KNEE FLEXION ANGLE ESTIMATION BASED ON FUNCTIONALLY INSTEAD OF ANATOMICALLY DEFINED COORDINATE SYSTEMS

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Introduction

Knee angles are commonly presented in gait analysis reports. They are typically calculated as the relative angles between coordinate systems (CSs) rigidly attached to the femur and the tibia. To give these angles a consistent meaning, the CSs are defined with respect to anatomical landmarks. Defining accurate anatomical CSs is not an easy task, because it requires skills in marker placement, landmark identification and definition of a biomechanical model. Therefore we present a novel method to (i) functionally define two CSs attached to femur and tibia and (ii) functionally calculate the knee angle based on the relative differential kinematics between those CSs. The method has the advantage of being independent (i.e. invariant) of the choice of the original CSs of the femur and tibia, removing the need for accurate marker placement. Consequently, (i) the markers may be placed on optimal landmarks, for example, minimizing the soft tissue artifacts or improving subject's comfort, and (ii) there is no need for anatomical calibration when technical marker clusters/triads are used.

Methods

The proposed method is based on representing the knee motion around an average screw (helical) axis (ASA), which is functionally determined across a gait cycle [1]. The method exploits the knee ASA to define a local CS relative to a body segment. The procedure is repeated twice, once for the femur and once for the tibia, in order to functionally obtain two CSs rigidly attached to the respective body segments. The relative pose of the two CSs can then be used to calculate features of the knee kinematics. In particular, when representing the orientation part of this relative pose in terms of Euler angles according to sequence XYZ, the angle about the X-axis represents the functional knee angle.
The method was tested on a gait analysis trial from the CAMS-Knee dataset [2] (trial 1 from subject "K8L") recorded through fluoroscopy. See [3] for more details.

Results

Figures 1 and 2 show that the method produced consistent results for the invariant knee angles (green and blue) calculated according to the proposed procedure, even when the measured poses of the anatomically referenced CSs were randomly modified. Obviously, the anatomical angles (red and pink) lost their biomechanical meaning after such transformation.

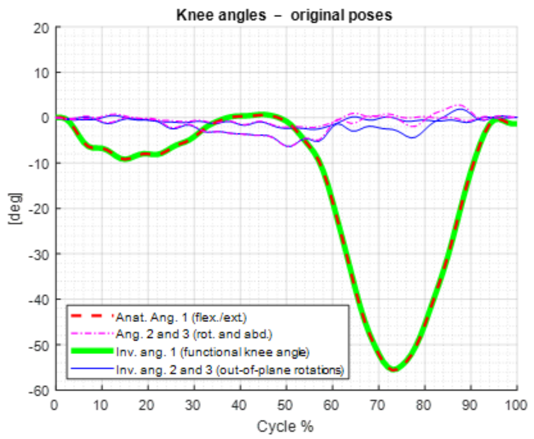

Figure 1: Anatomical and invariant angles based on the measured poses of anatomically referenced CSs.

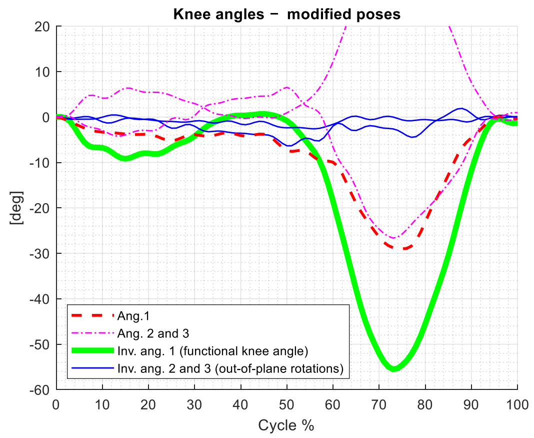

Figure 2: Anatomical and invariant angles after randomly transforming the measured poses.

Discussion

The invariant flexion angle is close to the anatomical one (figure 1). The method is useful when anatomical references are not available. As a limitation, it does not provide an absolute knee flexion angle, but an accurate estimation of the relative angular motion of the knee.

References

1. A. Ancillao et al., Sensors 2019, DOI: 10.3390/s20010049
2. W.R. Taylor et al. J. Biomech. 2017, DOI: 10.1016/j.jbiomech.2017.09.022.
3. A. Ancillao et al., Int J Environ Res Public Health 2022, DOI: 10.3390/ijerph20010500

Acknowledgements

The present study has received funding from the European Research Council (ERC) (grant agreement No. 788298).