.1. Find the phone number in the file

- Once user selects three or more digits, the system starts to search in the stored file for a match with the same start digits by dynamic programming technique, using Updated



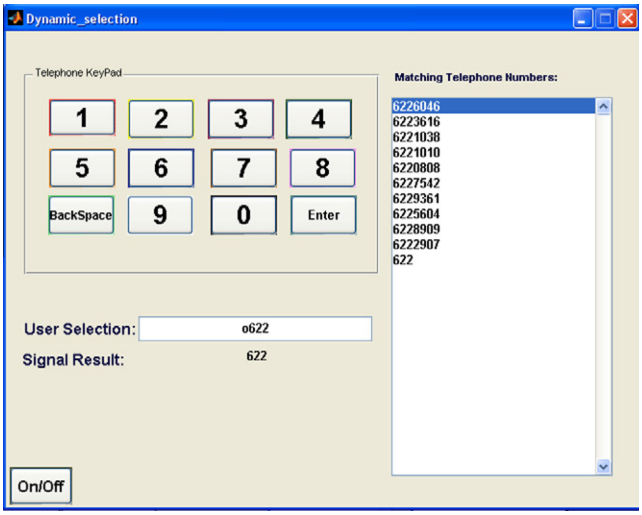
User Selection: o62

Signal Result: 62

Figure 9 Number of results eliminate once user enter more digits.

Longest Common Subsequence algorithm. Each result record assigned to special frequency between 17 and 35 Hz excluding 34 and 35 Hz for back and next buttons if the results records more than 20 records. First telephone keypad screen keep open to the user to give an ability to the user to shrink number of the resulted records by selecting more digits from the main screen buttons (see Figs. 6–9).

- Each selected number goes through the same cycle, that was mentioned previous with on/off button but with different frequencies depending on the user selection.
- The user selects one of the retrieved results (each result referred to special frequency between 17 and 33 Hz) that the system recognized the selection number, which helps user to call the desired phone number faster and with minimal number of selections, rather than entering all phone number digits every time user wants to dial the same number.

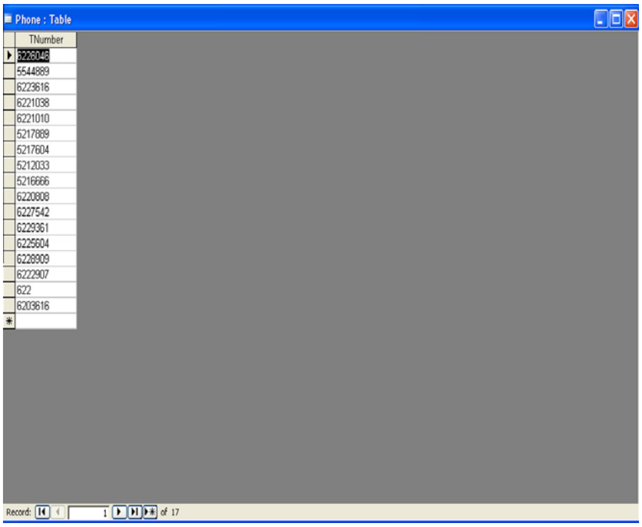


6226046
6223616
6221038
6221010
6220808
6227542
6229361
6225604
6228909
6222907
622

User Selection: o622

Signal Result: 622

Figure 10 User has to select Enter button.



TNumber
6226046
5544889
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6221038
6221010
5217889
5217604
5212033
5216666
6220808
6227542
6229361
6225604
6228909
6222907
622
6203616

Record: 1 of 17

Figure 11 No result found after user select three digits.

4.2. New record in the file

In this case user enters the first three digits of the desired phone number and cannot find in the file, the result extracted as follows:

- User has to select all telephone number digits.
- User has to select enter button (frequency = 16 Hz) to add this record in the file (See Figs. 10 and 11).
- Number stored in the file and it will be available in the next time if the user wants to select the same.

5. Conclusion

Paper presented a BCI system based on SSVEP displayed as a virtual telephone keypad in a GUI layout, which allow the user to select their desired phone number faster with fewer number of entries owing to a special telephone number file stored based on the user's entered telephone numbers which was dialed before. The telephone numbers retrieved from the file were based on at least the first three digits entered by the user, and this matching list decreased once user start selecting more digits from his/her desired phone number. The system was implemented used a dynamic programming technique with updated longest common subsequence algorithm constraint on at least the first three digits of the desired phone number and starts matching with data in the file and displays the matching list to the user as buttons with different frequencies. Compared to the previous study, this paper reached user requirement faster with little number of selections, which increased transfer rate.

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