Generalised joint kinematic analysis and 3D visualisation: a human wrist case study

O. Elnaggar[1], F. Coenen[2], A. Hopkinson[3], P. Paoletti[1]

[1] School of Engineering, University of Liverpool, Liverpool. [2] School of Electrical Engineering and Computer Science, University of Liverpool, Liverpool. [3] School of Psychology, University of Liverpool, Liverpool.

Introduction

Knowledge of joint kinematics is clinically useful for disease diagnosis, treatment planning and evaluation of rehabilitation effectiveness. Works on wrist joint motion analysis often parameterise the motion by rotations about two mutually orthogonal anatomical axes; *flexion-extension* (FE) and *radial-ulnar deviatio*n (RUD). Nonetheless, it has been known for some time that the wrist axes of rotation are rather oblique and non-intersecting [1]. There is evidence that kinematic coupling between FE and RUD rotations, e.g. ulnar flexion and radial extension, is inherent to many functional tasks involving the wrist [2].

Moreover, clinicians usually prefer to work with intuitive angle timeseries or angle-angle plots (e.g. FE versus RUD), normally derived from Euler angle decomposition. Although such visualisations may help in realising a tri-axial joint motion (ignoring errors due to non-orthogonality), they are less applicable to uni- and bi-axial joints (e.g. wrist joint) due to omitting the unused Euler angle(s).

A 4D axis-angle kinematic representation decomposes any arbitrary joint motion into the effective Cartesian axis and scalar angle of rotation and has the potential to overcome issues with traditional FE/RUD plots. This 4D representation was found useful across various biomedical applications, such as human sleep posture classification [3]. However, producing temporal axis-angle graphs remains only partially exploited as 4D visualisations are not readily interpretable. An intuitive visualisation is proposed in this paper to enable anatomy-inspired findings in the field, from rethinking joint range of motion to walking gait segmentation.

Methods

A human participant case study is considered with the aim of visually analysing the left wrist kinematics as the participant transitions between twelve postures. Two inertial measurement units are attached to the forearm and the hand to estimate the relative orientation about the wrist joint, obtained through fusing geo-inertial sensor measurements. The aim of the study is to show the feasibility of mapping the wrist's axis-angle orientations to a 3D pseudo-Cartesian space using the *Uniform Manifold Approximation and Projection* [4] (UMAP); a nonlinear dimension reduction technique. For effective dimensional reduction, a sufficiently large orientation dataset uniformly distributed in the 4D axis-angle space is a prerequisite, but the wrist joint is anatomically constrained. Therefore, a *procedural generation framework* is proposed to create a synthetic dataset of uniformly distributed orientations in the 4D axis-angle space, which is used to train a UMAP model. The pre-trained model then embeds the sensor-measured wrist orientations into the learnt 3D embedding space.

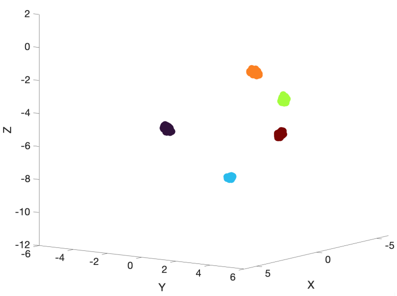

Figure 1. UMAP visualisation of the wrist kinematics for selected human postures.

Results & Discussion

The proposed procedural generation framework produced a dataset containing 48,600 synthetic axis-angle orientations, given preset framework-specific hyperparameters such as sample resolution. The UMAP training produced 3D data points resembling a sphere-like shell with a thick crust. Meaningful geometrical insights linking the 4D axis-angle space to the 3D embedding space were identified. Over 60 minutes of wrist orientation data were then collected from the wearable sensors at 30 Hz and fed into the pre-trained UMAP model. Figure 1 depicts how the proposed approach creates concise clusters of 3D data points unique for selected postures. Additionally, a video is created through playback of static 3D plots, showing the temporal changes in the axis and angle components of the wrist orientation during posture transitions.

Conclusion

A procedural generation framework is proposed to generate synthetic, uniformly distributed axis-angle orientations. Nonlinear dimension reduction has proven to be effective in allowing easily-interpretable 3D visualisation of joint kinematic data that do not suffer from the same issues of FE/RUD or Euler angles plots.

References

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