CHARACTERIZATION OF MONOPLANAR 3D FLUOROSCOPY CALIBRATION

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Introduction

3D fluoroscopy (3DF) allows to accurately reconstruct joint kinematics, theoretically, with a mm/deg accuracy level [Tersi, 2012]. Fluoroscopic 2D projections are gathered using clinical fluoroscopes and C-arms, designed for qualitative real-time imaging of internal body structures, but not meant for quantitative studies. The accuracy, with which the X-ray focus position is operatively set, is affected by the physical deformation of the C-arm. The calibration of X-ray focus position is carried out with the acquisition of a 3D cage with radiopaque beads in known position [Tersi, 2012a]. Conversely, the extent to which X-ray focus calibration affects the reliability of the measurements has not been clarified yet. The present work aimed at the in-silico investigation of 3DF calibration in order to identify the conditions needed to maintain a sub-millimeter pose estimation error.

Methods

The calibration procedure was repeated on a synthetic data-set of reference images, created with the focus and a 3D model of a calibration cage in known position. A global reference frame was defined with x and y axes parallel, z-axis perpendicular to the image plane, and with the origin in the centre of the image plane. The Euler zxy convention was used for rotations. The X-ray source was placed in Fref = (Fx, Fy, Fz), with Fx and Fy in [0-5]mm, and Fz in [1000-1010]mm. Pixel spacing was fixed at 0.3 mm, for 1024x1024 pixel image. A 3D cage virtual model was obtained reverse engineering the RSA cage Model 10-knee (Tilly-Medical Products AB, Sweden) composed by a fiducial and a control plane, each with a grid of nine 1mm spherical tantalum bead. The cage was placed in known reference poses Pref = (Tx, Ty, Tz, Ox, Oy, Oz), with Tx and Ty in [0-10]mm and Oz in [0-30]°, Tz=0mm, Ox=0° and Oy=0°. The fiducial plane resulted adjacent to the image plane. For every combination of Fref and Pref a reference image was obtained projecting the shadow of the tantalum beads, and adding Poisson noise to the images. Hough transform was applied to find the centres of the projected tantalum beads. The beads were then manually labelled in order to associate the projection with the correspondent 3D bead. A well known SVD-based calibration procedure was applied to estimate the focus position [Valstar, 2002]. Briefly, fiducial markers were used to estimate the cage pose; control markers were then used to estimate focus position (Fx,est, Fy,est, Fz,est). Focus calibration error was computed as Ferr=Fest–Fref. The effect of Fref and of Pref were investigated using a 6 way ANOVA (α=0.05).

Results

The median value of the error was nearly 0 mm. As expected given the symmetry of the problem no difference were found between Fx,err and Fy,err with a maximum absolute error lower than 0.9mm. Fz,err showed a slightly larger maximum absolute error of 2.0 mm, but this was also expected due to the nearly parallel projection setup. ANOVA highlighted that the focus reference position had no effect on Ferr bias (P-value>0.05), but Fx,ref and Fy,ref contributed to increase the measurement dispersion of the Fx,err and Fy,err respectively. On the other hand the cage reference position Pref influenced the measurement bias (P-value<0.05) but not its dispersion.

Discussion

3DF calibration procedure proved to be effective with any combination of the tested parameters. Considering the correlation between pose estimation error and calibration error (20% [Tersi, 2012b]), in the worst case scenario the mis-calibration will affect the pose estimation for 0.2mm for in-plane translations and 0.4mm for out-of-plane translation, but this can be improved operatively avoiding the overlapping of bead projections.

References

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