Temporal Calibration of Tracked Ultrasound

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BACKGROUND: Tracked ultrasound (US) machines use a tracking system to sample the probe's position and orientation (pose). The recorded poses are then associated with the corresponding US images, allowing each image to be positioned and oriented in 3-D space. Establishing correspondence, however, is complicated by unequal processing times of the imaging and tracking, which causes the corresponding US images and poses to receive different timestamps. To correct for this error, temporal calibration is needed to compute the time offset between the tracker and image data.

OBJECTIVES: The primary aim of this work is to develop and implement a robust and fully automatic temporal calibration algorithm for tracked US systems. The secondary aim of this study is to investigate temporal offset as a function of US imaging parameters.

METHODS: Calibration begins by imaging a plate with a tracked US probe undergoing periodic and uniaxial freehand motion; this process yields a series of line motifs in the US images (Fig 1. A). Next, a three-step algorithm is executed: *STEP1* forms an image position signal by segmenting the line-motifs using a center-of-gravity (COG) technique to locate line positions and the random sample consensus (RANSAC) algorithm to estimate line parameters (Fig 1. B). *STEP2* forms the tracker position signal by computing the principal axis of probe motion, and projecting the probe positions onto this axis. *STEP3* aligns the tracker and image position signals by normalizing the signals and then performing a multi-resolution search to minimize the sum-of-squared-differences between the two signals (Fig 2. A, B). This three-step algorithm was included as part of the PLUS open-source Public Library for US research (https://www.assembla.com/spaces/plus).

RESULTS: 200 US sequences, collected under varying imaging parameters, were used for evaluation. The algorithm was found to compute temporal offsets precisely, generally with a standard deviation of <5ms between scans. Additionally, temporal offsets were found to vary considerably as a function of imaging parameters, falling in the range of 40-90ms.

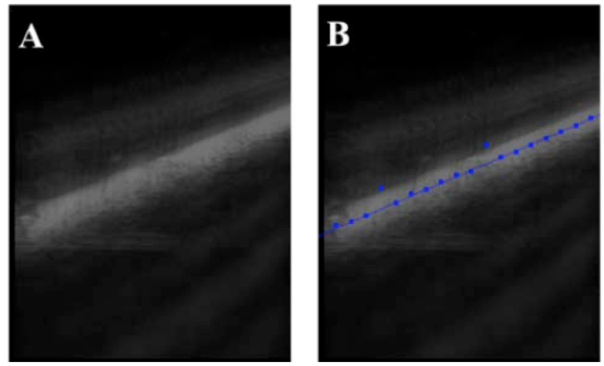

Fig.1 (A) *Original US image with a diagonal line motif.* **(B)** *Segmented line, with the dots found with the COG method and the line computed with the RANSAC method.*

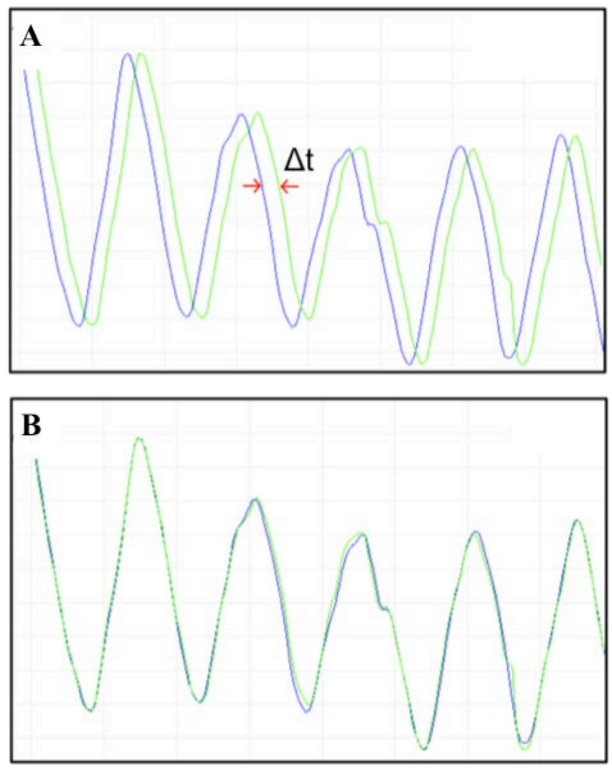

Fig. 2 (A) *Normalized tracker position signals (blue) and image position signals (green) before calibration and* **(B)** *after calibration. x-axes are time, and y-axes are the normalized signal values; Δt is the temporal offset.*

CONCLUSION: We presented a temporal calibration algorithm equipped with a robust line detection scheme. The precision of the algorithm was systematically evaluated under a range of imaging parameters, and the algorithm is freely available as part of PLUS.