Development of a 3D device guidance platform for the Scanning-Beam Digital X-ray (SBDX) system

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A growing class of cardiac interventional procedures requires navigation of catheter-based devices within 3D spaces such as the cardiac chambers. Conventional 2D x-ray fluoroscopy provides limited guidance in these procedures, in part due to the lack of depth resolution. Scanning-Beam Digital X-ray, or SBDX, is an inverse-geometry fluoroscopic system designed for dose reduction and depth-resolved imaging. The system has a multi-source x-ray tube with a 2D array of focal spots, a small high-speed photon counting detector array, and a real-time image reconstructor. In each fluoroscopic frame period, the system scans a narrow x-ray beam over the patient and reconstructs a stack of tomosynthesis images (32 planes x 15 frame/s). Previous work has shown that SBDX tomosynthesis can, in principle, be used to localize catheter elements in three dimensions. The purpose of this work was to develop a real-time 3D device guidance platform based on the SBDX catheter tracking principle. The work was divided into three parts. First, a real-time version of the catheter tracking algorithm was developed and implemented in the GPU-based image reconstructor of the SBDX system. Second, a real-time 3D visualization system combining the output of real-time catheter tracking and live fluoroscopy was developed. The completed tracking and visualization system was evaluated in a phantom study requiring operators to use SBDX to navigate a catheter tip to different 3D points in space. Third, a novel technique called dynamic electronic collimation (DEC) was developed to minimize the radiation dose associated with SBDX catheter tracking. Real-time SBDX catheter tracking was successfully implemented at a rate of 15 frame/s. The real-time visualization system provided a virtual 3D display of the tracked catheter positions relative to a 3D anatomic model, and an integrated 2D fluoroscopy display. In operator studies, this system resulted in reduced catheter targeting error relative to 2D-only image guidance. Dynamic electronic collimation enabled a reduction in dose-area-product during catheter tracking. This method can be combined with task-based fluence optimization and frame rate reduction to minimize radiation dose.