Purpose: We previously reported the implementation of a novel telerobotic ultrasound system capable of real-time soft-tissue imaging during radiotherapy beam delivery. Expanding on this capability, the aim of this work was to develop and characterize an image-based technique for real-time detection of prostate and liver displacements.
Methods: Image processing techniques were implemented on spatially localized images to generate two tissue displacement parameters (TDPs) in real-time. The TDPs were derived from the cross correlation similarity measure between a reference image template and the current image within the incoming stream. In five volunteers, soft-tissue targets were continuously imaged with a customized robotic manipulator while recording the TDPs. Variations of the TDPs in the absence of tissue displacements were evaluated, as well as the sensitivity of the TDPs to prostate translations and rotations. Robustness of the method to template window selection and total time lag of the system were also investigated. The system's applicability to liver respiratory gating was explored with two volunteers.
Results: Prostate translations of 1.8 mm, 2.1 mm, and 2.0 mm were detectable in the M/L, A/P, and S/I directions at the 95% confidence level. Prostate pitch of 3.8° was also detectable. False positives in the absence of displacements were registered at a rate of 1 false positive event per 7 minutes of continuous imaging time. Total system time lag was 173 ms, mostly limited by ultrasound acquisition rate. Respiratory signals based on liver blood vessel monitoring differed significantly from signals based on an external marker.
Conclusions: For the first time, quantitative real-time monitoring of soft-tissue target displacements was demonstrated in-vivo using telerobotic ultrasound. Such monitoring has the potential to detect small clinically-relevant intra-fractional variations of the prostate position during radiotherapy. An internal ultrasound-based respiratory signal could be a better predictor of liver target motion than an external surrogate.