3D-3D Non-Rigid Registration of an Organ Model with Intraoperative Measured Data in Case of Hepatectomy

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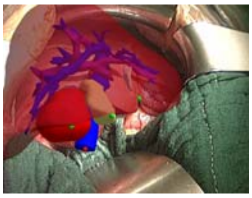
PURPOSE

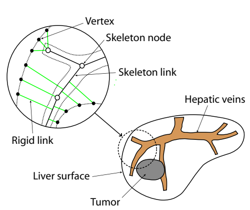
Nowadays, most modern and complex surgical operations are carefully planned in advance in order to define the strategy to pursue and identify the difficulties of the surgical process. A hepatectomy is a surgery consisting in the removal of liver parts affected by a tumor (e.g. hepatocellular carcinoma (HCC)). Before the operation, the surgeon plans the resection based on various kind of modalities ranging from CT scanner images to 3D virtual organ reconstructions. The principal difficulty at this stage is to decide which part of the liver will have to be removed to clear the tumor, without damaging the vessels irrigating the remnant liver.

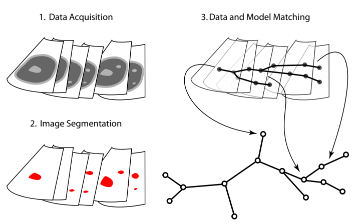


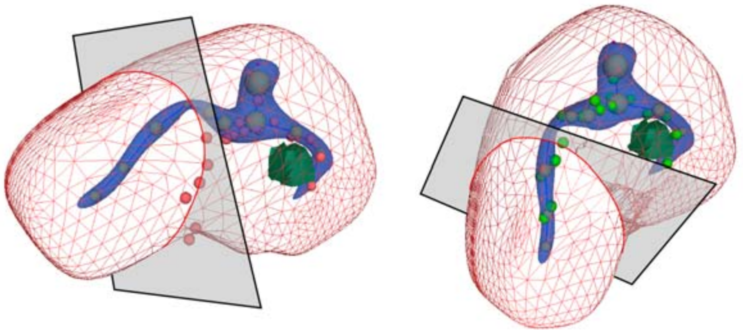
Our goal is to provide the surgeon with augmented reality (AR) based on the preoperative planning. It would help him interpret the situation by highlighting hidden body parts such as veins and arteries and localize himself in the patient's anatomy. Unlike computer assistance in orthopedic surgery, the mobility and deformations of an organ can have different and multiple origins. To produce reliable AR information, it is necessary to handle these changes during surgery and update the preoperative data accordingly.
Several research studies are on going to register preoperative scanner images with intraoperative ultrasound. Our goal is to go a step further by developing a fast non-rigid registration technique to update directly the virtual preoperative surgery planning while satisfying surgery time constraints.

METHOD

We use a skeleton based mass-spring representation to model the deformations of the organ 3D virtual mesh. The skeleton consists of a set of spherical control points (nodes) defined by mass, inertia and volumetric properties connected to each other with one or several elastic links. All the vertices of the mesh being initially connected to the skeleton, their position is only defined by some control points on the skeleton. That way, the computation time is greatly reduced compared to a more complex and accurate finite element model.
In our problem space, the control points of the skeleton are automatically generated from a CT based reconstruction of the hepatic veins and are connected together using an adaptation of the high-level Reeb graph. The liver being a highly irrigated organ, it contains a dense and well-distributed vascular network. Thereby,







we assume that if a vessel moves, surrounding tissues move accordingly and we can track vessels to deduce the shape of the organ.
In our approach, an optically tracked 2D ultrasound system is used to acquire a set of images of the patient's liver during surgery. A light intraoperative probe is used directly in contact with the surface of the organ, which reduces the deformations due to hand pressure compared to an external transducer. Even if the quality of ultrasound images is poor, hepatic vessels and tumor are easily distinguishable due to their texture difference with liver parenchyma. A segmentation algorithm extracts the areas of these features and computes their barycenter in 3D. This set of data points roughly represents the centerline of the hepatic vessels at time of surgery.
The non-rigid registration of the model with the data set is then performed by attracting the skeleton towards the measured points. This is done by applying on the control points forces proportional to the distance separating paired points. This process is iteratively performed until equilibrium is reached between internal and external forces.

RESULTS & CONCLUSIONS

We were able to demonstrate the feasibility of our non-rigid registration technique on models simulating the actual liver. The time of processing with a mesh formed of 2923 vertices is about 10 [s] on a standard desktop computer with an error RMS along the skeleton of about 3 [mm]. The deformation is rendered graphically in real-time with a frame rate of 20 [fps].
The first results obtained from tests performed on real data were promising but various problems arose. The sensibility of the model to external forces pushed us to start developing a hierarchical matching method using tree data structures. These graph structures are generated from a correlation between a priori knowledge on liver vessels anatomy and the pose of acquired US images.
To further control the liver mesh deformations, experiments are ongoing to validate the use of a second skeleton whose physical characteristics would be close to reality. It would help to preserve the organ volume while opposing internal forces to those driving the deformation.

ACKNOWLEDGEMENTS

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