Inertial Measurement Unit calibration methods for the wrist joint: Which one should I use?

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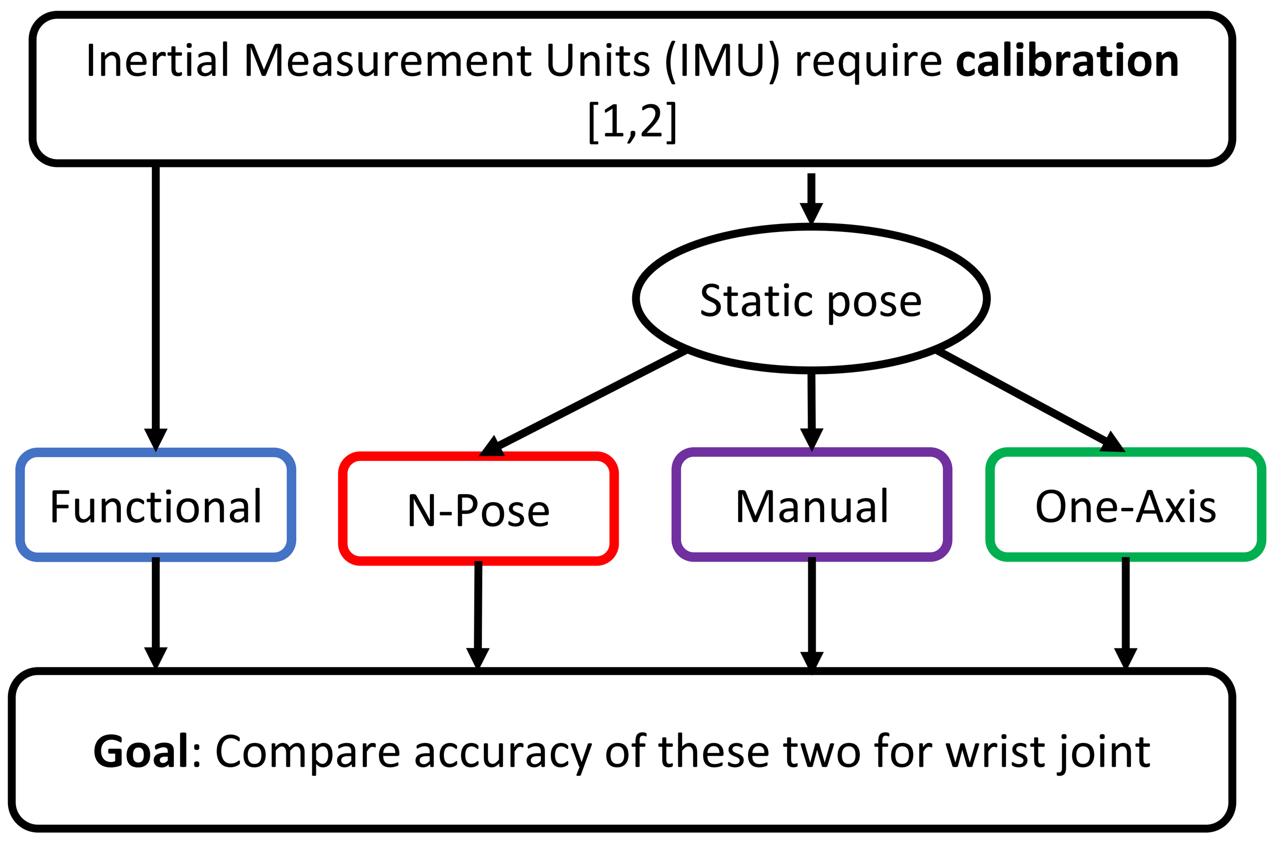

Introduction

Several papers have attempted to solve the calibration issue by proposing algorithms that rely on the execution of a strict movement (dynamic calibration) or a known pose (static calibration) [1–4]. However, few studies have compared the two against a gold standard system. We aim to compare the accuracy and precision of both static and dynamic calibration against a gold standard system. In particular, we focus on the wrist joint, although the same procedure could be applied to any joint.

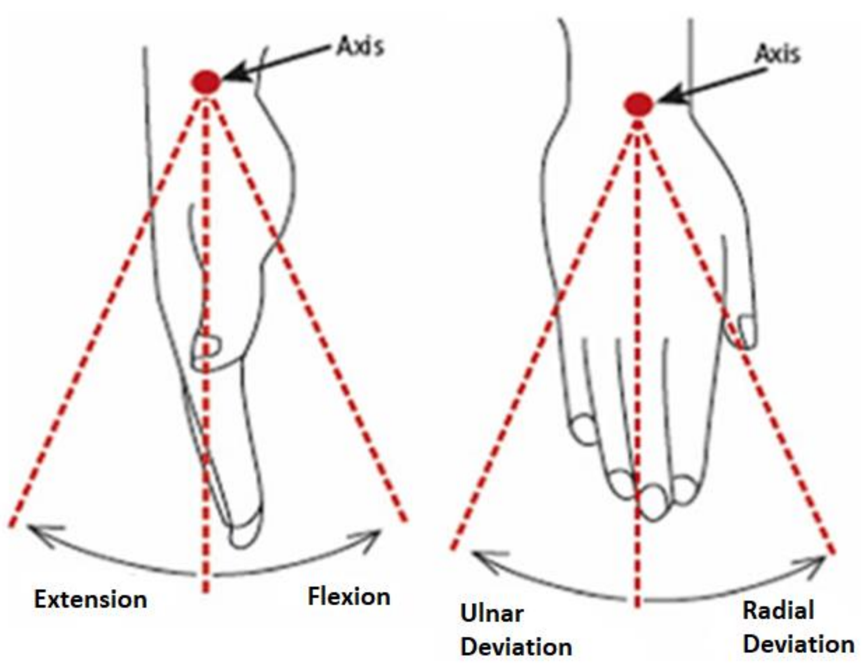

Figure 2: Axis representation of the wrist joint [4]

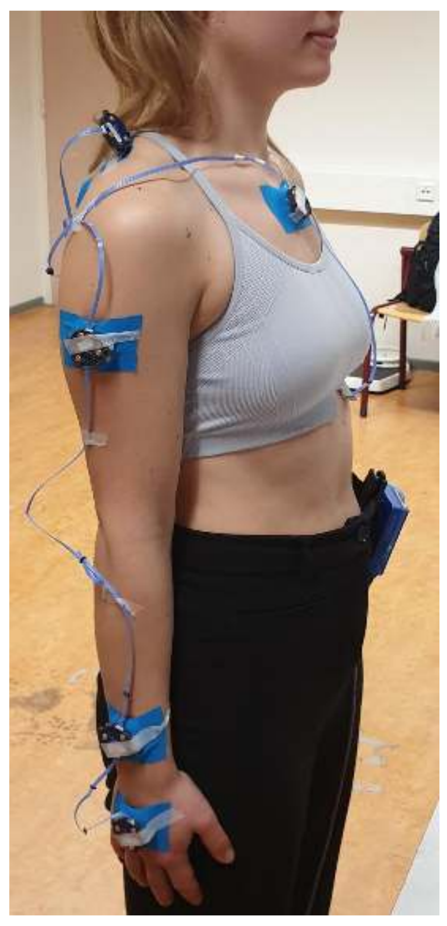

Figure 1: IMU Sensor positioning

Materials and Methods

13 healthy subjects with no sign of upper body injury or pain were recruited. Subject were instrumented with IMU and optical markers as shown in Figure 1. After performing static [7] and functional calibration [5,6] subjects performed **5 wrist flexion/extension** and **5 wrist radial/ulnar deviation** movements (Figure 2). Joint angles computed for each calibration protocol were compared with the optical reference system (Optotrak) as shown in Figure 3.

Results

Figure 3 and 4 wrist flexion/extension and radial/ulnar deviation movements for one subject. The plots show the optical reference in black and the data processed with the four different calibration procedures in colours. Table 1 shows RMSE, offset and correlation values calculated across the five subjects.

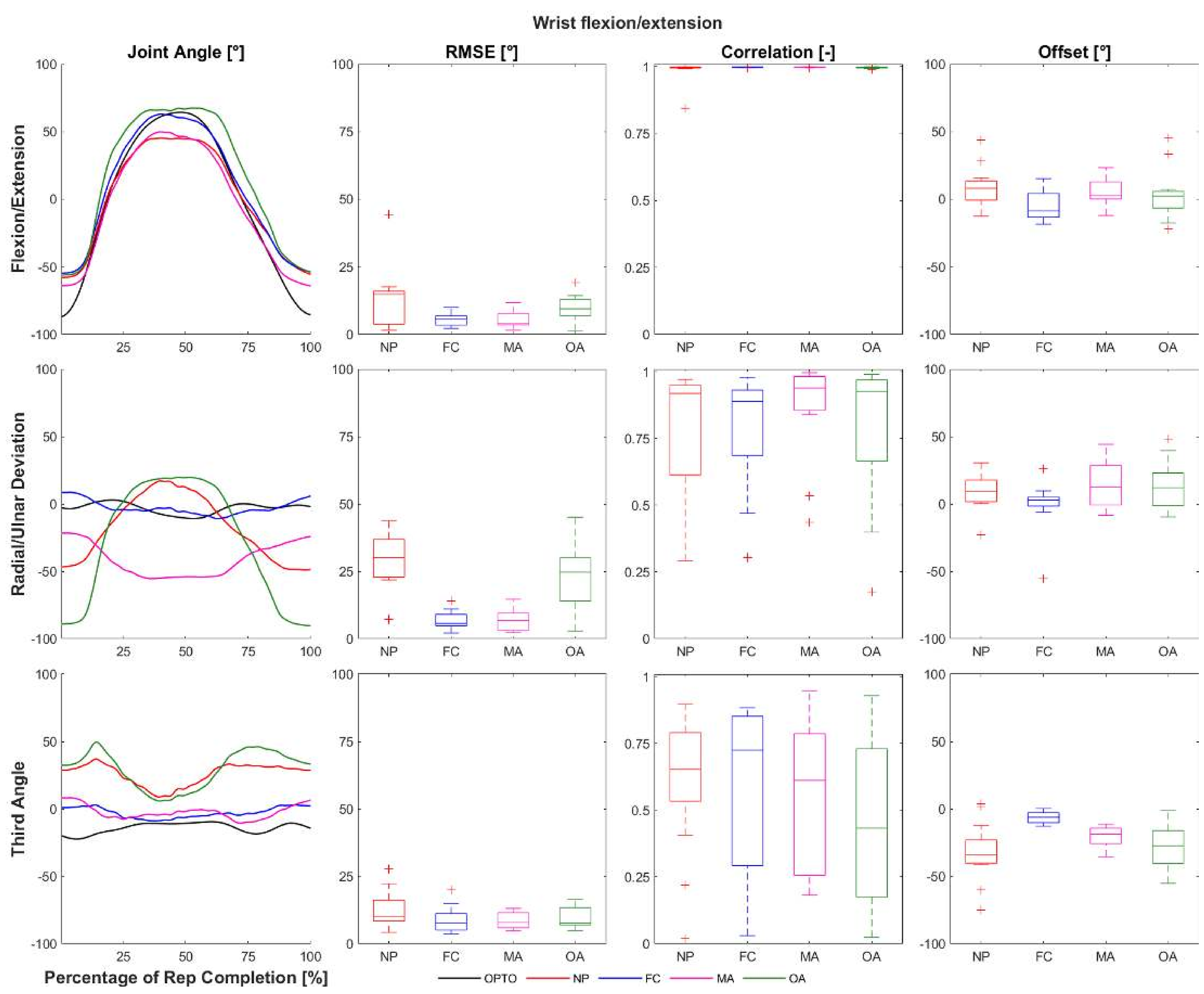

Figure 3: In the first column, the x-axis represents the percentage of rep completion where 0 and 100% indicate the wrist fully flexed. The other three columns respectively show box-and-whisker plots of RMSE, correlation and offset calculated across all subjects in the study. Red crosses in box-and-whiskers plot indicate data outliers.

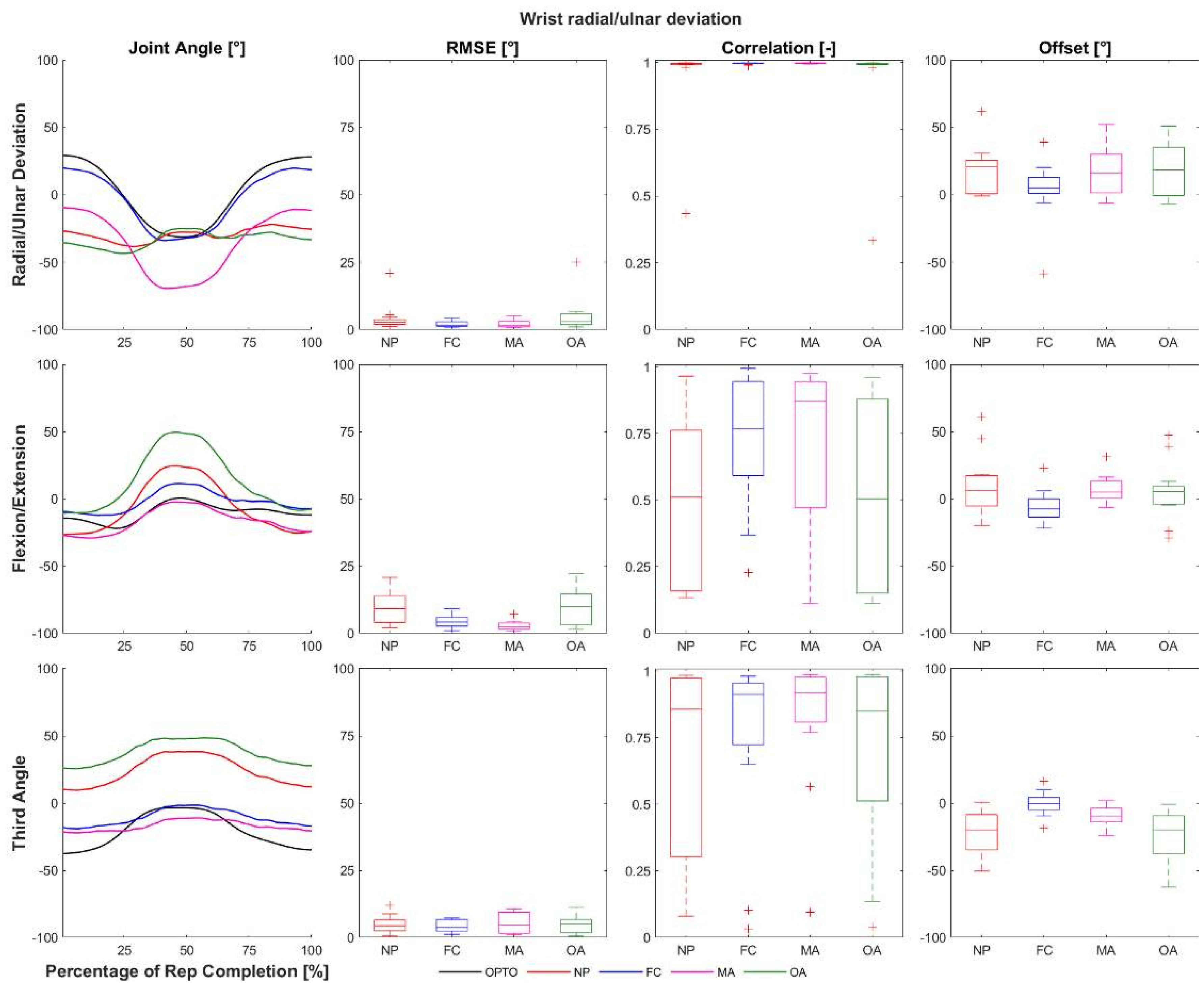

Figure 4: In the first column, the x-axis represents the percentage of rep completion where 0 and 100% indicate the wrist fully flexed. The other three columns respectively show box-and-whisker plots of RMSE, correlation and offset calculated across all subjects in the study. Red crosses in box-and-whiskers plot indicate data outliers.

Discussion

NP and OA often show larger errors than MA and FC in most of the indices analysed. We hypothesize this is because the forearm and hand reference frame are built by involving the trunk heading during the N-pose calibration, which is generally poorly correlated to the anatomical axis definition of forearm and hand. On the other hand, FC and OA generate the best predictions in terms of correlation, RMSE and offset.

Conclusions and Future work

All models perform rather similarly in estimating the main wrist joint angle, but their performance differs on the secondary rotation axis. Therefore, we advise a functional calibration approach for the best estimation of the overall wrist joint motion. However, for the highest accuracy possible on the main movement axis, we recommend the manual alignment (MA) method

Functional
- ↓ Slow ~ 10 minutes
- ↓ Hard to Perform
- ↑ Relies only on gyroscope
- ↑ Good axis estimation

N-Pose
- ↑ Fast ~ 5 seconds
- ↑ Easy to Perform
- ↓ Relies on gravity vector and trunk heading
- ↓ Hands and forearms are poorly correlated with trunk position in N-pose

Manual
- ↑ Fast ~ 5 seconds
- ↑ Easy to perform
- ↓ Relies on accurate sensor positioning
- ↑ Can produce low errors in sensors are placed correctly

One-Axis
- ↑ Fast ~ 5 seconds
- ≡ Easier than manual
- ↓ Relies on trunk heading and partially sensor positioning
- ≡ Hybrid between N-pose and manual alignment

References

[1] Filippeschi et al., 2017 [2] Bouvier et al., 2015 [3] Wu et al., 2005 [4] Narayan et al., 2021 [5] Cutti et al., 2008 [6] de Vries et al., 2010 [7] Liu et al., 2019

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