Quantification of measurement artifacts of skin-mounted IMUs

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Summary

This study aims to quantify angular measurement artefacts of skin-mounted inertial measurement units (IMUs) fixed with double sided and stretch tape. Repeated impact tests were conducted with sensors on a rod to quantify attachment artefacts, and on a lower arm to quantify soft tissue artefacts. IMU-to-skin artefacts were insignificant at 0.65 degrees. Soft tissue artefacts were larger at 3.13 degrees, and relevant depending on context.

Introduction

In recent research investigating lower back movement during repeated shocks, we found lumbar angles very close to the healthy range of motion (ROM) of the subject group. However, the accuracy of IMUs in measuring movement of the underlying bone remains unclear. Key factors include IMU movement relative to the skin due to flexible attachment and relative to the bone due to soft tissue deformation. The latter can have several causes: active tissue deformation, e.g. due to contraction of muscles [1], passive tissue deformation due to the impact force [2], passive deformation caused by soft tissue movement over, or due to, moving joints [1,3]. For soft tissue artefacts due to impact, a linear correction method has been developed [4].

We investigated angular measurement artefacts of IMUs in measuring effects of repeated shocks on the human body. Specifically, we used IMUs on multiple sides of a rigid rod and of a (in vivo human) limb bounced on a table, to quantify the magnitude of potential artifacts in orientations.

Methods

We conducted two measurements using IMUs (Movella DOT) attached with double-sided and stretch tape. 1). IMU-to-surface movement: a rigid rod served as test object. Two IMUs were placed on opposite sides of the rod, and one on top. 2). Soft tissue artefact: IMUs were placed ventrally and dorsally on the lower arm of a test subject (25,f). Prior to testing, sensors were synchronized and calibrated through a walking trial. Impact testing entailed bouncing the bottom of the rod/elbow on a table at least ten times, with the test rod/arm as upright as possible. Accelerations, angular velocity and quaternions were extracted, and Euler angles were calculated for each IMU.

Results and Discussion

Accelerations and angles of all sensor were very similar in both experiments. In experiment 1, for peak accelerations up to 4G, the mean (sd) peak relative angle between the top and side sensors was 0.65 (0.14) degrees in one direction (figure 1). This is equal to half the relative angle between the side sensors. In experiment 2, for peak accelerations up to 10G, the mean peak relative angle between the side sensors was 3.15 (0.43) degrees in one direction (figure 2). Assuming the bone is a rigid stave between the two sensors, the relative angle between one sensor and the bone would be approximately 2 degrees. The relative angle between opposing arm sensors around the vertical axis (z) is unexpectedly large. This suggests that the soft tissue of the arm as a whole moved in one direction with respect to the bone, likely because of a slight diagonal position of the arm during impact.

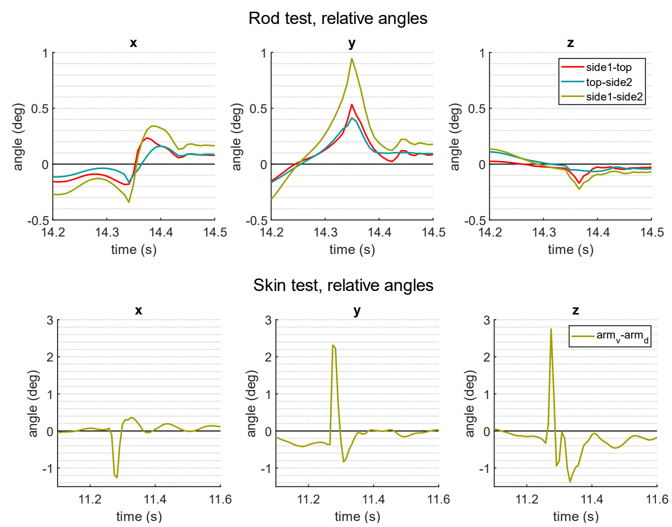

Figure 1: Relative angles of IMUs on a rod (top) and lower arm (bottom) for each sensor axis.

Conclusions

IMU-to-skin movement is negligible. IMU movement due to soft tissue artefact (~2 degrees) may be relevant depending on the size of the actual segment or joint angular changes.

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