# Automation of the preoperative image processing steps for ultrasound based navigation

C. Dekomien[1], S. Winter[1]

[1]Institut of Neuroinformatik, Ruhr University Bochum, Bochum, Germany

*Abstract*— **Ultrasound based navigation is a flexible, fast, and robust method for intraoperative navigation, where intraoperative 3D ultrasound is used for the registration procedure.**

**To establish ultrasound based navigation in the clinical routine, it is necessary to automate the preoperative image processing steps. The task of this process is the extraction of the bone surface from the preoperative CT or MRI data.**

**For the automation we developed an image processing pipeline. We designed a model of an ultrasound scan, which consists of a scan path and scan properties as transducer shape and width. The scan path was attached to anatomical landmarks. Based on these landmarks the model was registered within the preoperative image data and an ultrasound scan was simulated in the data to extract the bone surface visualised in ultrasound images. Additionally for complex structures as the lumbar spine it is necessary to separate single vertebrae. This segmentation was done by a shape-based level set method. The segmentation result was combined with the extracted bone surface, to assign the correct surface points to the vertebra.**

**The ultrasound registration with the described surface extraction method was evaluated by applying the proposed procedure on phantom and patient data. To estimate the overall accuracy, phantoms of the lumbar spine and the femur were used to compare the ultrasound registration with an accurate point-based registration. Therefore, 100 ultrasound registrations were compared with the reference registration and target registration errors were calculated for different anatomical regions. For instance, at the phantom of the femur the mean RMS error for all targets was 0.74 mm, where 0.64 mm was the systematic and 0.36 mm was the statistical error. The results lie within an admissible range for intraoperative navigation.**

*Keywords*— **Ultrasound Registration, Segmentation, Navigation, CT-data**

## I. Motivation

The request for minimally invasive surgeries leads to an increasing demand for surgical navigation systems. Requirements for navigation systems are low costs, flexibility and an easy handling [1, 2]. To establish a navigation system it needs to simplify the surgical work. Hence, a high automation of the preoperative data processing for the navigation process is essential.

For image based navigated surgery, the coordinate system of the patient has to be registered within the coordinate system of the preoperative data. To overcome some of the problems with the common landmark based registration methods [2], we use intraoperatively acquired freehand ultrasound to represent the coordinate system of the patient.

In previous work we developed a fast and robust algorithm to register the intraoperative ultrasound and preoperative CT or MRI data [3-5]. This surface-volume algorithm requires the extraction of the bone surface from the preoperative data. The bone surface is projected into the ultrasound data and, by the use of an optimization process, the surface is transformed into its optimal position. The optimization criterion is the sum of gray values of the ultrasound voxels which are masked by the transformed surface.

The preoperative process consists particularly of the extraction of the bone surface from the CT or MRI data. Our ambition is the automation of this process to keep the user interaction low. This will make the whole process more simple and less time consuming.

## II. Material and Method

### A. Data

We acquired 3D ultrasound and CT data from a spine phantom and a femur phantom. Moreover, spiral CT and ultrasound patient data from the lumbar spine were obtained. We used a Telemed ultrasound device with a 9 MHz linear array transducer to record the phantom ultrasound data. For the patient ultrasound data acquisition a Siemens Sonoline Omnia system and a 5 MHz curved array transducer was used. To get isotropic data all dataset were resampled to a resolution of $0.5 \times 0.5 \times 0.5$ mm$^3$.

### B. Image processing pipeline

For the automation of the preoperative bone surface extraction we developed an image processing pipeline (see Fig. 1).

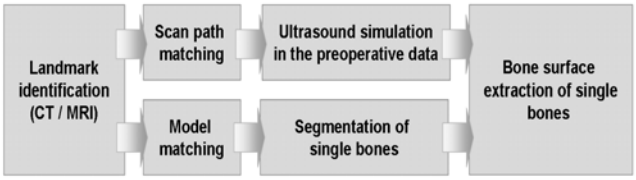


Fig. 1. Diagram of the preoperative image processing pipeline. After a landmark identification a scan path is matched with these landmarks. According to this scan path the ultrasound scan is simulated in the preoperative data. Simultaneously the landmarks are used for the model matching to segment single bones. The surfaces of single bones were extracted by combining the segmentation result with the extracted bone surface.

The precondition for the preoperative image processing pipeline is the design of models of ultrasound scan paths. These model paths should correspond approximately to the intraoperatively used ultrasound scan paths. Hence, the shapes of the model scan paths should nearly approximate the skin surface in the data. Additionally, some scan attributes of the intraoperatively used ultrasound transducers were also attached to the models. We distinguished between linear and curved array transducers and considered different transducer breadths and different angles for curved array transducers. For each anatomical region and for each ultrasound transducer a scan path model was designed. Additionally, anatomical landmarks were attached to the scan path models. Thus, a model scan path consists of the path with additionally scan and transducer features, and corresponding landmarks.

The first step of the image processing pipeline (see Fig.1) is the identification of predefined anatomical landmarks in the preoperative data. After this the model of the scan path was matched with the preoperative data by the use of a rigid point registration which is based on anatomical landmarks.

According to the registered scan path and the scan properties, the ultrasound scan was simulated in the preoperative data. To extract the bone surface every single ray of the simulated ultrasound was followed and the first voxel with a defined intensity, hit by the ray, was added to a set of surface points.

Because of the relative movement of bones it is important to register single bones. Therefore, in complex anatomical regions like the lumbar spine it is necessary to segment single vertebrae.

For the separation of the bone surface of a single vertebra, the vertebra was segmented from the whole lumbar spine with a flexible shape based level set segmentation technique [6], which is based on the algorithm from Tsai [7].

Finally, the extracted surface of the whole lumbar spine was combined with the segmentation result. By means of a distance function between segmentation result and surface we assigned surface points to single vertebrae.

### *C. Evaluation*

For the evaluation of the new bone surface extraction method we compared the ultrasound registration with an accurate point registration. Two plastic phantoms were used for the evaluation experiments: a lumbar spine phantom and a femur phantom. Both contained a number of drill holes, which were used as reference points for a point-based registration. For the reference registration the drill holes in the phantom were marked ten times with a pointer and a mean point set was build.

For the ultrasound registration we acquired ten 3D ultrasound datasets and created ten surfaces with the described image processing pipeline. With the ultrasound datasets and the surfaces we performed 100 ultrasound registrations.

The target registration error between the 100 ultrasound registration and the accurate reference registration was calculated for different point sets. At the lumbar spine, point sets of anatomical regions which are important for a pedicle screw insertion were marked. The anatomical regions are the right and left pedicle of the vertebra and the ventral face of the vertebral body. At the femur we marked anatomical regions, which are important for an anterior cruciate ligament reconstruction, where a borehole is drilled for a graft fixation. The first and the second region we chose, are the insertions of the anterior and the posterior cruciate ligament (these points are near the entrance point of the drill). The third region is the intersection between the lateral epicodyle and the femur diaphysis, where the graft is fixated.

## III. Result

After performing 100 ultrasound registrations for each of our phantoms the target registration error was calculated. The RMS error at the pedicle of the vertebra was 1.04 mm and at the ventral face of the vertebral body 1.11 mm. At the drill entrance at the femur point the RMS error was 0.76 mm and at the intersection between the lateral epicodyle and the femur diaphysis 0.69 mm. The overall RMS error at the femur was 0.74 mm and at the lumbar spine the overall RMS error was 1.14 mm. All results are listed in Table 1.

The target registration error consists of a systematic and a statistical error. The statistical error equates to the mean distance of all ultrasound registration to the center of all ultrasound registrations and the systematic error is the difference of the center of all ultrasound registrations to the accurate point registration.

Table 1 Target registration error at the femur and the lumbar spine; RMS: root mean square; MAX: maximal error; STA: statistical part of the error; SYS: systematic error. All values are mesured in mm. The different anatomical regions are the insertions of the anterior (AC) and posterior (PC) cruciate ligament, the intersection between the lateral epicodyle and the femur diaphysis (ED), the left (LP) and the right (RP) pedicle of the vertebra and the ventral face of the vertebral body (VB).

| anatomical region | RMS | MAX | STA | SYS |
|---|---|---|---|---|
| femur AC | 0.77 | 1.43 | 0.37 | 0.66 |
| femur PC | 0.78 | 1.78 | 0.41 | 0.67 |
| femur ED | 0.7 | 1.42 | 0.36 | 0.61 |
| entire femur | 0.74 | 1.78 | 0.38 | 0.64 |
| lumbar spine LP | 1.04 | 1.69 | 0.21 | 1.04 |
| lumbar spine RP | 1.27 | 1.95 | 0.19 | 1.25 |
| lumbar spine VB | 1.11 | 2.37 | 0.2 | 1.09 |
| entire lumbar spine | 1.14 | 2.37 | 0.2 | 1.12 |

Over all regions at the femur the mean statistical error was 0.36 mm; at the lumbar spine the statistical error was 0.2 mm. In Fig. 2 the deviation of all ultrasound registrations to the center of all ultrasound registrations are displayed. At the femur 100% were lower than 1 mm. At the lumbar spine 99.6% of the cases were lower than 1 mm.

The systematic error at the femur was 0.64 mm and at the lumbar spine 1.12 mm.

The preoperative pipeline for the surface extraction was although evaluated with patient data. Because in patient data we could not measure the accuracy, we visually estimated the correlation between the preoperative data and the ultrasound data. In Fig. 3 the registration result at the lumbar spine is illustrated. The registration showed a good correlation of the bone surface in the ultrasound and the preoperative data.

## IV. Discussion

The extraction of the bone surface with the preoperative pipeline showed good results. It was possible to perform ultrasound registrations with patient and phantom data. The high reliability oft the registration is reflected in the values of small statistical errors (see Table 1). The statistical errors of 0.38 mm at the femur and 0.2 mm at the lumbar spine were within an admissible range for intraoperative navigation. However, the main direction of the systematic error corresponds to the direction of the ultrasound propagation. After a systematic evaluation of the causes we will be able to reduce this error.

The calculation process of the automatic surface extraction is preoperative and therefore the computing time is not that relevant. The operating time was 3-5 minutes on an Intel Core 2 Duo 2.19 GHz CPU, whereas the shape based level set segmentation needed most of the time.

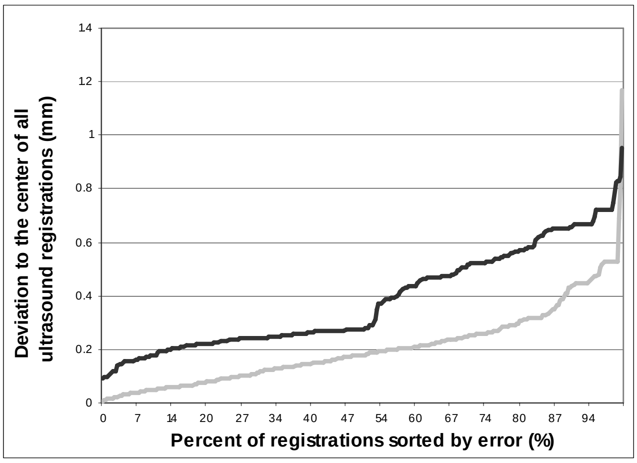


Fig. 2. The deviation of the ultrasound registrations to the center of all ultrasound registrations. The grey line represents the errors at the lumbar spine and the black line the errors at the femur.

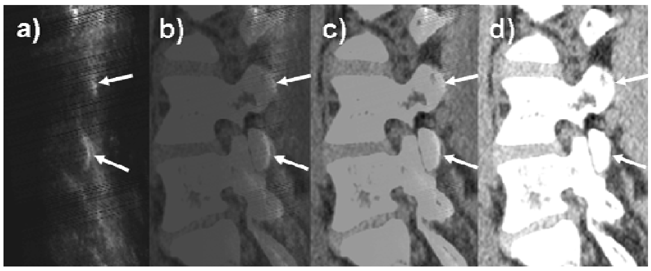


Fig. 3. Registration result at lumbar spine with patient data. The arrows mark the bone surface in the Ultrasound and CT data. a) Ultrasound volume b) and c) Overlay of ultrasound and CT data d) CT data

## V. Conclusion

We developed a preoperative image processing pipeline for ultrasound based navigation. Our preoperative process, advances the automation of the whole navigation process. Therefore, this work enhances the possibility of applying ultrasound based navigation in the clinical routine.

Next steps of our work will be the automatic detection of landmarks. These landmarks are necessary for the scan path matching and for the initial start position for the shape based segmentation method. Furthermore, we want to evolve the vertebra segmentation and expand the method to MRT segmentation at different anatomic regions.

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- Author: Claudia Dekomien
- Institute: Institut of Neuroinformatik
- Street: Universitätsstr. 150
- City: Bochum
- Country: Germany
- Email: Claudia.Dekomien@neuroinformatik.rub.de