REAL-TIME FOOT STRIKE PREDICTION IN WALKING GAIT USING WEARABLE SENSORS

Bruno Oshiro, João Gouveia, Jorge Martins and Rui Coelho

IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Portugal

bruno.akira.oshiro@tecnico.ulisboa.pt; joao.g.gouveia@tecnico.ulisboa.pt; jorgemartins@tecnico.ulisboa.pt; rui.coelho@tecnico.ulisboa.pt

KEYWORDS: Walking gait, Forecasting, heel-strike, Long Short-Term Memory, Wearable Sensors.

1 INTRODUCTION

Gait disorders resulting from disease, accidents, or aging, have been increasing and tremendously hinder the quality of life of individuals. Lower-limb assistive devices, namely exoskeletons or orthoses, are currently very limited in their functionality, typically employing passive assistance mechanisms that do not adapt to user gait speed. In this paper, we propose an algorithm for real-time prediction of foot strike during walking, using low-cost, wearable sensors. Data from a foot-mounted inertial measurement unit (IMU) and a pressure-sensitive insole is fed into a Long Short-Term Memory (LSTM) neural network, which forecasts the time instant of the next heel-strike[1].

2 METHODS

2.1 EXPERIMENTAL PROTOCOL

Eight healthy subjects were asked to walk on a level-ground terrain for 10 minutes, while using a foot-mounted IMU, placed at the dorsal part of the foot, and an insole with two force-sensitive resistors (FSR), at the heel and the ball. The data from the sensors was synchronously collected using an STM32F4 microcontroller, with a sampling time of 3ms (Figure 1). To have the subjects walking at different speeds, they were given an audio cue to keep a certain pace. Three different walking speeds were imposed by the audio cue, in randomized order.

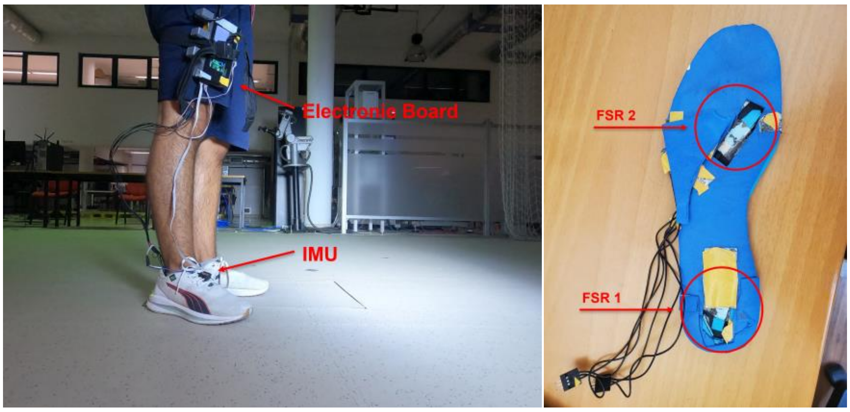

Figure 1 – Data acquisition hardware: an STM32F4 microcontroller acquires synchronized data from a foot-mounted IMU (left) and two FSRs in an insole (right).

2.2 Data Processing

Heel-strike was detected using the FSR placed at the heel, using a threshold-based approach. Kinematic data is estimated from the IMU angular velocity and linear acceleration, including orientation, position and linear velocity. We then use FSR and kinematic data to train an LSTM-based forecasting neural network to predict the time at which the next heel-strike occurs. The model is trained using a Leave-One-Subject-Out cross validation scheme, ensuring that it generalizes well to unseen subjects.

3 Results

Using a single layer LSTM neural network, the algorithm accurately forecasts the moment of the next heel-strike from IMU and FSR data, with a mean absolute error of 30ms along the different phases of the stride (Figure 2). The model has a better performance during the swing phase due to the major variability on the kinematic data, achieving errors lower than 20ms. Such precision in forecasting the heel-strike moment starting at 500ms before the event (early swing), outperforms the state-of-the-art methods in heel-strike forecasting [2, 3].

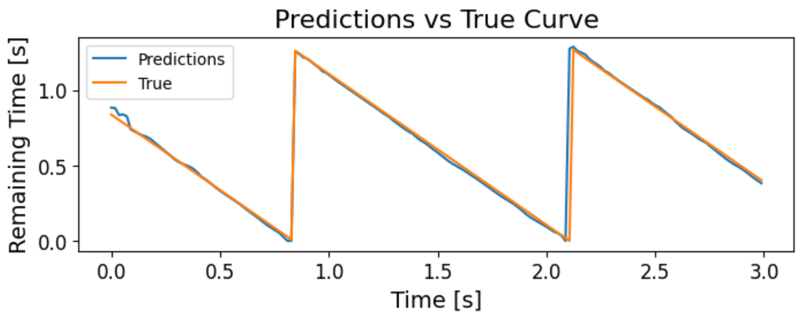

Figure 2 – An example of real-time heel-strike forecasting from wearable sensors using the LSTM neural network. The heel-strike moments correspond to the points where the remaining time is equal to 0.

4 Conclusions

The present study presents an LSTM-based model that accurately and timely forecasts the heel-strike moment during the walking gait cycle, using data from insole pressure sensors and one IMU on the foot. Such results make it suitable for implementation on a assistive device that requires information on the heel-strike timing to adapt its assistance profiles.

ACKNOWLEDGEMENTS

The authors acknowledge Fundação para a Ciência e a Tecnologia (FCT) for its financial support via the projects LAETA Base Funding (DOI: 10.54499/UIDB/50022/2020) and ReflexES (DOI: 10.54499/2022.04834.PTDC).

References

[1] R. Moura Coelho, J. Gouveia, M. A. Botto, H. I. Krebs, and J. Martins, “Real-time walking gait terrain classification from foot-mounted inertial measurement unit using convolutional long short-term memory neural network”, Expert Systems with Applications, 203:117306, 2022.

[2] H. T. T. Vu, F. Gomez, P. Cherelle, D. Lefeber, A. Nowe, and B. Vanderborght, “Ed-fnn: A new deep learning algorithm to detect percentage of the gait cycle for powered prostheses”, Sensors, 18(7), 2018.

[3] K. Tanghe, F. De Groote, D. Lefeber, J. De Schutter, and E. Aertbelien, “Gait trajectory and event prediction from state estimation for exoskeletons during gait”, IEEE Transactions on Neural Systems and Rehabilitation Engineering, 28(1):211‑220, 2020