Estimation of 3D center of mass velocity through millimiter-waves radars

P. Brasiliano[1], F. Carcione[2], G. Pavei[3], E. Cardillo[2], E. Bergamini[4]
[1]Department of Motor, Human and Health Sciences, University of Rome "Foro Italico"
[2] Department of Engineering, University of Messina
[3] Department of Pathophysiology and Transplantation University of Milan
[4] Department of Management, Information and Production Engineering, University of Bergamo
Email: paolo.brasiliano@uniroma4.it

Summary

This study validates a radar-based system for estimating the whole-body center of mass (BCoM) velocity during walking. Sixty healthy participants walked on a treadmill at 2, 4, and 6 km/h. Radar data capturing anteroposterior, mediolateral, and craniocaudal components were compared with motion capture data. Nine Recurrent Neural Networks (RNNs) were tested to estimate the BCoM velocity, with performance evaluated using Root Mean Square Error. Errors were below 20%, demonstrating good accuracy, with potential for improvement through further RNN refinement.

Introduction

Accurate assessment of walking is crucial for identifying movement impairments and evaluating rehabilitation. Traditional motion capture systems provide detailed data but are limited to laboratories and require intrusive markers. Marker less technologies and wearable sensors offer flexibility but often lack accuracy, comfort, or have privacy concerns. Radar systems present a promising alternative, enabling contactless, privacy-friendly, and unobtrusive monitoring [1]. This study validates a radar system for estimating whole body center of mass (BCoM) velocity during walking, comparing its accuracy and reliability to standard motion capture systems.

Methods

Sixty healthy participants (26 F; age: 31 yrs; mass: 68.1 kg; height: 171.1 cm) were recruited for the study. Each participant walked on a treadmill for one minute at three speeds: 2, 4, and 6 km/h. During each trial, movement data were simultaneously recorded using three radar systems and a stereophotogrammetric motion capture system. The radars were positioned to capture participants' upper body movement along three orthogonal components: anteroposterior (AP), mediolateral (ML), and craniocaudal (CC). Eighteen reflective markers were placed on anatomical landmarks to estimate the three-dimensional BCoM velocity, following [2]. All the recording devices were electronically synchronized and controlled through a field-programmable gate array, and motion capture data were resampled to match the radar data temporal resolution. Each one-minute recording was divided into 5-second windows, excluding the first and last 2.5 seconds to avoid inaccuracies of marker position reconstruction. This resulted in 11 temporal windows per participant, which were split into training, validation, and test sets containing data from 42, 9, and 9 subjects, respectively. Nine Recurrent Neural Networks (RNNs) were tested—one for each combination of walking speed and movement component—to estimate BCoM velocity from radar signals. Each RNN featured a sequence input layer, a Long Short-Term Memory layer with 64 hidden units to capture temporal dependencies, a fully connected layer, and a regression output layer to predict BCoM velocity. The performance of the radar-based RNN estimates was assessed by comparing the velocity curves to those obtained from the motion capture system using Root Mean Square Error (RMSE).

Results and Discussion

Results are reported in Table 1.

Conclusions

The results show the potential of radar-based systems for accurate BCoM velocity estimation during walking. While promising, performance could improve with further RNN refinement, pending reduced computational demands.

Acknowledgments

Funding: Eurepean Union - NextGenerationEU - M4, C2, 1.1; project: PRIN 2022 (DD MUR n.104 del 02.02.2022) Title: CARAMELLA; CUP H53D23000550006; project code: BERG_E_24_RN_PRIN_CARAMELLA_01 (2022TLSWHM).

References

[1] Gutbuz SZ et al. (2024). *IEE OJEMB*, **5**: 735-749.
[2] Pavei G. (2020) *Gait Posture*, **80**: 199-205.

Table 1: Absolute values of RMSE (percentage values with respect to velocity range obtained from gold standard data)

	Walk 02 km/h			Walk 04 km/h			Walk 06 km/h		
	AP	ML	CC	AP	ML	CC	AP	ML	CC
RMSE m/s (percentage)	0.039 (18.2)	0.071 (23.7)	0.029 (20.69)	0.04 (16.36)	0.05 (19.2)	0.074 (14.05)	0.045 (15.94)	0.044 (19.59)	0.074 (15.25)