Fast, Robust 3D Visualization and Automatic Slice Repositioning ("Snap-To") for MR-guided Interventions Using Active Device "Profiling"

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Introduction: In MR-guided interventional procedures [1] it is important to be able to quickly and automatically re-position the imaging slices to contain the active device in order to safely guide the procedure. Active interventional devices (devices that contain receiver coils whose signal can be collected separately from the other coils in the MRI scanner) may be tracked using embedded micro-coils and interleaved tracking pulse sequences ("tracking") or by incorporating signal detected by larger antennae into images ("profiling"). When using profiling, the operator may wish to update the 2D MRI slice prescription to correspond optimally to the current device position. Manual slice repositioning can be time-consuming, and complicated by difficulties in visualizing in 3D, through-plane motion of the device, and difficulty finding the device tip. Automatic repositioning ("Snap-To") should be robust for a wide array of active devices with varying coil characteristics, shapes, and varying numbers of active channels, and for the imaged slice(s) to be located at specific regions of the device --- such as the tip or the shaft.

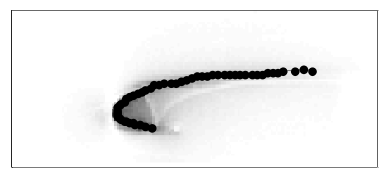
In this work we demonstrate a method to compute a 3D parameterization of the active device from sparse MR data. From three perpendicular 2D projection images we are able to compute a set of curvilinear 3D points representing the device. The points on this curve are used to determine the position and orientation of the slices to be imaged. Note that our parameterization of the device is a description of the whole length of the device, not merely a tracking of point-like microcoils.

Methods: To demonstrate the method a single-channel active guidewire was inserted in an aortic phantom (Shelly Medical Imaging Technologies, London, Canada) made of soft-silicone and tap-water. MR imaging was performed using a 1.5T Siemens Espree scanner (Siemens Medical Solutions, Erlangen, Germany). An SSFP imaging sequence was employed to obtain three 2D projection-images (Sagittal, Coronal and Transverse), each 256 x 256, with an FOV of 384 x 384 mm.

Given a set of 3D voxels, a moment of inertia tensor [2] can be computed whose principal eigenvector represents the principle axis of orientation of the 3D image. Consider a volume image that is zero-valued everywhere except along a curvilinear set of voxels. The moment tensor of a sub-volume centered at a voxel along the curve would have a principal eigenvector pointing along the direction of the curve (similar to how in diffusion tensor imaging, the principal eigenvector of the diffusion tensor represents the direction of diffusion [3]).

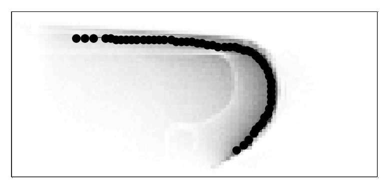
While we do not have access to the 3D image of the curvilinear catheter, we use the three perpendicular 2D projection-images to create an approximation to it. We do so by forming the product of these three projection-images. Specifically, we backproject each of the three projection-images onto the volume of interest to create three single-projection images (each of which is constant-valued along a set of parallel lines). We compute the voxel-by-voxel product of these three single-projection images. We then trace the curve of the active device in this product volume image as follows.

Starting from an automatically selected seed point, the principle eigenvector of the moment tensor of the local volume at the seed-point is used to determine the orientation of the curve through that point. Next, the adjacent point in the curve is identified by the center-of-mass of a local volume displaced along the direction of that principle eigenvector. This process is repeated until the distance between subsequent points is less than a sub-voxel threshold. We similarly extend the curve in the other direction away from the seed point. We use three separate seed points (produced by finding the maximally-valued voxel of the pair-wise product of the three single-projection images). Each seed-point produces a separate curve. The three curves are automatically merged based on proximity and continuity of points to produce a single curve. Finally, this curve is further refined by traversing through it once and identifying the center of mass of perpendicular slices of the product-volume image along it.



Sagittal View

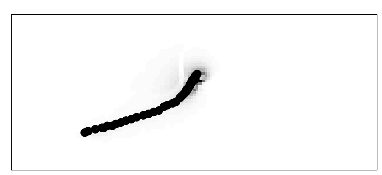
This process gives a complete parameterization of the device curve. The slice-plane to be imaged is positioned to contain as much of the length of the curve as required. The imaging plane is defined by the two principle eigenvectors of the moment tensor of subsets of points along the curve that are required to be imaged. The slice-plane can be located along specific sections (e.g. shaft or tip) of the device curve by more heavily weighting the corresponding points along the curve, or solving exactly for the plane[4], if it exists, that contains the specified segment of the device.



Coronal View

Results: The active device was correctly identified and parameterized. This was verified by getting a full 3D reconstruction of the whole volume and making sure that the points along the curve of the active device matched those in the 3D volume. As shown in the first three figures, further verification was performed by re-projecting the points of the device-curve (black dots) onto the 2D projection-images (underlying gray-scal images). The projections shown are zoomed in to show 90 (out of 256) rows, and the gray-scaling is reversed for easier visualization. As shown in the final figure, a slice-plane through the whole device-curve was computed.

Discussion: Previous work [5] in tracking the slice planes of an active needle has utilized the specific shape of the active device. Our method, on the hand, does not use any characteristic of the device other than its piece-wise-continuous shape. While the reconstruction shown here was created from projection-images with large FOVs, in order to reduce imaging time the small FOV of the device channel can be estimated from a quick pre-scan consisting of three orthogonal single radial 3D k-space lines. Three full 2D projection images containing the FOV of the device can be obtained in about 1 second. The parameterized curve can also be fed into a multi-slice visualization system [6] for through-plane 3D visualization of the device.



Transverse View

Conclusions: Active devices can be parameterized by a curvilinear set of points using sparse MR data. This parameterization can be used to reposition the slice plane to contain the active device and for better visualization

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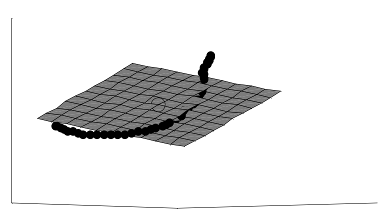

Slice Plane through curve