HearRestore: Nanotracking for Image-guided Microsurgery

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The goal of this work is to provide a highly precise and accurate tracking system for minimally invasive microsurgeries, such as cochlear implants. Our tracking system needs to compute the position of the surgical tool with respect to the patient at all times, in real time and under highly varying conditions. We designed an off-the-shelf hardware platform that control our LED targets, and embed the computation of the 2D position of each LED, based on the 2D spaceCoder technology. Moreover, we developed a 6D algorithm to derive the final target position.

In this work we aim at replacing invasive standard cochlear implantation surgeries with minimally invasive, image-guided ones, where a robotic arm drills a very small tunnel from the surface of the mastoid bone to the inner ear or cochlea, so as to allow the surgeon to easily insert the implant. Specifically, we need to derive a navigation system able to track the position of the robotic drill with respect to the patient. The drill is supposed to follow a specific trajectory, which is defined by the surgeon from the anatomy of the patient (e.g. using CT scans). Once in the operating room (OR), and using fixed references on the patient, the drill is positioned so as to follow the pre-defined trajectory. The 6D position of the drill has to be very accurate, precise, and robust, to avoid irreparable damages to, for instance, the facial nerve or the ear's external membrane. To this end, our HearRestore tracking system, coupled with a navigation system, should provide a 6D position with 80 um accuracy, a 50 um precision, and 0.015°angular accuracy. It should also run in real time, be easily integrable in the OR environment and be compact.

We built the first HearRestore demonstrator consisting of a camera, a 6D spaceCoder platform, a 6D tracking algorithm, a 4-LEDs target, and a navigation application.

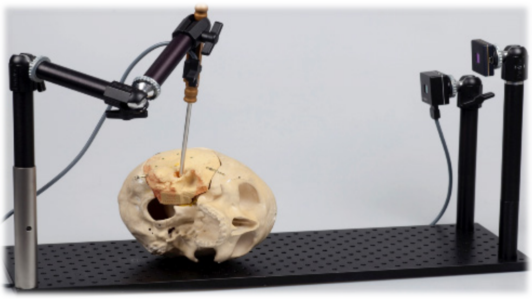

Figure 1: Initial HearRestore demonstrator for handheld medical devices. A 6D spaceCoder observes a 4-LEDs target The 6D spaceCoder platform synchronizes the acquistion of the uEye camera with the LEDs and controls the target. The images are sent to a PC to estimate the 6D position.

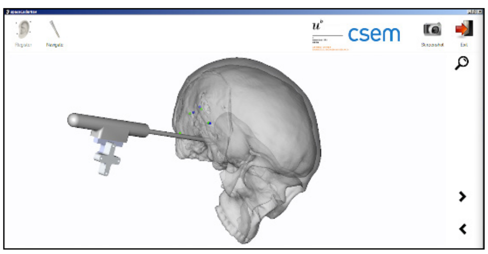

Figure 2: Navigation application representing the model with the moving surgical instrument. Joint work with ARTORG, Bern.

The platform drives the target and synchronizes the acquisition of the camera with the LEDs, whereas the navigation system shows in real time the 6D position of the instrument w.r.t to the patient. The 6D tracking algorithm computes the 6D position of the target based on projective geometry methods and using the 2D positions of each LED of the target. The 2D spaceCoder technology consists of an optical sensor coupled with a shadow mask and a 2D pattern. A point light source creates a shadow image, the phase of which encodes the position of the light source. Using at least 4 light sources on a rigid target, we can thus compute their 2D positions and the 6D position of the target.

To compute a 6D position with a high accuracy and precision, we first need to understand the sources of noise and error: why, when and how they occur. We can then derive appropriate calibration and corrective measures. We have identified and studied several sources of error, amongst which those due to light reflection and refraction.

Assuming a fixed spaceCoder setup in front of which a light source moves in a circular manner from -60° to +60°, we observed that whether it is reflections from the sensor's Silicon or from the mask's Chromium, the errors can be as high as 40 mdeg,depending on the light's incident angle (see Figure 3). We also simulated the effect of the refraction index of the shadow mask (glass) and observed that a slight change in the index can lead to large errors in the computed position.

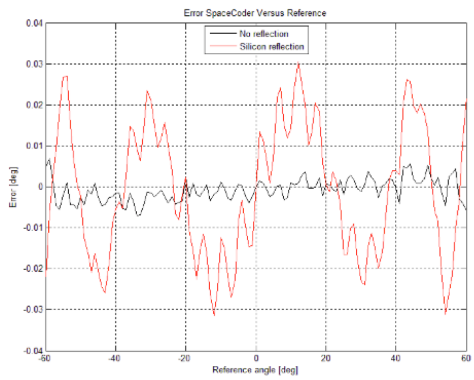

Figure 3: Errors due to the sensor's light reflections as a function of the incident angle. The large deviations from the center (red) are due to the Sillicon's reflections.

The next steps in improving the overall tracking system consist of the following: estimate the refraction index instead of using the theoretical one, derive corrective measures for each source of error, design a new LED target with a larger baseline and add a non-planar LED to lift position ambiguity in the 6D optimization, and finally embed all 2D-position computation to increase the frame rate and the apparent rigidity of the target.

A US patent application has been filed [1]. This work is supported by the NanoTera program.

[1] Patent: "6D positioning system using a shadow sensor", US number 14597434, filed 15-Jan-2015