Experimental evaluation of needle deflection estimation for brachytherapy

H. Sadjadi[1,2], K. Hashtrudi-Zaad[2], H. Xu[1], G. Fichtinger[1]
[1]Queen's University, School of Computing, Kingston, Canada
[2]Queen's University, Department of Electrical and Computer Engineering, Kingston, Canada

Keywords Electromagnetic tracking · Sensor fusion · Needle deflection · Brachytherapy

Purpose

Needle placement is commonly employed in clinical procedures for diagnostic or therapeutic purposes, such as prostate biopsy and brachytherapy. In these interventions accurate needle placement is required to carry out the desired diagnosis or therapy. However, complex needle behavior within tissue poses a major challenge, particularly when needle deflection exacerbates the targeting error. Accurate needle deflection estimation can help compensate for needle bending before and during insertion. Numerous mechanical models have been proposed for needle deflection estimation in soft tissue [1, 2]. The majority of techniques demand precise a priori quantification of deflection model parameters and in actual clinical settings they suffer from errors inherent in such quantification. Through extensive simulation studies [3], it has been observed that this error can be significantly reduced by integrating additional measurements taken directly from the needle tip. Accordingly, a needle deflection method has been proposed that combines a kinematic deflection model with data collected from two electromagnetic (EM) trackers located at the needle tip and base using Kalman filters. This paper presents experimental validation of the simulation results.

Methods

The experimental method evaluates the effectiveness of the proposed fusion approach [3] in estimating needle deflection that occurs during brachytherapy needle insertion procedures performed on prostate phantoms. As shown in Fig. 1, a total of 21 needles (beveled tip, 18 Gauge, 200 mm length) were manually inserted through a template, and towards different targets distributed within three prostate phantoms made from polyvinyl chloride (PVC) of varying stiffness. The needle deflection was modeled as a kinematic quadratic polynomial. Parameters of the deflection model were identified and perturbed by 50 % to simulate uncertainties in model parameters. An external 8 mm EM tracker and an internal 0.55 mm EM tracker were attached to the needle base and tip, respectively, to provide observations of their positions. These measurements were then fused recursively with the deflection model using a Kalman filter (KF) and an extended Kalman filter (EKF) to improve on the needle tip position estimation accuracy. C-arm fluoroscopy was subsequently used to obtain the ground truth deflection, and assess the performance of the proposed fusion technique. To quantify the estimation error, two metrics were used: the direct linear tip position estimation error and the cumulative deflection error (CDE). The former is the Euclidean distance between the estimated tip position and the ground truth tip position observed at a specific insertion depth, and the latter is the integral of the linear error over a range of insertion depths.

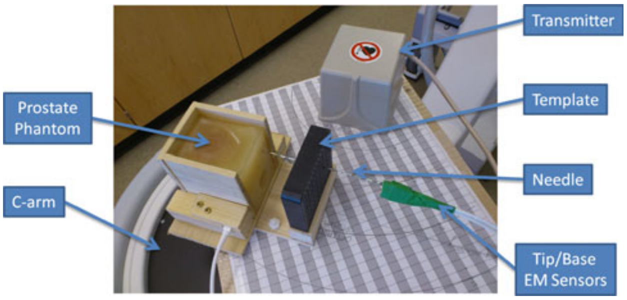

Fig. 1 Experimental setup for needle deflection measurement in prostate brachytherapy

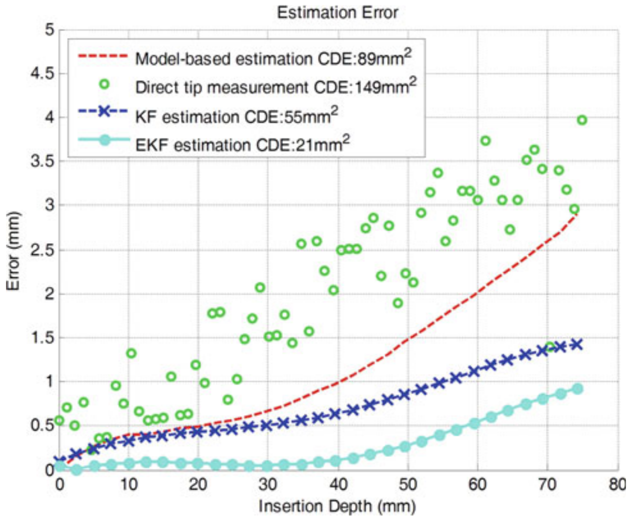

Fig. 2 Comparison of needle deflection estimation errors at various insertion depths, with the measurement data down-sampled for clarity

Results

Needle deflection during the procedure ranged from 2 to 8 mm at an insertion depth of 76 mm. As illustrated in Fig. 2, our experiments validated the simulation results shown in [3]. Compared to the estimations relying exclusively on a deflection model, the method reduced the direct linear needle tip position estimation error by 52 ± 17 %, and the CDE by 57 ± 19 %. While the KF was effective only in situations where the extent of deflection was limited, the EKF was efficient in the majority of cases and proved to be robust to model uncertainties as its formulation included a deflection model. The EKF, however, required more processing time due to the additional states, the nonlinearity of the process equations, and the computation of Jacobian matrices. Still, the recursive structure of both filters still enabled real-time implementation on a single core of an Intel® Core™ Quad 2.4 GHz CPU.

Conclusion

In general, estimation methods based exclusively on needle deflection models normally include some degree of uncertainty due to the error in the model parameter quantification. Similarly, direct observations of the needle tip contain some degree of uncertainty due to the measurement noise. As a result, statistical sensor fusion techniques, such as Kalman filters can help improve the estimation accuracy. In this work, we tested the usability of our proposed fusion approach [3] during simulated brachytherapy procedures performed on prostate phantoms. The results demonstrated significant improvement compared to the methods relying entirely on model-based estimations or solely on direct tip position measurements. We will continue to examine the performance of this method using alternative needle deflection models and expand the experimental validation to a wider range of clinical applications.

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A concept for a new working training culture for CAS research teams

W. Korb[1], N. Geissler[1], G. Strauss[2]
[1]University of Applied Sciences, Innovative Surgical Training Technologies (ISTT), Leipzig, Germany
[2]Universität Leipzig—Medical Faculty, Innovation Center Computer Assisted Surgery (ICCAS), Leipzig, Germany

Keywords Interdisciplinarity · Teamwork · Shared mental model · Cooperative learning · Surgical training

Purpose

Working in interdisciplinary teams is an ongoing challenge, “[…] a straightforward transfer from one problem area to another, however, often fails because the individual problem-specific discourse is not adequately understood, neither in other scientific fields, nor in the area of society affected by the problem” [1, p.29–30]. Different researchers (outside the surgical field) have developed concepts to support this interdisciplinary work with results from psychological and sociological literature [1]. The goal of the underlying work is to find new paradigms for a cooperating working and training culture in CAS. In this paper we give an insight into the results of (1) the own experience of more than 10 years of work in this research area, (2) the research of the corresponding interdisciplinary literature as well as (3) a think-tank on “Surgical Training” held in Leipzig in 2011.

Methods

First a structured analysis of the authors’ experience in different development projects in surgical technology was carried out. Further to this, the results of the discussions with renowned scientists within the CAS community were added.

This structured analysis was based on different keywords: problem solving, learning, personal development and understanding teamwork.

The literature review was based on these keywords from existing literature databases taken from the authors. Furthermore, the keywords were used to search the databases: Pubmed, Psyndex and Psycinfo. Additionally the German National Library was used.

The think-tank “Surgical Training” was organized together with experts from different institutes in Leipzig (University of Leipzig; University of Applied Sciences Leipzig; International Reference and Development Center for Surgical Technology). The think-tank included clinical, pre-clinical and engineering experts as well as experts in medical training. The think-tank took two hours and was analyzed based on the written protocol of the statements as well as on the power point slides.

Results

Methods of problem solving in CAS: Engineers and surgeons tend to have different strategies for problem solving. Surgeons are rather application-oriented; engineers are normally engineering-oriented. The importance of human-factors analysis is increasing and can be realised e.g. by psychologists. The literature research gives strong evidence that it is important to have a so-called “shared mental model” (SMM) [2] on project level. A mental model is a “…mechanism whereby humans generate descriptions of system purpose and form explanations of system functioning and observed system states, and predictions of future system states” [3, p. 360]. A SMM should include a common project goal and a common understanding of this project goal. For CAS this includes a common understanding of medical technology concepts as well as a common understanding of the patient model.

Differences in learning methodologies and understanding of teamwork: Currently there is no consensus on learning strategies between the different disciplines (surgeons, engineers and psychologists). Clinical structures are hierarchically organised and teamwork is different compared to engineering or psychology work groups. The literature [1] shows relevant concepts for learning strategies in interdisciplinary projects, such as the tandem, advocate or mentorship principle. For a common goal, social interdependence is quite helpful. Social interdependence appears if individuals share common purposes and individual outcomes depend on activities of other group members [4]. Especially in the recent literature several such strategies were newly structured and published [1].

Results of think-tank: It is mandatory to design advanced training courses in two directions: (1) for surgeons courses with technological background knowledge are needed and (2) for engineers such courses with clinical background knowledge should be devised. In the future there is a demand for training courses for surgical trainers including clinical, didactic and technological modules.

Conclusion

First there is the need that all group members agree on a common goal. This agreement process (which yields in the SMM) may need a reasonable time and a moderator. To overcome borders is sometimes difficult and it may be difficult to reach an overall consensus, but within a specific project a consensus needs to be defined.

The second main challenge for the future is “cooperative learning”. New strategies that can lead to a new cooperating working culture are the tandem, advocate or mentorship principle. Thorough observations and listening as well as appropriately training interdependence and interaction coupled with a direct instruction are relevant especially in dealing with conflicts and are to be expanded [4].

This will lead to the demand for new training courses in the CAS community: Surgeons need to be trained in technological competence and engineers in clinical basics. Future research is needed for good adequate training environments where interdisciplinary training is possible.

In summary, working in interdisciplinary teams is challenging because of different working cultures. A new cooperating working culture is only possible based on the understanding and respect of the “other” working culture. The goal of all disciplines (consensus) is the development of efficient new technologies, which can be adequately used in the OR and enhance patient safety. This study showed that it is worth to investigate the recent literature in this field to learn from that for CAS research.

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A RFID system for automated instrument recognition for a precise identification of the intraoperative workflow

A. Schneider[1], E. Schwan[2], M. Kranzfelder[2,1], D. Wilhelm[2,1], T. Vogel[2,1], H. Feussner[2,1]
[1]Klinikum r.d. Isar der TU Muenchen, Department of surgery, Munich, Germany
[2]Klinikum r.d. Isar der TU Muenchen, Research Group MITI, Munich, Germany