Registration of the landmark points on human body and the sequences of computed tomography image

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Abstract

Image registration is a process of transforming different sets of data into one coordinate system. In recent years, the number of surgical operations that use the image navigation increases. They consist of tracking the position of surgical instruments and placing them on the model of the patient's body, which is reconstructed from the computed tomography (or magnetic resonance) image. The accuracy of the system depends mainly on the accuracy of registration process of CT image with the position of the patient during surgery. So-called landmark-based registration algorithm that takes a set of characteristic points was used. The research has been done, what landmark points are the best for the registration algorithm.

In this study nine points on the surface of the human body were pre-selected: xiphoid process, points on right and left costal margin, iliac spine anterior superior left and right, greater trochanter of the right and left femur, navel and pubic symphysis. Eight patients were examined. The position of points on patient's skin was recorded with the Polaris Spectra tracking system. Terms of coordinate measuring points were varied as anatomical attributes affected the accuracy. To verify the accuracy of measurement, the measuring plate prepared specially for this purpose was used. It consisted of cardboard with four fixed snippets of lead. The plate was placed immediately before the CT examination on the patient, so that it could be found within the CT volume. Points on the board have been recorded in the same way as natural points on the human body.

After the examination, all accessible points were manually segmented on CT image and the registration algorithm was performed. Statistical parameters of accuracy were computed.

1. Introduction

In recent years, the number of surgical procedures using imaging navigation has increased. They involve tracking the position of surgical instruments and visualization the model of the patient's body, which is generated on the basis of 3D image series. The accuracy of the system depends primarily on the accuracy of registration of CT image with the position of the patient during his operation. Landmark-based registration algorithm is used, as it transforms a set of characteristic points.

The goal of this study is to prove, what anatomical landmark points are the best for registration process, i.e. errors of their transformation are the smallest. Also in this study the comparison of registration accuracy between anatomical landmarks and artificial points marked on the body had been done.

2. Registration algorithm

Image registration is the process of transforming different sets of data into one coordinate system. It is used in medical imaging, but also in computer vision, robotics or cartography. Various registration algorithms are used [1, 2], depending on the type of input data and the required computational complexity. In this work a Horn algorithm [3], also known as "Landmark-based registration algorithm" was used, basing on finding the geometric isometric transformation that minimizes the sum of squares of residual errors (RSS). The algorithm is a closed-form solution to the RSS problem of transformation and that does not require iterations. The implementation of algorithm has been taken from open-sourced library Visual Toolkit (VTK) version 6.0.0, which is a complex library for 3D computer graphics, image processing and visualization.

3. Materials used

To determine the landmark points on the surface of the human body optical tracking system Polaris Spectra has been used [4] The system composed of two conjugated lenses tracks dedicated markers (fig. 1) recording their position with an accuracy of 0.1 mm. A marker has the form of four spheres with a diameter of 1 cm attached to limbs of cross of length about 5 cm. One limb of the cross is ended with a ten cm long stylus, by which accurately indication of the selected points can be done.

Fig.1. Polaris Spectra camera and the marker.

Developers of Polaris system both provides software to track objects as well as the API, making it possible to create own application. In this study the program that records localization of points has been created by extending library PLUS [ref]. Also an application has been created, which computes transformation matrix and registration error based on recorded points. Registration algorithms were implemented in ITK and VTK libraries.

CT series were acquired in Radiological Department of university hospital in Zabrze with spiral technology. All examinations were multi-phased, that means more than one (usually four) CT volumes were taken. Typical resolution of the image series was approx. 0,7×0,7×1,25 mm.

4. Method of determining the landmarks

After analysis of the literature [5], nine landmark points on human body surface has been pre-selected:

- Xiphoid process of sternum (XP)
- A point on costal arch both left and right (CA)
- Anterior superior iliac spine right and left (ASIS)
- Greater trochanter of right and left femur (GT)
- Umbilicus (U)
- Pubic symphysis (PS)

A point coordinates' recording is done by touching it by the stylus with Polaris marker attached and saving current position of marker. Terms of measuring the points were varied, main circumstances hindering the measure were: obesity of the patient, the presence of an ostomy bag on the left part of abdominal wall, bandages after recent surgeries of abdomen and pelvis or a thick layer of clothes. Not all the points were located on each patient's body, usually missed points were trochanters and pubic symphysis. Full abdomen and pelvis examinations were preferred. However, not all the points are within the volume of the CT image. The most common cropped landmarks were greater trochanters.

All selected points should be considered as fuzzy points, of a certain diameter. Patient's anatomy mainly affects the level of blur. Position of all points was independent of the others except points on the costal arch, which was depended on the accuracy registering the xiphoid process. The selection of points on the costal arch was as follows - one point in the middle section of the arc was selected, then the Euclidean distance between this point and the appendix xiphoid was computed. The corresponding point on the CT is a point on the costal arc lying at the same distance from the xiphoid process.

The reason of including points on the costal arch to the study protocol was that the arch is a structure situated very superficially and xiphoid process seems very easy to register [5]. In the case of navel, its upper edge in the median line was chosen. Segmentation of an image CT was performed manually. All selected points described by the index of voxels are scaled linearly to physical coordinates using the metadata from the DICOM header (DICOM dictionary). The dictionary includes, inter alia, information about the position of the beginning of the coordinate system related to physical indexes voxels, voxel resolution or spacing between the layers.

4.1 Reference coordinate system

Specially prepared for this purpose measuring plate to verify the accuracy of measurement was used. It was consisted of cardboard with dimensions of 18 by 8 cm with permanently fixed four scraps of lead (A – D) on the corners. These scraps are used to determine the parameters of the transformation between the coordinate systems of DICOM image and Polaris tracking system, since the accuracy of the identification points is significantly higher, both by Polaris stylus pointing it and by selecting a point on the DICOM image.

The plate was placed immediately before the examination on the patient, in such a way to be also found within the CT volume. Points on the board have been recorded in the same way as natural landmarks on the human body. The plate was fixed on the surface of the abdominal cavity so that it did not slide during the examination. However, in one case, the plate was significantly displaced and the error of the registration algorithm is one order of magnitude greater than in other cases. In this study the results of this measurement has not been included. In other cases, although the plate does not slide relatively to the patient's body, but it elevates and fall with the trunk during patient's breathing. As a result, the coordinates of the plates were taken

at a slightly different position by Polaris system and CT image.

The landmark-based registration algorithm was performed only with four points on the plate (A – D), giving as a result the parameters of the isometric transformation. Then, this transformation was applied on all recorded landmarks on the human body. The distance between positions calculated by the algorithm and segmented on the CT image for each point was computed. This distance is a registration error value [6].

5. Results

Registration results of sets of points are shown in the figures 1 – 3. They all present the results of patient number 5. The Model of the skin has been prepared directly from the CT image. Dark points are segmented from the CT image, and the bright points mark the positions recorded by Polaris transformed to the DICOM coordinate system. There can be seen that only four pairs of points on the abdomen, which are recorded from the reference plate, are relatively close fitted, while the other pairs have larger differences.

Fig.2. Anterior view of body model.

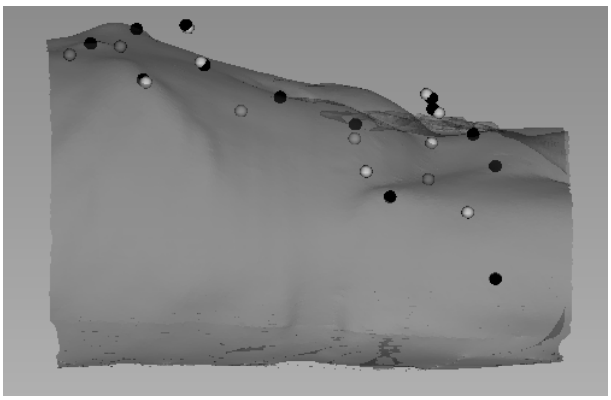

Fig.3. Lateral view body model.

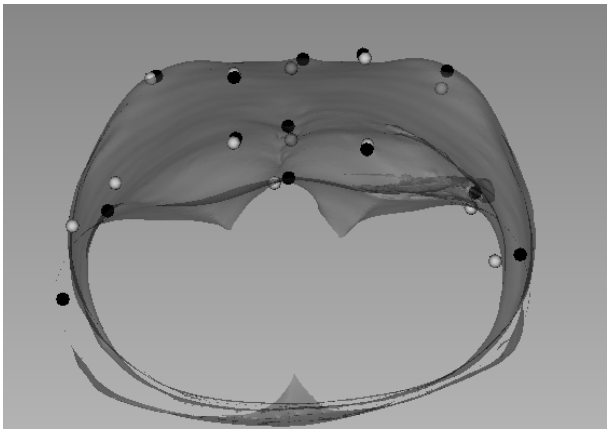

Fig.4. Inferior view of body model.

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Table 1 contains the error values of all the measurements. It can be seen that the registration errors of the reference points are meanly from 4.1 mm to 5.6 mm, while the registration errors of points on the surface of a human body are meanly from 13.5 to 40.5 mm. Such a large difference of results is caused by the fact that the landmarks are fuzzy points and their selection is very intuitive, especially in obese patients, in whom the skeletal system is deeply hidden. Respiratory activity of the patient also affects inaccuracy. Although all measurements were performed during inspiration of air, the anteroposterior dimension of the chest and abdominal can vary between breathing cycles. Furthermore, if the board has not only translation, but at least a small rotation, then registration errors of distant points have to increase significantly.

Tab.1.

Registration errors. Columns 1-8 indicate different patients and in rows there are specific points on measurement plate (A-D) and on patient body. Minimal values of rows are colorized.

	1	2	3	4	5	6	7	8	Mean	Std Dev
A	1,682	4,163	6,875	5,331	3,483	3,046	8,123	11,849	5,569	3,073
B	1,908	2,687	4,994	2,246	3,185	2,054	7,246	8,642	4,120	2,413
C	2,315	1,538	5,663	4,179	4,683	3,446	3,441	12,004	4,658	3,029
D	2,471	4,401	4,609	2,344	5,528	6,885	4,301	5,605	4,518	1,449
XP	44,054	40,539	25,235	59,595	19,702	33,378	32,711	35,826	36,380	11,403
CAr	31,674	49,563	62,311	33,942	4,386	14,533	38,931	6,713	30,256	19,241
CAl	46,135	45,447	56,375	38,152	18,316	21,840	54,829	18,684	37,472	14,841
ASISr	40,755	71,096	17,084	33,675	26,394	37,326	21,259	26,947	34,317	15,765
ASISl	43,093	49,803	12,618	41,647	10,950	25,328	30,273	40,882	31, 824	13,592
GTr	-	41,167	40,437	-	54,762	33,443	-	32,919	40,546	7,888
GRl	-	68,835	48,165	-	55,705	33,903	-	11,517	43,625	19,634
U	40,967	24,352	16,542	5,642	31,471	-	28,435	14,903	23,187	10,917
PS	-	0,871	15,601	3,888	34,217	-	-	13,080	13,531	11,710

5. Conclusions

As a result of this study, there was shown that anatomical landmarks on human skin are not good choices for origin registration points if the accuracy of registration process is crucial, because the error varies from 13.5 to 40.5 mm. Use of artificial points fixed to human body gives error results almost one order of magnitude smaller (from 4,1 mm to 5,6 mm).

However, additional use of two points (pubic symphysis and umbilicus) might be allowed, if very precisely performed, as the smallest errors are respectively 0,9 mm and 5,6 mm. Then only third point necessary for registration should be artificial.

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