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Workflow-integrated Electromagnetic Tracking for Navigated Ultrasound-guided Interventions

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Computer-assisted Interventions (CAI) are becoming an integral part of modern patient care. This is attributed to a number of expected benefits compared to conventional approaches, including increased accuracy, reduction of complications and decreased intervention time. Despite the fact that these benefits of CAI have been shown in various studies, not many CAI systems have found their way into clinical practice yet. The lack of clinical use of these systems can be attributed to the difficulty of integrating these highly complex systems into clinical workflows, a lack of reliability, e.g. because of missing motion compensation, and high additional costs.

The localization of medical instruments, referred to as tracking, can be regarded one of the key techniques related to CAI. In this context, electromagnetic (EM) tracking is the only widely available technique that allows for localization without line-of-sight, as required for many minimally invasive procedures. However, clinical application has been hampered by issues of workflow-integration and a lacking robustness of EM tracking. In this thesis, a new concept for workflow-integrated and robust EM tracking of medical instruments was developed and validated. The contributions are: (1) a comprehensive analysis of the industrial and research state of the art, (2) standardized assessment of new developments in the area of EM tracking, (3) the new CAI concept EchoTrack for simultaneous instrument and patient localization derived from (1) and (2), and (4) validation of the concept by means of a prototype CAI system for navigated needle insertion.

EchoTrack integrates a new mobile EM field generator (Compact FG) and an ultrasound (US) probe in one single device and thus allows for simultaneous real-time localization of patient and instrument. It employs the following key advantages in comparison to previous systems: (1) No additional external hardware is required as the FG is directly integrated into the handheld EchoTrack Probe, which simplifies workflow integration. (2) Moving the FG together with the probe implies high precision and accuracy, since the area of interest automatically and continuously is situated near the center of the tracking volume. Initial validation studies performed with a research prototype of EchoTrack indicate that the concept allows for accurate tracking in clinical environments and that distortions caused by the attached US probes can be neglected for some probes. For validation in a clinical context, a prototype CAI system for navigated needle insertion based on EchoTrack was successfully assessed in phantom and animal studies, yielding a targeting error of 3-4 mm.

In conclusion, these results demonstrate the potential of the new EchoTrack navigation concept, in particular in facilitating US-guided needle insertions. Future work should be directed towards a larger animal study for greater statistical power and to clinical translation of the system. Due to the broad applicability of the EchoTrack concept for CAI in general, the potential impact can be regarded as extremely high.