Optimizing Wearable Motion Tracking by Assessing Sagittal Joint Angle Accuracy with Minimal Sensor Use

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Introduction

Wearable motion tracking technology often focuses on reducing the number of sensors to simplify design and lower costs. Research has shown that single IMUs can reconstruct leg kinematics [1, 2] and ground reaction forces [3] effectively. We aim to assess the accuracy of sagittal joint angle estimations using strain sensors while minimizing sensor count. As an initial investigation, we focus here on estimating the sagittal plane hip angle during running from just one strain sensor.

Data Collection

In previous work [4], we collected treadmill gait data:

- Ten healthy participants jogged on an instrumented treadmill at 8 km/h–10 km/h wearing athletic pants embedded with nine piezoresistive strain sensors.
- Four sensors were placed on the hip, two on the knee, and three on the ankle.
- Optical motion capture provided reference kinematics.
- With machine learning, inter-subject sagittal plane leg kinematics could be estimated from these nine strain signals with an average 5.2° error.

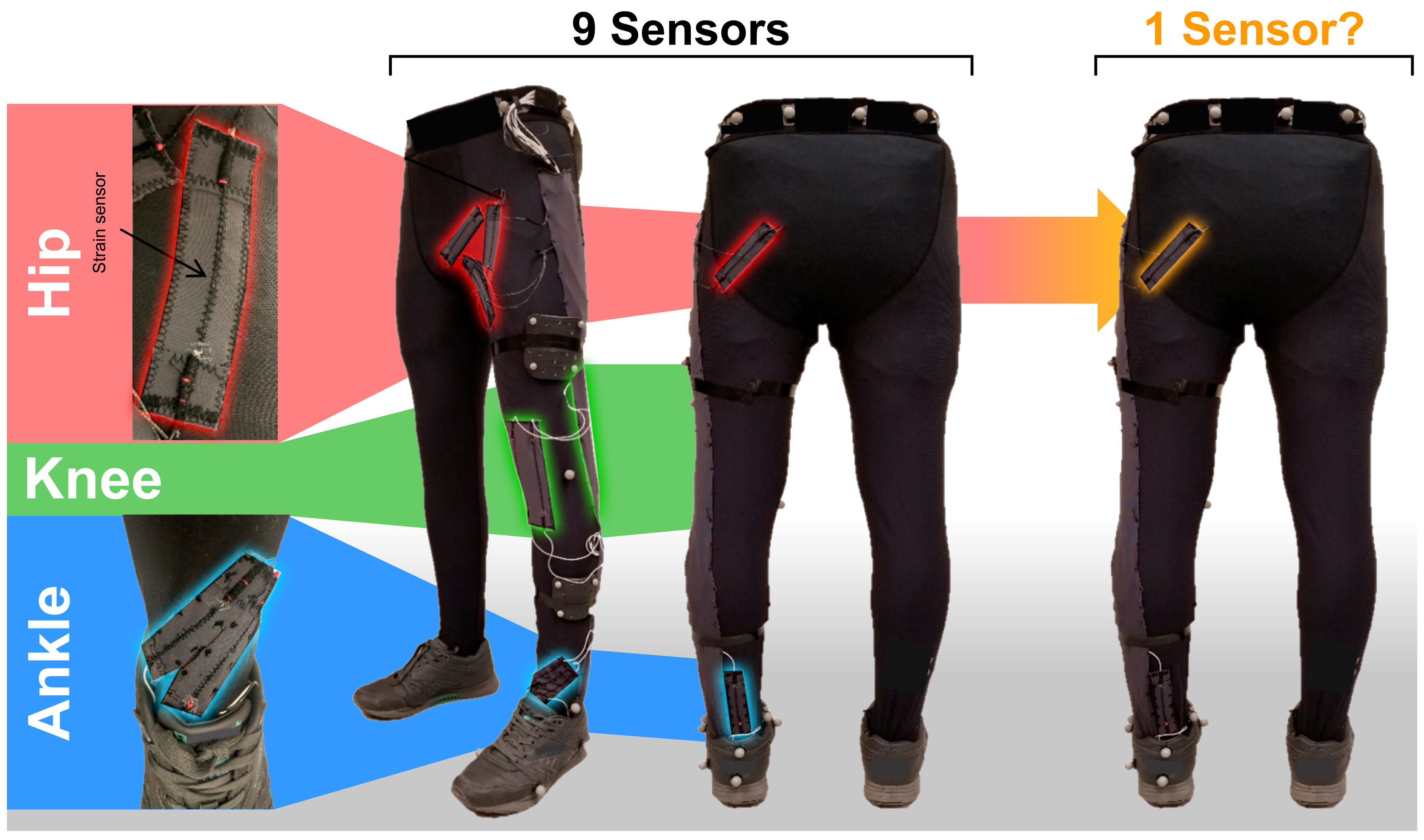

Figure 1: Strain sensor placement on the hip (red), knee (green), and ankle (blue). Our method indicated a feasible reduction of strain sensors from nine to just one on the posterior hip (orange).

Using these data, we aim to explore the extent to which strain sensor reduction is possible without meaningful loss of accuracy.

Methods

We evaluate the possible sensor reduction using three methods:

- Pearson correlation between each strain sensor signal and reference joint angles.
- Root-mean-squared error (RMSE).
- Dynamic time warping (DTW), which accounts for time shifts between the signals.

Results

- We observed a very high correlation between hip angle in the sagittal plane and one of the sensors placed on the hip.
- A low RMSE and DTW distance confirmed this observation.

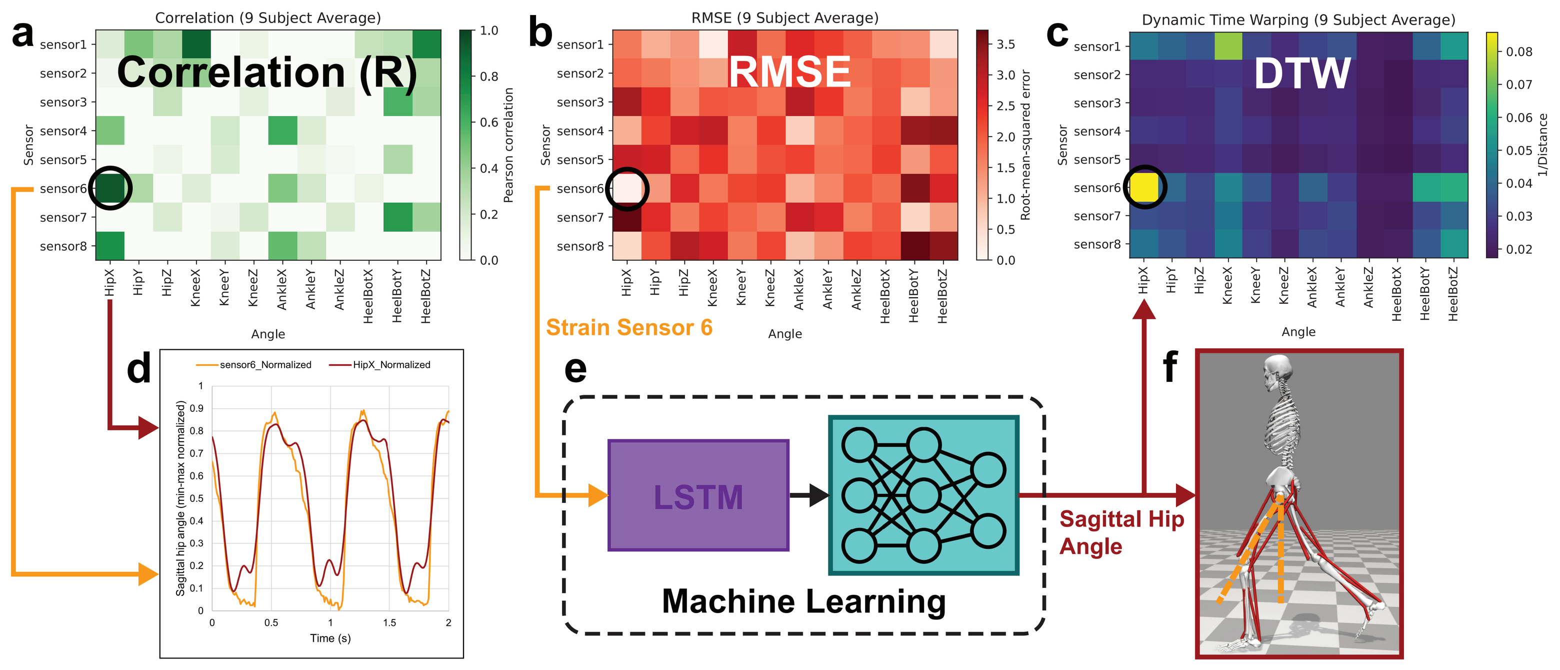

Figure 2: **a** Correlation, **b** RMSE, and **c** Dynamic time warping distance between sensors and joint angles; **d** Time-series comparison between sensor 6 and sagittal hip angle; **e** Data processing pipeline; **f** Angle of interest.

- We trained a recurrent neural network model to predict the sagittal plane hip angle from this single hip-mounted strain sensor.
- Inter-subject training done using leave one out cross validation.

Table 1: Test-set RMSE and coefficient of determination (R^2) for sagittal hip angle estimation (possible outlier).

Subject	1	2	3	4	5	6	7	8	9	Avg.
RMSE (°)	7.6°	4.6°	5.1°	5.8°	7.9°	16.4°	4.7°	6.5°	3.9°	6.9°
R^2	0.69	0.92	0.82	0.86	0.76	-0.19	0.82	0.84	0.93	0.72

- We identified one outlier participant, whose hip kinematics differed significantly from the rest.
- With only the best 8 out of 9 subjects, we obtained an average 4.9° RMSE and R^2=0.84.

Conclusion

A correlation analysis allowed us to identify a sensor reduction strategy and develop a model that balances between accuracy and a minimal number of sensors. We were able to estimate sagittal hip angle with a single strain sensor with only marginally more error (6.9° RMSE) versus using all nine sensors (5.4° RMSE). This has practical implications in sports science, where athletes could benefit from less intrusive and more comfortable performance monitoring.

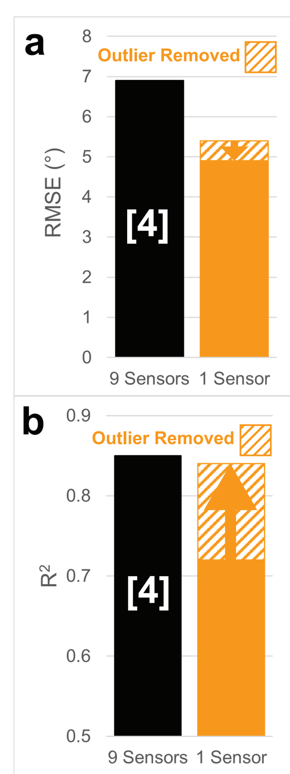

Figure 3: Sagittal hip **a** RMSE and **b** R^2 from [4] using 9 sensors and this work using 1 sensor, where the hatched area shows the improvement if the outlying subject is excluded.

References

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