C-arm inverse geometry CT for 3D cardiac chamber mapping

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Image-guided navigation of catheter devices to anatomic targets within large 3D cardiac chambers and vessels is challenging in the interventional setting due to the limitations of a conventional 2D x-ray projection format. Scanning-beam digital x-ray (SBDX) is a low-dose inverse geometry x-ray fluoroscopy technology capable of real-time 3D catheter tracking. SBDX performs rapid tomosynthesis using an electronically scanned multisource x-ray tube and photon-counting detector mounted to a C-arm gantry. While this technology could facilitate 3D image-guided navigational tasks, SBDX currently lacks the ability to perform volumetric computed tomography from a rotational C-arm scan. C-arm CT is an expected feature of interventional x-ray systems that could provide, for example, the necessary 3D cardiac chamber roadmap during catheter ablation of left atrial fibrillation. This work develops a novel volumetric CT capability for the SBDX platform, termed C-arm inverse geometry CT, suitable for rotational scans of the beating heart. The work is divided into three tasks: development of image reconstruction algorithms, implementation on the SBDX hardware, and performance assessment for the example task of 3D cardiac chamber mapping. SBDX-CT data acquisition is performed by simultaneous x-ray source scanning at 15 scan/s and C-arm rotation over a 190º short-scan arc in 13.4 seconds. An iterative reconstruction method based on prior image constrained compressed sensing was developed to accommodate fully truncated projections and data inconsistency resulting from cardiac motion during rotation. Hardware implementation included development of a C-arm angle measurement method, development of a geometric calibration method to account for non-ideal C-arm rotations, and detector response nonlinearity correction. The geometric calibration procedure mitigated artifacts from C-arm deflection during rotation. SBDX-CT image quality was evaluated in terms of artifacts, uniformity, and spatial resolution in a series of static phantom studies. Dynamic phantom studies evaluated chamber segmentation accuracy in the presence of chamber motion and field-of-view truncation. Segmentation error was quantified as the 99th percentile of a histogram of the surface deviations from the reference. For a chest phantom containing an atrium undergoing 60-88.2 cycle/minute motion and imaged at 50% full power, segmentation errors were 3.0-4.2 mm. Feasibility of in-vivo SBDX-CT was demonstrated in a porcine model.