Wearable-derived joint kinematics for sleep posture analysis

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1. INTRODUCTION

Prolonged sleep in provocative postures has been associated with musculoskeletal disorders [1]. While relationships have been reported, the disorder aetiology remains partially understood, hence the need for monitoring technologies to uncover provocative postures.

Sleep posture monitoring technologies have conventionally classified a few standard postures and required extensive data and annotations, which are rarely available during sleep. Despite limited attempts to classify more variable sleep postures, these have investigated only minor variations of standard postures. Further work is needed for real clinical impact.

Herein is an evaluation of wearable sensor-measured joint kinematics as clinically meaningful biomechanical markers for the classification of twelve complex sleep postures, agreed upon with NHS-based clinical experts.

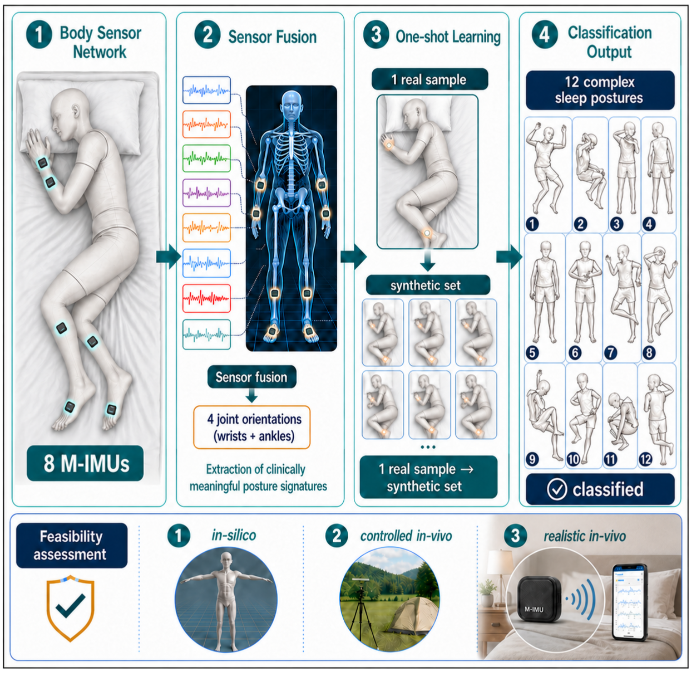

Figure 1. Proposed sleep posture classification system.

2. METHODS

We propose a novel framework for non-standard sleep posture classification [2] using a body sensor network comprising 8 magneto-inertial measurement units (M-IMUs). The framework incorporates sensor fusion and a one-shot posture learning scheme. Sensor fusion enabled, for the first time, the extraction of clinically meaningful posture signatures, defined by four joint orientations (wrists and ankles). The one-shot learning facilitated synthetic sample generation using only one measurement of any given posture.

The development and validation of this framework spanned three feasibility phases:

(i) *in-silico study*: a computer-graphics pipeline to animate a three-dimensional character model replicating sleep postures.

(ii) *in-vivo study* (controlled): pilot simulated sleep sessions conducted outdoors to avoid indoor disturbances causing sensor-orientation drift. Bespoke M-IMU sensor hardware was used.

(iii) *in-vivo study* (realistic): same as (ii) but indoors and using commercial M-IMU sensors with a proprietary drift-compensated orientation tracking algorithm.

3. RESULTS

The in-silico study achieved 100% classification accuracy. The outdoor in-vivo study showed that, on average, 11 postures could be reliably classified (~90% accuracy), supporting the effectiveness of one-shot learning in addressing the lack of labelled sleep data and handling participants' mild-to-moderate inconsistency in posture replication. A deeper analysis confirmed that inter-posture similarity is an inherent challenge in this classification problem, echoing findings in the related literature. The indoor in-vivo study posed a much harder classification problem because of severe orientation drift, despite a commercial proprietary drift-compensation sensor-fusion algorithm. Despite this error, the one-shot learning scheme classified 7 non-standard postures, compared with only 5 postures when no data augmentation was used.

REFERENCES

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