Abstract: Deep Geometric Supervision Improves Spatial Generalization in Orthopedic Surgery Planning

Florian Kordon[1,2,3], Andreas Maier[1,2], Benedict Swartman[4], Maxim Privalov[4], Jan S. El Barbari[4], Holger Kunze[3]

[1]Pattern Recognition Lab, Friedrich-Alexander Universität Erlangen-Nürnberg (FAU), Erlangen
[2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Friedrich-Alexander Universität Erlangen-Nürnberg (FAU), Erlangen
[3]Siemens Healthcare GmbH, Forchheim
[4]Department for Trauma and Orthopaedic Surgery, BG Trauma Center Ludwigshafen, Ludwigshafen
florian.kordon@fau.de

Careful planning of the individual surgical steps is an indispensable tool for the orthopedic surgeon, elevating the procedure's safety and ensuring high levels of surgical precision [1]. A surgical plan for routine interventions like ligament reconstruction describes several salient landmarks on a 2D X-ray image and relates them in a geometric construction. Previous attempts to automate this planning type typically separate automatic feature localization with a learning algorithm and geometric post-processing. The separation allows us to mimic the manual step-wise workflow and enables granular control over each planning step. However, this approach comes with the drawbacks of optimizing a proxy criterion different from the actual planning target, limiting generalization to complex image impressions and the positioning accuracy that can be achieved. We address this problem by translating the geometric steps to a continuously differentiable function, enabling end-to-end gradient flow. Combining this additional objective function with the original proxy formulation improves target positioning while preserving the geometric relation of the underlying anatomical structures. We name this concept Deep Geometric Supervision. The developed method is evaluated for graft fixation site identification in medial patellofemoral ligament (MPFL) reconstruction surgery on (1) 221 diagnostic and (2) 89 intra-operative knee radiographs. Using the companion objective reduces the median Euclidean Distance error for MPFL insertion site localization from (1) 2.29 mm to 1.58 mm and (2) 8.70 px to 3.44 px, respectively. Furthermore, we empirically show that our method improves spatial generalization for strongly truncated images where only a small part of the relevant anatomy is visible.

References

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