**Matching of fiducial lines to slice intersection points in ultrasound images**

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***Abstract***

The need for accurate calibration for ultrasound systems in the treatment of prostate cancer is important as the dose for brachytherapy has to be determined precisely. Many calibration phantoms exist to perform these tasks but none of them is perfect. Therefore, one must provide new code for each phantom used by the calibration algorithm process. We propose a method that handles several phantom configurations with no manual tuning required. The idea is to introduce a scheme to describe the features of the quality assurance phantom, create a generic algorithm that can work without any manual tuning and optimize on any phantom by only requiring its description via a phantom definition xml file. The method also automatically computes segmentation and registration parameters which provide more accuracy and avoid a lengthy trial and error process to determine these parameters. From the fiducial point segmentation algorithm results (Chen, 2009), lines consisting of the fiducial candidate points are computed and then automatically registered to match the phantom description. The results are displayed in a 3D Slicer module which shows the matching between fiducial points and centroids of the point segmentation results; this module was extensively used for software debugging, testing, and creation of ground truth data sets for automatic testing. Our tests on real ultrasound data sets have given significant results and the method managed to segment and register two 3-point lines as well as computing automatically and successfully the maximum and minimum inclination of these lines for registration purpose.

*Index terms: brachytherapy, ultrasound imaging, segmentation, registration, automatic computation.*

***Purpose***

Ultrasound-guided low dose rate brachytherapy is now one of the popular therapy choices for treatment of early prostate cancer (Nag, 2000). It is important to avoid too high dose to preserve healthy tissue and too low dose which would not be sufficient to treat the tumor; therefore, imaging systems have to be calibrated and tested as precisely as possible. Current image quality assurance procedures are manual and therefore lengthy, require an operator with special skills and experience, and the results may be operator-dependent. All these limitations could be resolved by automating the quality assurance procedures. However, this automation is a challenging task, requiring extensive research and development work. One of the most important components of an ultrasound image quality assurance system testing system is the measurement phantom. The phantom is an object that can be imaged by the ultrasound device and contains a number of precisely manufactured features for supporting ground truth data for various measurements. Unfortunately, currently there is no one single measurement phantom that is suitable for performing all the required tests. Geometric calibration of ultrasound imaging systems requires phantoms and even though many versions are available, none of them is perfect, so more research and development work is required to develop and optimize new phantoms. Automatic fiducial line segmentation is therefore an important part of image quality assurance and calibration of ultrasound imaging systems and some algorithms already exist that could be utilized for automated quality assurance. However, the current methods need to develop new code specific to a phantom. This operation is very time consuming and the tolerance parameters are often constant and obtained via a trial and error process. We propose a method that helps this research and development work by not requiring any software changes when using different phantom geometries. by handling several configurations for the fiducial lines, this method will detect coplanar lines that be contained in multiple planes for any number of lines per plane as well as any number of points per line. This method will also determine the tolerance parameters automatically from inputs such as maximum angular movement.

***Method***

1. *Overview*

The method computes, from a list of segmented fiducial points provided by the fiducial segmentation algorithm by (Chen, 2009), a list of fiducial points registered to the fiducial line they belong to. The method also pre-computes automatically different segmentation parameters with precision and low input requirements.

1. *Phantom definition*

Here is an example of a phantom definition file:

<PhantomDefinition version="1.0">

<Description

Institution="Queen's University PerkLab"

Version="1.0"

Type="Double-N"

Name="fCAL"

/>

<Model

ModelToPhantomOriginTransform="

1 0 0 -15.0

0 1 0 10.0

0 0 1 -5.0

0 0 0 1"

File="FCal\_1.0.stl"

/>

<Geometry>

<!-- N wire definitions -->

<NWire>

<Wire Name="E3\_e3" EndPointBack="20.0 40.0 5.0" EndPointFront="20.0 0.0 5.0" Id="1"/>

<Wire Name="F3\_j3" EndPointBack="45.0 40.0 5.0" EndPointFront="25.0 0.0 5.0" Id="2"/>

<Wire Name="K3\_k3" EndPointBack="50.0 40.0 5.0" EndPointFront="50.0 0.0 5.0" Id="3"/>

</NWire>

<NWire>

<Wire Name="E4\_e4" EndPointBack="20.0 40.0 0.0" EndPointFront="20.0 0.0 0.0" Id="4"/>

<Wire Name="J4\_f4" EndPointBack="25.0 40.0 0.0" EndPointFront="45.0 0.0 0.0" Id="5"/>

<Wire Name="K4\_k4" EndPointBack="50.0 40.0 0.0" EndPointFront="50.0 0.0 0.0" Id="6"/>

</NWire>

</Geometry>

</PhantomDefinition>

Figure : Example of Phantom Definition File.

1. *Generic method*

From the list of fiducial points, N-point lines are computed and sorted by their intensity so that we have a list of lines each made of N fiducial points. The number of fiducial lines (fiducial points in a cross plane) is provided in the phantom definition file, as well as their basic structures such as parallel fiducial lines and Z-shaped fiducial structure. The number of these structures is not limited and is provided in the phantom definition file. Then, a backtracking algorithm is performed on the N-point lines found previously to match the actual lines made from the fiducial points from the phantom definition file. The choice for a backtracking algorithm is its simplicity and the fact that there are not too many candidate lines so the computation time of this part of the method is not preponderant. Once the lines are correctly matched, we can determine from image orientation and a transform matrix the correspondence between the fiducial points we found the actual one and therefore register them to the labels provided in the phantom definition file.

The different thresholds to accept points on a line or to register a potential line to an actual one is computed by the algorithm instead of implemented directly after a trial and error process. From the angular maximum movements of the ultrasound probe, we can determine how far from the actual position the candidate line can be. This angular maximum movement provides the range in which the image can actually be, as the image plane might not necessarily be perpendicular to the fiducial lines due to user movements, or could be slightly rotated around one axis or the other. These angular parameters can be obtained from the phantom definition file and the input data and would allow an optimal choice of threshold parameters that are automatically determined for any line configuration in the phantom. From these angles we can estimate the uncertainty of the image plane position by applying three rotations , one around each axis, to the change of coordinate system transform matrix. Then we can compute the intersection of the fiducial plane, defined by three wires in a N-shape configuration, and the image plane, and then compute the maximum and minimum possible inclination of the intersection line in the image plane. This computation will provide us automatically two important segmentation parameters with great accuracy.

1. *Implementation*

The method has been developed in C++ with the **Insight Segmentation and Registration Toolkit** (ITK) for portability, speed and robustness. A 3D Slicer module has been developed for visualization of input data and results. This module was extensively used for software debugging, testing, and creation of ground truth data sets for automatic testing. Here is a screenshot of the 3D Slicer module:

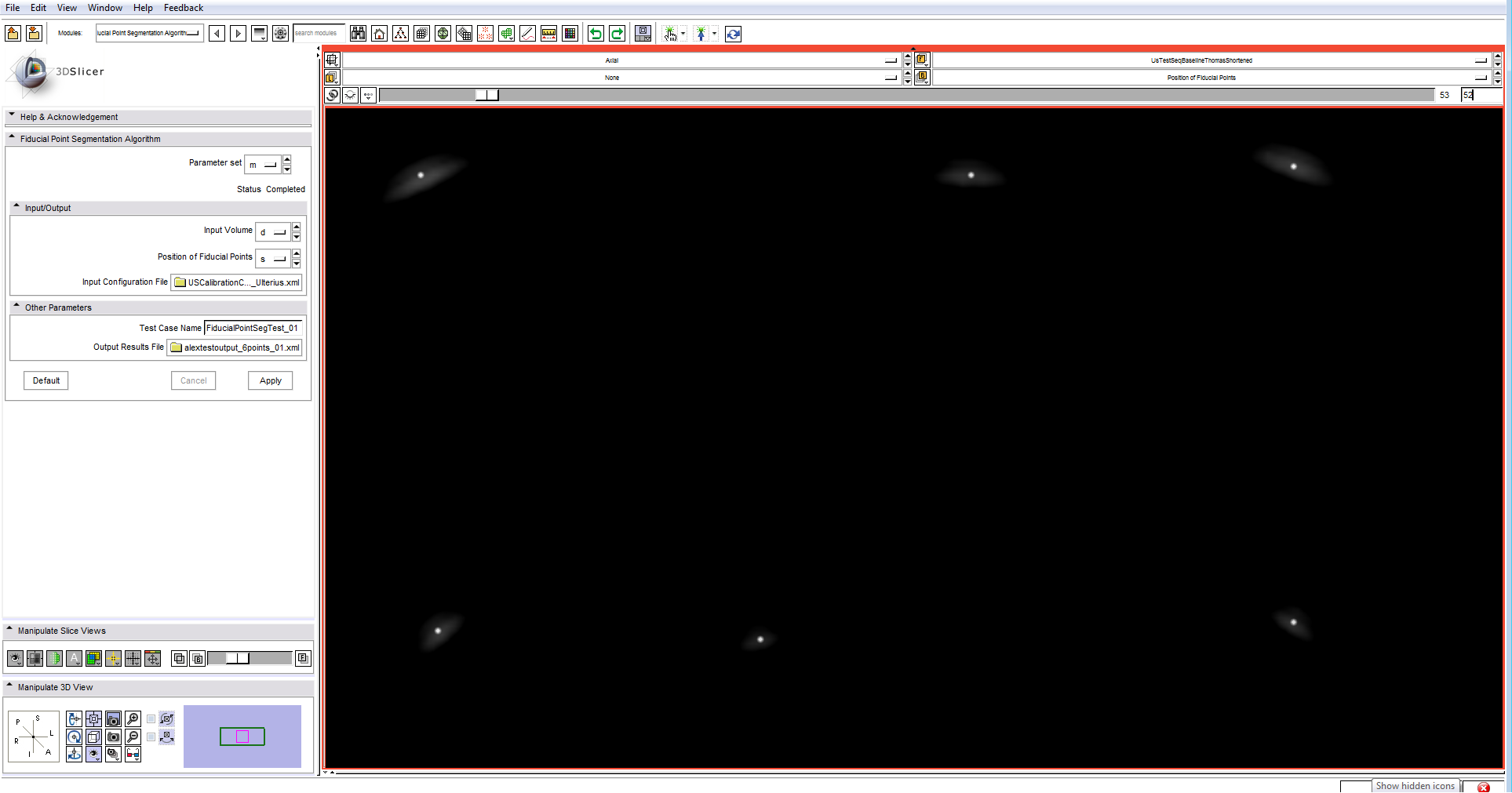
The algorithm is tested every night using CDash, which provides a consistent tool for testing and analyzing different information about the method such as speed of computation over time and after each update of the code to see what changes improved or slowed down the computation time.

Figure 2: Slicer Module displaying the dot segmentation result. The bright dots are the segmented centroids of the fiducial dots.

***Results and Discussion***

The automatic computation of some of the segmentation parameters, minimum and maximum angle of a line in the image plane, has been a success as tests on ultrasound dataset have been passed successfully. The next steps will be to extend the list of parameters that can be computed automatically to make the method as operator independent as possible and to compute accurate segmentation parameters without a trial and error process. The method also segments and finds the intersection of the fiducial lines with the image planes accurately and detects 3-point lines within an image.

***Conclusion***

The method we presented provides good segmentation and registration results on the current datasets while some segmentation tolerance parameters are computed automatically. The next steps are to implement the detection of n-point lines and more fiducial lines configuration as well as computing automatically more segmentation and registration parameters to provide a more operator independent and accurate algorithm in order to make ultrasound calibration processes as automatic as possible.

***References***

1. 1-2 papers on automatic US image segmentation, slice pose recovery (could be the Sangyoon paper, some other papers from the PerkWeb, …)

Chen, T. T. (2009). Chen, T.K., Thurston, A.D., Ellis, R.E., and Abolmaesumi, P. *Ultrasound in Med. & Biol, 35(1) pp. 79–93*.

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