Abstract

This paper discusses the design, development, features and clinical evaluation of the research platform for cochlear implant. This highly versatile and portable research platform allows as to perform experiments related to CI with great ease and flexibility. Improved spatial hearing performance has been provided by the bilateral cochlear implants to the CI users. The success rate is limited by the interaural mismatch of the place of stimulation caused by the electrode arrays inserted at different depths in each cochlea. The design of the platform for offline mode is been discussed and subjective pairing methods can be used to optimize the interaural electrode pairing (IEP) in BiCIs. Matched interaural electrodes are expected to facilitate binaural functions such as binaural fusion, localization or detection of signals in noise.

1. INTRODUCTION

Cochlear implants (CI) serve as a benchmark technology for their high success rate in restoring hearing to the deaf and their growing and widespread use. According to the U.S. Food and Drug Administration (FDA), as of December 2010 approximately 219000 people worldwide have received CI[3].Comparison of these statistics to the year 2005 when there were about 110000 implant recipients and the year 1995 when there were only 12000 implant recipients, indicates the growing demand and satisfaction with the implant performance[2]. The cochlear implant system has been continuously improved from front-
ending sound processing and fitting software to internal stimulator and electrode design.
In particular, sound processor technology has played a significant role in the growth of CI uptake in the community.

The present work focuses on the development of a general purpose sound processing research platform which could be used to design new experiments and evaluate user performance over time. Implant manufacturers usually provide research speech processors for use with human subjects that allow researchers to develop and test new signal processing algorithms. However, most labs are unable to use them due to limited technical resources or due to the constrained framework of the interface provided by the manufacturer. These limitations include flexibility, portability, and wear ability, ease of programmability, long-term evaluation and features to design the experiments. One of the important factors which hinder their use for speech processing research is that a skilled programmer is required to implement the algorithms in a high level or low level language. This provides flexible software driven solution for both clinicians and researchers without requiring advanced programming skills or major hardware investment.

The PDA platform has since undergone numerous hardware and software updates and has been used to implement different algorithms. Until now, all the coding and algorithm testing on the PDA platform had to be carried out in C or assembly which might be a cumbersome and time consuming process for a researcher trying to make small changes in the code. Also, it might not be suitable for clinicians having little knowledge of C or experiments that would not necessarily require real time processing. To overcome these limitations, we propose a setup to use the PDA platform for offline experiments by interfacing the platform with a personal computer running MATLAB [1]. The proposed setup allows researchers and clinicians to implement their algorithms in a familiar MATLAB environment and evaluate the performance of their algorithms with great ease without writing C code or learning the syntax and communication protocols. Hence, the complete PDA platform now supports both real-time and offline capabilities, a feature not available in any other CI research platform.

1.1 Cochlear Implant

![Ear with cochlear implant](image)
An implant has the following parts:

- A microphone, which picks up sound from the environment.
- A speech processor, which selects and arranges sounds picked up by the microphone.
- A transmitter and receiver/stimulator, which receive signals from the speech processor and convert them into electric impulses.
- An electrode array, which is a group of electrodes that collects the impulses from the stimulator and sends them to different regions of the auditory nerve.

An implant does not restore normal hearing. Instead, it can give a deaf person a useful representation of sounds in the environment and help him or her to understand speech. A cochlear implant is very different from a hearing aid. Hearing aids amplify sounds so they may be detected by damaged ears. Cochlear implants bypass damaged portions of the ear and directly stimulate the auditory nerve. Signals generated by the implant are sent by way of the auditory nerve to the brain, which recognizes the signals as sound. Hearing through a cochlear implant is different from normal hearing and takes time to learn or relearn. However, it allows many people to recognize warning signals, understand other sounds in the environment, and enjoy a conversation in person or by telephone.

Children and adults who are deaf or severely hard of hearing can be fitted for cochlear implants. In the United States, roughly 42,600 adults and 28,400 children have received them. Adults who have lost all or most of their hearing late in life often can benefit from cochlear implants. They learn to associate the signal provided by an implant with sounds they remember. This often provides recipients with the ability to understand speech by listening through the implant, without requiring any visual cues. Cochlear implants, coupled with intensive post implantation therapy, can help young children to acquire speech, language, and social skills. Most children who receive implants are between 2 and 6 years old. Early implantation provides exposure to sounds that can be helpful during the critical period when children learn speech and language skills. In 2000, the FDA lowered the age of eligibility to 12 months for one type of cochlear implant.

2. SOFTWARE ARCHITECTURE

The software architecture is designed such that PDA acts a server which accepts the incoming connections while the PC acts as a client with MATLAB as a front-end. Overall design can be broken down into three main software components:

i. Server running on the PDA
ii. MATLAB client called from the MATLAB front-end
iii. MATLAB front-end running on PC.

![Figure 2.1: Data exchange in offline mode](image-url)
Server client interface is based on Winsock which is a technical specification that defines how Windows network software should access network services, especially TCP/IP. It defines a standard interface between a Windows TCP/IP client application and the underlying TCP/IP protocol.

2.1 MATLAB front-end

The MATLAB front-end is the application layer of the system around which most researchers would work. It could either be a simple command script to create synthetic stimuli and stream them to the PDA by calling the client dll (dynamic link library responsible for invoking client-server communication protocol) or it could be an elaborate GUI or application which implements speech coding algorithms and uses client dll as a backbone. A variety of applications can be created at the front end suitable for different experiments using the same client dll. The MATLAB front-end has following important functions:

i. Load patient map
ii. Load/Create stimulus data
iii. Check stimulus parameters and amplitude levels for safe operation
iv. Call client dll to stream data to the PDA.

Details of some of these functions are given below.

- **Patient MAP:** First, the patient map is created either from a patient map file or an application to load stimulation parameters specific to a patient. Patient map includes parameters like implant and electrode type, speech processing strategy, stimulation rate, pulse width, MCL and THR values.

- **Checking Parameters:** For the safe implant operation within the implant limits, a parameter checking routine is hardcoded in the main routine. Parameters which are checked for the safe operation are stimulation rate and pulse width for both left and right ear implants depending upon the implant type. Other than this, rate-centric and pulse-width centric parameter checking routines are also hardcoded. In a rate-centric routine, for example, if a user specifies stimulation rate and pulse width that are not realizable, the pulse width will be adjusted to fit the pulse rate. These routines are also hard-coded at the server end for further safety purposes.

- **Stimulation Parameters:** The stimulation data is sent to the PDA server from the client dll in frames. Once the stimulation rate, pulse-width and number of active electrodes have been specified and verified for safe operation, following stimulation parameters are computed where n channels is the number of active electrodes and Pulses per frame is the number of stimulation pulses delivered to all active electrodes every frame interval.

- **Stimulation Data:** Stimulation data essentially comprises of two data arrays containing magnitude and electrode information. Electrode information comprises of an array containing the stimulation sequence of the active electrodes while magnitude information corresponds to the amplitude levels of the stimuli for the respective electrodes. Stimulation data may be loaded from a pre-processed file or it may be
created by implementing any speech coding strategy. Alternatively, a waveform of synthetic stimuli may be created for psychophysical experiments. The stimulation data, however, should correspond to the stimulation parameters already specified.

- **Error Checking:** Before streaming, a final check on the stimuli amplitude levels is done to make sure that the amplitudes fall within the safe range specified by the patient’s map. This is done by comparing the amplitude levels of each electrode with the MCL and THR levels of that electrode. If any amplitude level is greater than the MCL value of that electrode, the amplitude is then saturated to the MCL level. On the other hand, if the amplitude levels are lower than the THR levels of the respective electrodes then they are floored to the THR level. The maximum amplitude level allowed varies across electrodes, cochlear implant patients and for different electrode arrays. Error checking routine is hardcoded both at client and server ends for safety reasons.

- **Call to client:** Finally, client dll is invoked with stimulation parameters and data for each of the right and left implants as its input.

2.2 Client dll

The client dll initializes Winsock, creates a socket, connects to the server and transmits parameters and frames of stimuli created in the MATLAB front-end application. The dll is compiled from the C source using the MATLAB MEX compiler.

2.3 PDA Component – Server

The PDA component initializes Winsock, creates a socket, binds the socket, “listens” on the socket, accepts incoming connections, and performs blocking receives to receive the parameter and stimuli data from the client. The “receive” is performed within a thread in two steps. In the first step, information about the total number of frames, denoted as n frames and the number of pulses per frame is received. The server then performs n frames receives, each time sending the data for the error checking routine. After n frames are sent and received, the server closes the socket and the connection. The PDA server which runs continuously in a Windows thread will automatically initialize a new connection for the next incoming stimulus and wait for the client to transfer the corresponding next set of parameter and amplitude frames.

3. PROPOSED METHOD

Figure 3 shows the organization of the software for the proposed method. The software running on the PC performs the signal processing. The input to the system is the patient’s MAP file along with the signals captured by the left and right microphones. Among other things, the MAP file specifies the stimulation rate, stimulation mode, pulse width, type of electrode array used and the threshold (T) and most comfortable current levels. The block READ PATIENT FILE reads in a patient’s file saved in the local directory as ASCII text file and returns a structure containing information about:

- threshold (T) and most-comfortable (M) levels for each electrode
- the sound coding strategy used (CIS-like, ACE-like)
- number and set of active electrodes
- mode of stimulation
- biphasic stimulus information (phase width, phase gap, pulse period)
- stimulation rate (pulses/sec)
- type of electrode array (e.g., contour)
- implant type (e.g., CI22, CI24, CI24R)

Figure 3.1: Software organization of the proposed method

The GET INPUT DATA block captures and buffers the signal from the microphone, located in the BTE. The PROCESS DATA block takes as input the patient’s MAP file and acquired signal(s) and returns the amplitudes to be transmitted to the cochlear implant. The amplitudes can be obtained either by band pass filtering the signal into a finite number of band and detecting the envelope in each band. The ERROR CHECKING block takes as input the stimulation parameters along with the envelope amplitudes. The envelope amplitudes are checked against the M levels to ensure that they fall within the electrical dynamic range of each electrode. The user can change dynamically all stimulation parameters, except the M levels. The user cannot change the M levels from those originally entered in the patient file. The majority of the information contained in the MAP can be used by researchers to implement new sound processing strategies. Limits, however, are imposed on all MAP parameters. Certain stimulation parameters cannot be modified by the user. For instance, the biphasic pulse width cannot exceed 400 microsecs/phase (in general, the maximum allowable pulse width depends on the stimulation rate). Hence, even if the researcher chooses to modify the contents of the MAP, those changes will be checked to ensure that the electrical stimulation pattern is safe. The stimulation parameters are checked in each cycle to ensure that they fall within the acceptable and safe limits, and validation tests were conducted to verify this. If any stimulation parameters are found to fall outside the permissible range, they will be saturated to the maximum allowable value.

4. INTERAURAL ELECTRODE PAIRING

The proposed IEP clinical research system is comprised of psychophysical test procedures. Five monaural and binaural (bilateral) psychophysical test procedures are included:
• loudness estimation
• loudness balancing
• interaural pitch ranking
• sound image centering
• IPTD sensitivity.

Figure 4.1: Stimulation of CI
The loudness estimation procedure estimates the maximum comfortable level (MCL) and hearing threshold (HL); the loudness balancing procedure determines levels of equal loudness for each electrode pair; the pitch ranking procedure identifies the pitch-matched electrodes; the sound image centering is a pre-test and interaural level calibration for the IPTD sensitivity procedure; and the IPTD procedure determines the binaurally most sensitive electrode pair. The IEP obtained by pitch ranking and the IEP derived from the BIC tuning can then be compared against the IEP drawn from IPTD sensitivity, which is defined as the standard reference.

4.1 Evaluation Of The IEP System
The processed output of the proposed software architecture is given in figure 4. The obtained stimulus data will further subjected to electrode pairing for the bilateral cochlear implant. By this way we can synchronize the stimulus data at both the left and right cochlear implant. Pitch ranking is one of the methods used to obtain the electrode pairing on the both CI.

Figure 4.2: Proposed output of the software organisation
For the pitch ranking, values below the chance level indicate a lower pitch at the test electrode compared to the reference electrode, while values above chance level indicate a higher pitch percept at the test electrode side.

5. CONCLUSIONS

The typically observed large variability of performance in BiCIs is because of the mismatch in the place of stimulation arising from electrode arrays being inserted at different depths in each cochlea. This paper discusses about the interaural electrode pairing in BiCIs. The IEP methods includes pitch ranking, IPTD sensitivity etc. the results of the different electrode pairing methods will be compared between different pairing methods and thereby developing an improved interaural electrode pairing strategy for BiCI users.

6. REFERENCES


