SafeRPlan

Spinal fusion surgery requires highly accurate implantation of pedicle screw implants, which must be conducted in critical proximity to vital structures with a limited view of the anatomy. Robotic surgery systems have been proposed to improve placement accuracy. Despite remarkable advances, current robotic systems still lack advanced mechanisms for continuous updating of surgical plans during procedures, which hinders attaining higher levels of robotic autonomy. These systems adhere to conventional rigid registration concepts, relying on the alignment of preoperative planning to the intraoperative anatomy. In this paper, we propose a safe deep reinforcement learning (DRL) planning approach (SafeRPlan) for robotic spine surgery that leverages intraoperative observation for continuous path planning of pedicle screw placement. The main contributions of our method are (1) the capability to ensure safe actions by introducing an uncertainty-aware distance-based safety filter; (2) the ability to compensate for incomplete intraoperative anatomical information, by encoding apriori knowledge of anatomical structures with neural networks pre-trained on pre-operative images; and (3) the capability to generalize over unseen observation noise thanks to the novel domain randomization techniques. Planning quality was assessed by quantitative comparison with the baseline approaches, gold standard (GS), and qualitative evaluation by expert surgeons. In experiments with human model datasets, our approach was capable of achieving over 5% higher safety rates compared to baseline approaches, even under realistic observation noise. To the best of our knowledge, SafeRPlan is the first safety-aware DRL planning approach specifically designed for robotic spine surgery [1)]

1)
Ao Y, Esfandiari H, Carrillo F, Laux CJ, As Y, Li R, Van Assche K, Davoodi A, Cavalcanti NA, Farshad M, Grewe BF, Vander Poorten E, Krause A, Fürnstahl P. SafeRPlan: Safe deep reinforcement learning for intraoperative planning of pedicle screw placement. Med Image Anal. 2024 Sep 16;99:103345. doi: 10.1016/j.media.2024.103345. Epub ahead of print. PMID: 39293187.

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