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Outliers detection and removal for accurate surface-based registration

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Purpose

A novel approach is presented to improve the accuracy of a surface-based registration. This approach strongly reduces the inaccuracies occurring within the point acquisition process.

A registration process is required in any computer-assisted surgery in order to map the preoperative data into the intraoperative frame. In surface-based registration, one of the largest sources of inaccuracy lies in the point acquisition process [1]. Because of the presence of other surrounding tissues, the slippery bone surface and the occasional lack of attention from the surgeon, the acquisition of points lying far from the bone surface is inevitable. These points, called outliers, tend to worsen the overall registration accuracy, which may become unacceptably low in critical cases. A method to deal with this issue is therefore required [2].

A method is presented here to detect and remove most outliers from the acquired point set prior to perform the registration in order to significantly improve its accuracy.

Methods

In surface-based registration, the surgeon acquires a point set that will be mapped onto the bone surface in the preoperative CT-scan. To avoid this process from converging to an undesired mapping due to local minima trapping, a preregistration step is first performed. This preregistration consists in finding a rough spatial transform using three points acquired on the bone surface and their corresponding positions localized by the surgeon in the CTscan.

Our method detects the outliers as they are acquired so that they can be automatically removed from the point set and replaced by additional points newly acquired. The main idea of the detection is to attach, to each of the acquired points, additional data that are statistically correlated to the distance from the bone at which they were acquired. Such data, called features, include the speed and the acceleration of the probe when the point was acquired, and the preregistration error, *i.e.* the error estimated by means of the preregistration transform.

All these features are expected to have a much larger value for outliers than for regular points. Comparing the value of the features with some threshold values allows classifying each point as an outlier or as a regular point. Before performing the registration, we can therefore select a point set that contains few or no outlier.

Two types of errors could be observed: *false negatives* (outliers classified as regular points) and *false positives* (regular points classified as outliers). Ideally, both these errors would be zero. Too many false negatives would fail to improve the point set quality while too many false positives would increase the acquisition time due to the additional points that need to be acquired in order to

compensate for the large number of removed points.

To assess the efficiency of our method, surgeons were asked to acquire points all over a plastic iliac bone on which soft tissues were simulated by wet clay. In each experiment, the registration was first computed using the initial point set without detection of outliers and then recomputed using the point set from which outliers were removed and replaced by additional acquired points. The accuracy and the time required for the entire acquisition step were computed in both cases.

Results

Our approach showed excellent results both in terms of false positives and false negatives. Two thirds of the outliers accidentally acquired by the surgeons were removed while only 7% of regular points were incorrectly removed along with them.

The additional acquisition time was less than ten seconds on average for a total acquisition time of sixty seconds.

Further experiments are being carried out to validate the exact impact of the outlier detection on the overall registration accuracy. The preliminary results give us confidence that a significant accuracy improvement is expected (statistical analysis in progress).

Conclusion and discussion

The presence of outliers in the point set used for the registration is responsible for the largest part of inaccuracies in the navigation system. This issue cannot be avoided and some methods are required to deal with it. The simplest method is to estimate the registration accuracy and to subsequently ask the surgeon to redo the entire registration process if the estimated accuracy is too low. This can be very inconvenient as the registration process takes a long intraoperative time.

Other methods that can be found in the literature deal with outliers by using the result of a first registration to detect outliers and perform a second registration with the remaining points [3] intro. However, these methods take a much longer computational time and may eventually remove too many points, leading to lower registration accuracy [4].

Instead, our method deals with outliers straight when they are being acquired, which allows the acquisition of additional regular points prior to the registration. This ensures that a fix amount of points is available for the registration.

Although further experiments are currently carried out to validate the actual improvement of accuracy and to generalize it to other bones, there are strong expectations that this method is promising and should be used whenever a point acquisition step is required in computer-assisted surgery.

References

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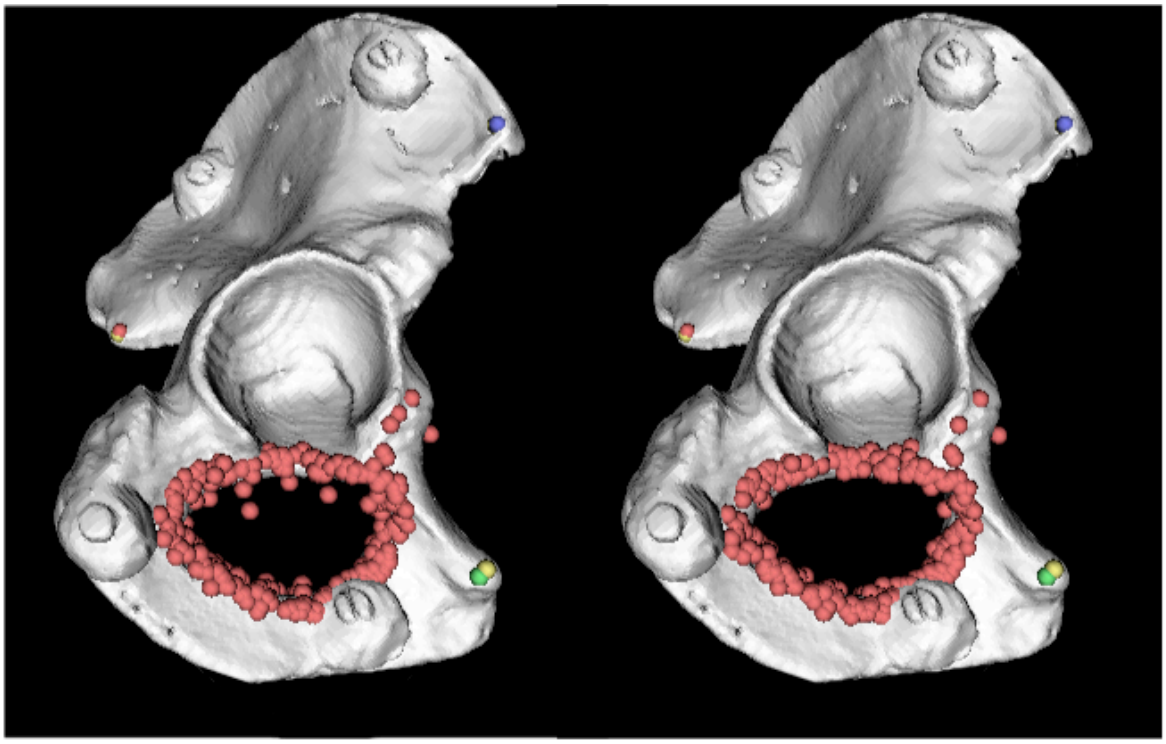

Points initially acquired (left) and after removal and replacement of outliers (right)