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ScienceDirect

Procedia Computer Science 114 (2017) 401–407

Procedia Computer Science

www.elsevier.com/locate/procedia

Complex Adaptive Systems Conference with Theme: Engineering Cyber Physical Systems, CAS October 30 – November 1, 2017, Chicago, Illinois, USA

Fuzzy Inference System-based Recognition of Slow, Medium and Fast Running Conditions using a Triaxial Accelerometer

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Abstract

This paper introduces a fuzzy inference system (FIS)-based model for recognizing running conditions using data collected with a triaxial accelerometer. Specifically, data from three axes of a triaxial accelerometer were used as the input, and various running conditions (slow, medium and fast) were considered the output of the FIS. The MATLAB® fuzzy toolbox, which includes processes such as fuzzification, sets of fuzzy rules, fuzzy inference engine and defuzzification, was used to model the system. Mamdani-type fuzzy modelling was selected for developing the FIS. The structure of the generated fuzzy inference system includes three fuzzy rules (using if-then) and an initial set of membership functions. The performance of the proposed FIS model was assessed using the root mean square error (RMSE), mean absolute error (MAE) and non-dimensional error index (NDEI), which were found to equal 0.059, 0.213 and 0.147, respectively, for the test data. Additionally, the correlation coefficients (r) and coefficient of determination (R^2) between the FIS-predicted and the actual values were 0.89 and 0.81, respectively. Finally, the model performance accuracy was measured using Variance-Accounted-For (%VAF), which equaled 96.54%. Thus, the assessment of the overall performance suggests that the proposed FIS model has potential to detect slow, medium and fast running conditions.

Peer-review under responsibility of the scientific committee of the Complex Adaptive Systems Conference with Theme: Engineering Cyber Physical Systems.

Keywords: Accelerometer; Fuzzy Inference System; Running Condition.

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1877-0509 © 2017 The Authors. Published by Elsevier B.V.
Peer-review under responsibility of the scientific committee of the Complex Adaptive Systems Conference with Theme: Engineering Cyber Physical Systems.
10.1016/j.procs.2017.09.054

Nomenclature

Accl	accelerometer data
FMS	fast-medium-slow
FIS	fuzzy inference system
MAE	mean absolute error
MF	membership function
NDEI	non-dimensional error index
RMSE	root mean square error
RMS	root mean square
SISO	single-input and single-output
VAF	variance-accounted-for

1. Introduction

The number of studies in the field of human gait recognition using various artificial intelligence techniques has increased over the last two decades [1]. Fuzzy logic is an influential rule-based technique in the artificial intelligence domain that helps predict and identify patterns of human gait movement and running conditions [2, 3]. However, few studies have utilized FIS to predict running conditions (e.g. slow, medium and fast) and patterns.

A recent study conducted by Mikołajewska *et al.* assessed the results of post-stroke gait re-education through the application of traditional and fuzzy-based analyses [4]. Specifically, these researchers assessed spatiotemporal gait parameters before and after therapy and compared the results using a fuzzy-based assessment tools. Xu *et al.* used fuzzy logic and neural network techniques and four parameters, namely the Staheli index, Chippaux-Smirak index, arch index and modified arch index, as the classification features and collected gait data using various instruments, such as a force platform, stereometric system, accelerometer and pressure platform [5]. Another fuzzy-and-neural-network-based study focused on the gait performance, postural stability, and depression of Parkinson's patients [6], using the Berg Balance Scale, the Dynamic Gait index, and the Geriatric Depression Scale. In another medical-based expert system using fuzzy and neural networks for patients with idiopathic scoliosis, researchers extracted kinetic data and used time and walking parameters in the analysis [7]. Several studies have applied fuzzy systems for the development of a mechatronic-based system (such as a robotic haptic or exoskeleton device) that can be used for assessing gait [8-10]. Researchers have selected different input-output parameters related to walking, force and motion velocity, such as ground reaction force, impulse disturbance, and internal biological electromyography noise interference, for evaluating their fuzzy system with the aim of improving the tracking performance and driving the exoskeleton. In contrast, fuzzy logic has been applied for identifying different speed patterns in cases such as vehicles, electronic motors and wind turbines, but not for detecting human running speed [11-13].

While these aforementioned studies have shown the use of fuzzy-based systems, these studies have generally used multiple camera-based gait analysis systems for the input data. However, these gait analysis tools are relatively expensive and restricted to gait labs. In contrast, wireless accelerometers are inexpensive and portable. Unfortunately, few studies have incorporated FIS-analysis techniques using accelerometer gait data [14, 15]. Thus, the FIS-based recognition of running conditions using a triaxial accelerometer is a novel idea in gait analysis. Therefore, this study investigated whether the developed Single-Input and Single-Output (SISO)-based fuzzy model was able to accurately identify different running conditions. Specifically, we proposed the following hypotheses: (*i*) if the triaxial accelerometer yields low, average and high RMS values, the output will be slow, medium and fast running condition, respectively, and (*ii*) the calculated RMSE, MSE, VAF, NDEI and correlation results from the actual and predicted values are acceptable in terms of evaluating performance and error evaluation. To the best of our knowledge, this study provides the first FIS-based running conditions identification approach based on signals generated by a single triaxial accelerometer.

2. Methodology

Three runners participated in the study and provided written informed consent. The runners did not have any history of disorder or pain in their lower limbs. This protocol was approved by the University of Calgary Conjoint