ISIP 2020 Team Project

Introduction to Signal and Image Processing

Handout: May 13th, 2020
Handin: June 3rd, 2020 15:15

Instructions

The project is an opportunity for you to work out a solution to a clinical problem using the material covered in class. Your aim will be to determine the position of electrodes that have been implanted in the cochlea (inner ear) to restore the hearing in deaf patients. The project is conducted in groups of 3 students. In exceptional cases, a team may consist of fewer members.

Your hand-in will consist of a `.zip` archive named `project_groupName.zip` containing the following items:

- Your report named `report_groupName.pdf`.
- An Excel-file named `results_groupName.xlsx` containing your results (please enter your results only in the template provided).
- Python source files and all necessary files to run the code.

Your archive must be uploaded on ILIAS before the deadline. A submission of the assignment is mandatory.

Report

For the team project, the report is particularly important as it is the only way to explain to us how you solved the problem. For this reason you should provide a clear and concise documentation. It should contain a very short description of the problem (section "Introduction", max. 1/2 page). Describe the approach you used and the algorithms you applied/implemented in the "Methods" section. **Don't put code listings in the report**. All code files have to be submitted separately. Give an overview of your findings in the "Results" section. For example, you can provide a plot of the angular insertion depth of each electrode averaged over all subjects. Finally, discuss your findings and your method, e.g. the advantages and disadvantages of your approach, difficult cases and potential room for improvement in the "Discussion" section. Also, summarize the contributions of each team member in keywords in the "Contributions" section.

IMPORTANT: The posed problem is not trivial. If you have encountered problems and have not managed to complete the task or sub-tasks, it is mandatory that you explain what you have tried and what difficulties you have encountered in your approach.

Assessment

In total, up to 25 points will be given for the assignment (+5 extra points) - each team member will receive the same amount of points. For evaluation purposes, your algorithm will be tested with separate data that is not contained in the data set. Most emphasis will be put on the quality of the report. Detection of the spiral center of the cochlea is a non-trivial task, therefore we will not explicitly rate the accuracy of the spiral center detection. For particularly elegant solutions up to 5 extra points can be given.

1 Background

1.1 Cochlear Implants

The cochlear implant (CI) is a hearing prosthesis that bypasses non-functioning parts of the cochlea (inner ear) and directly stimulates the auditory nerve with electrical impulses. In 1957, a French group achieved the first stimulation of the auditory nerve with an implanted electrode. Especially since the 1980s, the CI was further advanced from an experimental device to the predominant treatment for profound hearing loss. To date, over 500,000 CIs have been implanted worldwide in patients with severe-to-profound deafness. Current CI systems consist of an implantable part and an external audio processor (Figure 1).

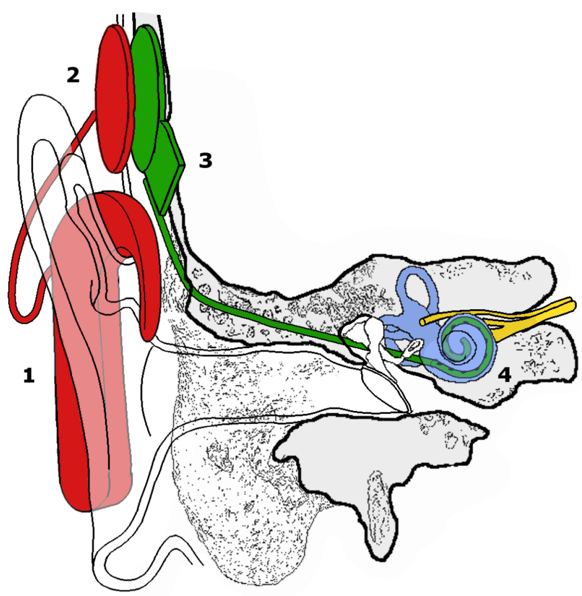

Figure 1: The main parts of a cochlear implant system. External audio processor (1); transmission coil (2); implant with receiver/stimulator unit (3); inserted electrode array (4).

The external part is usually worn behind the ear and consists of one or more microphones, the batteries, the signal processing unit, and the transmission coil which is magnetically held above the implant. The implantable part consists of a receiving coil, the receiver/stimulator unit, the reference electrode which can be part of the implant body, and the electrode array that is inserted into the cochlea (Figure 2).

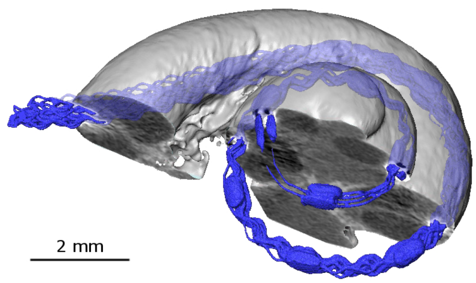

Figure 2: 3D surface model of a left human cochlea with a deeply inserted cochlear implant electrode array (blue). In this case, the array was inserted approximately 2 turns.

1.2 Computed-Tomography Imaging for CIs

Computed tomography (CT) is most commonly used for cochlear implantation. On the one hand CTs are used to check the patient's anatomy preoperatively. On the other hand, they are used to evaluate the outcome of the surgery postoperatively. A CT is an absorption image, i.e. dense structures appear brighter on the image. Therefore the bone has high intensities and air-filled regions appear dark. The cochlea is filled with fluid, therefore it has intensities between those of air and bone.

NOTE: The images provided in the project have been windowed, so the calibrated intensity values (so-called Hounsfield units) are not contained in the images anymore. It would be reasonable in your algorithm to first perform a normalization of the image data to enable that your algorithm works consistently with different brightness values.

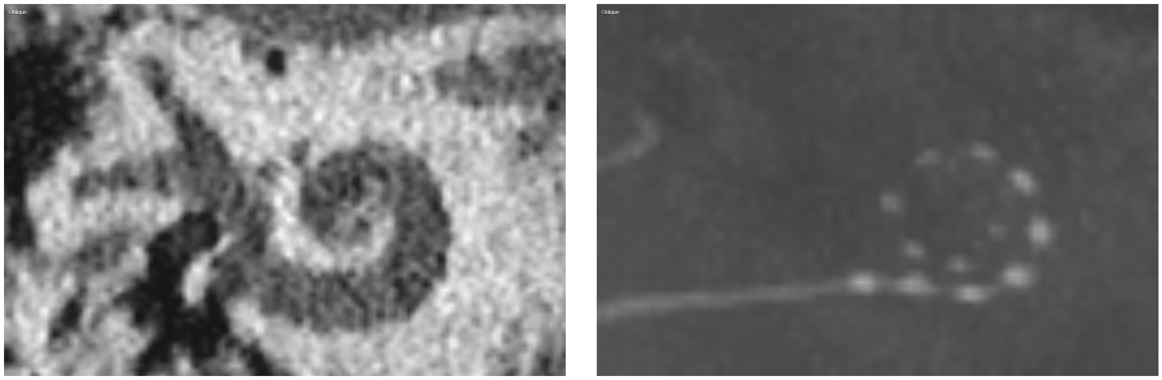

Figure 3: Input images for a sample consisting of a preoperative CT slice of the cochlea (left image) and postoperative CT of the implanted array (right image).

1.3 Position of Electrode Arrays

The cochlea is organized tonotopically, which means that it is mainly the position of the stimulation that determines the perceived pitch. Electrodes located near the basal end of the cochlea cause high frequency perception, while electrodes in the apex (top) cause low frequency perception. An estimate of the perceived frequency for a particular patient can be made if the angular depth of the electrodes is known. This will be the actual task in your project.

2 Tasks

You will be provided with data of 12 subjects. For each subject there is a preoperative computed-tomography (CT) image showing the basal turn of the cochlea. In addition, a registered postoperative image is contained in the data set (see Figure 3). Because the images are registered, they share the same image coordinate system. That means that each pixel position in the preoperative image corresponds to the pixel position in the postoperative image.

Your task will be to identify the angular insertion depth (θ_i) of the cochlear implant electrodes for different subjects. To do this, you will need to (1) find the center of the spiral of the cochlea and (2) detect the electrode contacts in the postoperative image. After you found the coordinates of the center and the electrodes, you will be able to compute the angular insertion depth (θ_i) for each electrode i.

The preoperative image can be used to estimate the axis of the cochlear spiral. The postoperative image needs to be used to detect the electrode positions (see Figure 3). You are free, however, to combine the information of both images. To solve the task you may use any method/algorithm you want; any algorithmic approach you like to take will be considered. However, make sure to provide explanations for the steps taken.

NOTE: Sometimes it will be difficult to detect some electrodes. In case you are not able to detect specific electrodes you can mark these with a specific code, e.g. "-1" for the angular insertion depth.

NOTE: The postoperative images are so-called maximum intensity projections. That means that the image contains information from several slices projected onto a single slice. This way, the three-dimensional extension of the implanted array is "compressed" into a single image (see Figure 4). Also, because of imaging artifacts the electrode arrays appear larger than they actually would be. Therefore, it can happen that some arrays overlap with the bony wall of the cochlea. The postoperative images may not always be as clear like the example in Figure 3 right. Sometimes electrodes overlap or the wire between electrodes is also visible.

HINT: The electrode contacts are equally spaced along the array, this could be used to predict the position of contacts that are not clearly visible.

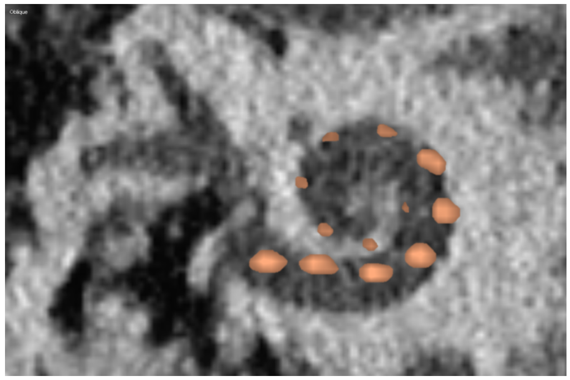

Figure 4: Electrode contacts from the preoperative image overlaid with the postoperative image.

3 Example

The following example illustrates the task in more detail (Figures 5- 8). Any algorithmic solutions to arrive at the results are allowed. A possible result for this example is given in Table 1.

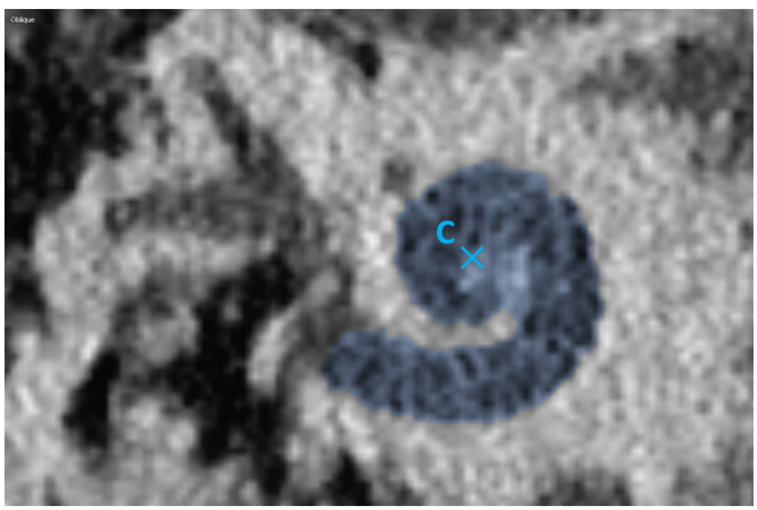

Figure 5: Step 1 - Detected spiral center (C) in the preoperative CT image.

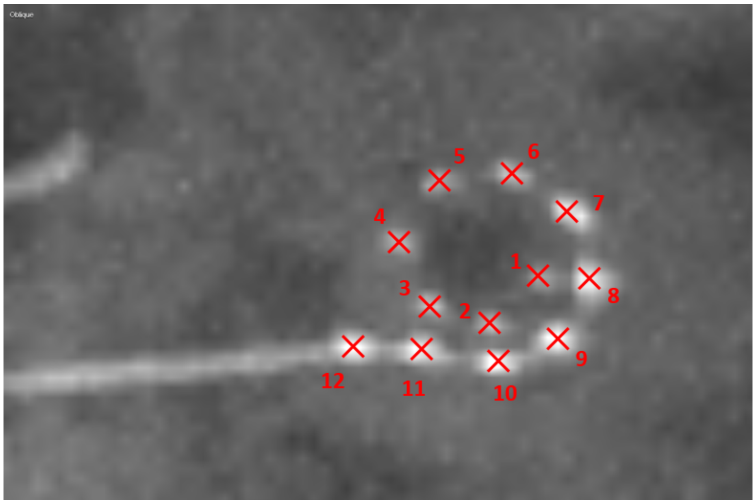

Figure 6: Step 2 - Detected positions of all electrodes i in the postoperative image. Note, that the counting of the electrodes starts at the innermost contact (contact 1) and extends towards the basal end of the cochlea (contact 12).

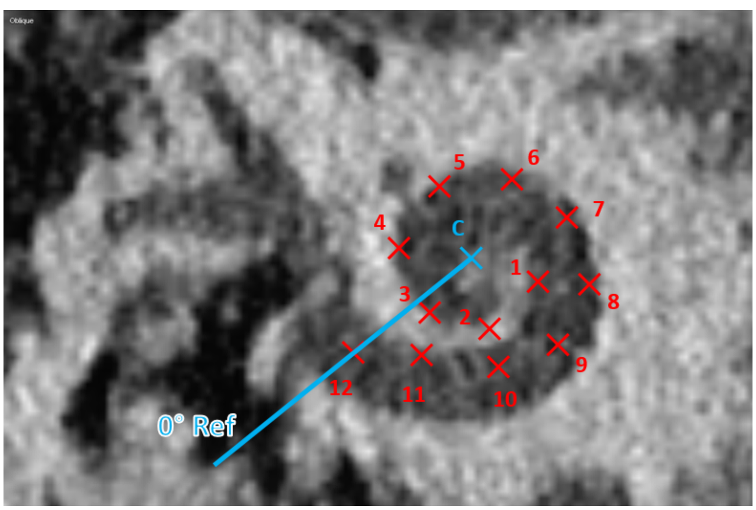

Figure 7: Step 3 - The 0-degree reference line is specified by the line between the center of the spiral (C) and the outermost electrode (12). NOTE: Usually an anatomical landmark is used as reference, the so-called round window. However, to simplify the task we will use the outermost electrode contact as reference.

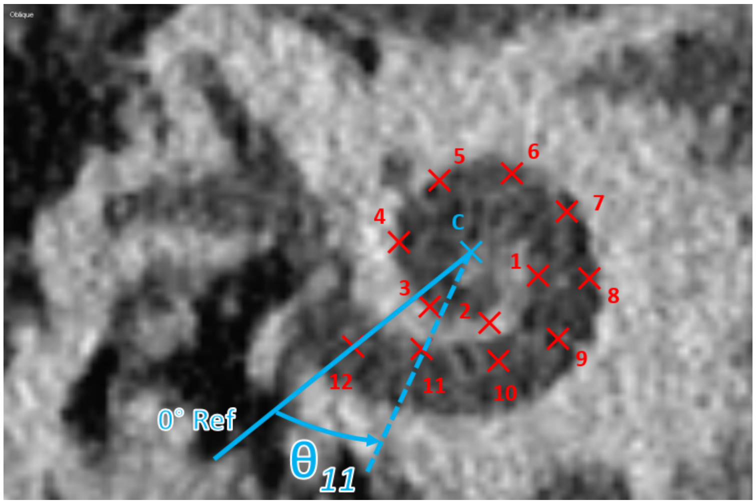

Figure 8: Step 4 - Angular insertion depth θ_{11} of electrode 11.

Table 1: Results of the shown example. Make sure to also enter your results in the provided excel sheet.

Electrode i	θ_i (in degrees)
1	482
2	426
3	374
4	312
5	254
6	203
7	164
8	128
9	96
10	65
11	24
12	0