Fusion of 3D MRI and X-Ray Fluoroscopy

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Abstract
The registration between pre-interventional three-dimensional MRI and X-ray fluoroscopy on an interventional cardiovascular flat-panel X-ray system is presented. The aim of this study is to evaluate the added value of the recently introduced flat-panel X-ray detectors for simplification of the fusion of MRI and X-Ray data. This study clearly shows that the complete absence of any detector introduced distortions enables an accurate fiducial-marker-based registration without any complex geometry or distortion correction, purely based on the dicom header information of the X-ray data. The registration accuracy was assessed by means of a phantom study. An average registration accuracy between the projected MRI data and the X-Ray data well below 1mm could be achieved in the standard LAO, RAO and AP projection directions.

Introduction
MRI is known to provide accurate morphological and functional information for a variety of diseases. Its application to diagnosis and treatment selection and planning is well accepted. However, its direct application to intervention guidance has not yet reached clinical practise and is only pursued at a very limited number of research sites. The use of pre-interventionally acquired MRI data during the intervention can be seen as an intermediate step towards a fully MRI-based solution. To make full usage of the MRI data during the intervention, it must be fused with the X-ray fluoroscopy for combination of the strengths of both modalities. On the standard image-intensifier-based (II) X-ray fluoroscopy systems, the required registration demands a correction of the II-induced distortion, which depends on the orientation and position of the X-ray gantry [1,2]. To avoid cumbersome calibration procedures and enable the image fusion for any view direction, a method not demanding any distortion corrections would be highly appreciated. In this contribution the application of a flat-panel detector for MRI-X-ray image registration purely based on the dicom header information without any additional calibrations is investigated.

Methods
All image acquisitions were performed on a Philips Intera 1.5T MRI system and a Philips Allura FD10 interventional cardiovascular X-Ray system. For accuracy assessment, eight multi-modal fiducial markers (donut-shaped hydrogel plates, 15mm diameter, 3.5, height, inner hole 5mm) were arranged on the surface of a standard MRI quality phantom (21cm diameter, 11 cm height). The phantom was imaged by a standard three-dimensional true-FISP sequence (50° flip angle, TE/TR 3ms/6ms) at an isotropic spatial resolution of 1mm³.

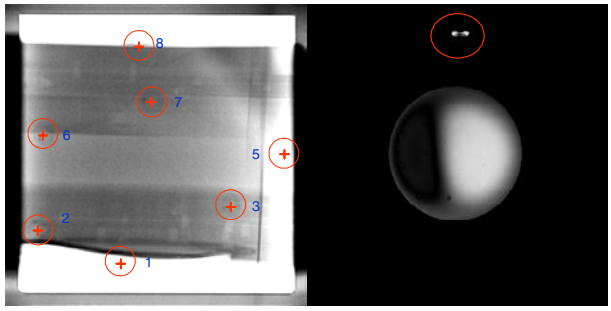

Figure 1: X-ray projection (left) and representative MRI image of the MRI IQ phantom with attached markers. The circles indicate the position of the marker in the image. The crosses indicate the projected position of the MRI marker in the X-ray image after transformation. (Marker 1 and 5 are not visible due to the windowing.

Subsequently, the phantom was imaged on the X-ray system at LAO, RAO and AP orientation with standard Cine exposure settings (73KV, 600mA, 5ms exposure time). The position of the markers (3D in MRI, 2D in X-ray) was determined manually in both data sets (see Figure 1). For determination of the transformation parameters, a 3D rigid-body transformation T_{rigid} was applied to the MRI marker positions (P_{MRI}). The error e used for the optimization was calculated as the mean square error between the projected transformed P_{MRI} and the position of the markers in the X-ray image ($P_{X\text{-}ray}$) according to:

$$e = \frac{\sqrt{\left(\sum_i T_{proj} T_{rigid} P^i_{MRI} - P^i_{X-ray}\right)^2}}{n},$$

with T_{proj} being the projection operator. Minimization was done applying a Simplex algorithm.

Results
The resulting accuracy was assessed using three to seven fiducial markers for determination of T_{rigid}. For all investigated combination of markers and view orientations, the resulting average error after optimization was well below 1mm. Considering the spatial resolution in the MRI image and the magnification during the projection, this implies an accuracy which is in the order one voxel in MR space (see Figure 1).

Discussion
Registration between MRI and X-Ray fluoroscopy can be done purely based on the information stored in the Dicom header of the X-ray image acquired on a flat-panel detector X-ray systems without any additional calibration. The resulting accuracy is in the order of the resolution of the MRI and should be sufficient to precisely superimpose the information derived by MRI onto the X-ray fluoroscopy data. Although this study is done by a fiducial-marker based registration, its extension to image-based 2D-3D registration techniques is straightforward and is expected to result into a similar accuracy of the registration.

References
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