People Identification Based on Dynamic Determinants of Human Gait

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Abstract

In the paper a way of people identification, based on ground reaction forces during gait, is presented. The authors established that each individual has an unique gait pattern that can be described by quantitative parameters, calculated using measurements coming from the force plates. Fifteen volunteers took part in this study. Each person walked barefoot at least 100 times through 10-m-long walkway with the force plates built in. Determinants were calculated based on vertical and anterior-posterior components of the ground reaction force. The obtained parameters were used as an input matrix of the artificial neural network designed for identification of each person. Effectiveness of the recognition was assessed as root mean square error between expected and obtained output values. It was proved, that human identification based on presented determinants of the gait and artificial neural network is possible at a high level.

Keywords: people identification, human gait, force plates, artificial neural networks

1. Introduction

In biomechanics there are different techniques for analysing human motion [1-3]. The most common method for analysing movements in different kind of sport or pathological cases is motion capture system [4]. When considering muscle activity the electromyography can be very helpful [5, 6]. In order to evaluate human joints the dynamometers are used in sport and rehabilitation [7]. In this study human gait is analysed using the force plates [8]. This technique enables to measure the ground reaction force (GRF) during human gait or other activities.

The human gait can be defined as human locomotion resulting from cyclic, coordinated combination of body movements [9]. It is a periodic motion which has a common pattern. It means that the movements occur in a specific temporal order. Two main phases can be distinguished during human gait: the stance and swing phases. The differences between these phases can be observed e.g. in the plot of the GRF.

One can notice that a way of walking is typical for each of us. It is also typical for gender. Men walk in another way in comparison to women. It can be observed also in the GRF plot.

Identification of people based on different characteristics of human body or human behaviour is called biometrics. There are many different techniques for people recognition, e.g. based on face image, hand geometry, voice, palm prints, palm veins, fingerprints, iris, DNA and many others. The authors of the paper presented their results in which people or gender are recognized based on dynamic parameters coming from the force plates [8, 10] or additionally based on kinematic parameters recorded by the motion capture system [11].

The aim of this study is to examine effectiveness of recognition for each individual separately in application of the artificial neural networks with parameters coming from the force plates as the inputs.

2. Design and methods

In this study 15 volunteers took part, varied by height, mass, age and gender. Each person was asked to walk barefoot 100 times through 10-m-long walkway with the force plates built in. Obtained recordings were used to calculate gait parameters, associated with vertical and anterior-posterior component of the GRF. Determinants were divided into time-dependent and force-dependent parameters and were normalized by stance phase time and body weight accordingly for each recording and each person, to allow comparison of results between participants of this research. Left and right foot were considered separately. One full set, designed for a person, consisted of 32 parameters and one additional that indicated left or right foot. Few determinants calculated for the research are listed below, the complete list of the parameters could be find in [5]:

- maxima of loading response phase for vertical component of GRF,
- minima of midstance phase for vertical component of GRF,
- maxima of terminal stance phase,
- ratios between presented above forces,
- coordinates of the geometrical curve centre for vertical component of GRF,
- time of contact with floor of both feet,
- time of gait cycle,
- occurrence time of characteristic vertical force parameters listed above.

Some of described determinants are presented in Figure 1, for example the vertical component of the GRF during gait is presented.

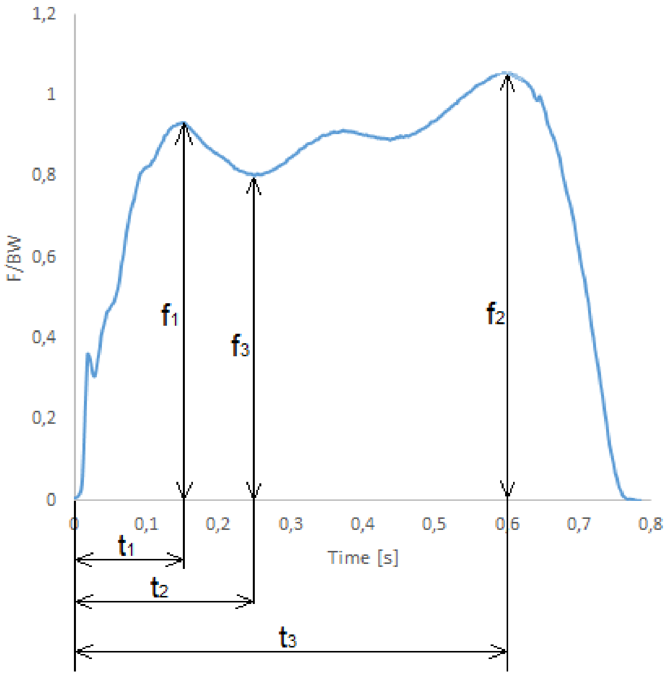

Figure 1. Examples of the dynamic determinants calculated from the vertical component of the ground reaction force

Calculated parameters were used to create input matrix for designed neural networks in Matlab NN Toolbox. The authors built fifteen neural networks, with the same structure, for each person participating in the study. One neural network was designated to recognize one chosen person, which means that this neural network was learned to recognize this particular person parameters. It was built as perceptron, feed-forward network, consisted of two hidden layers, with 20 neurons in the middle and 1 neuron in the output layer. Neural networks were learned with use of about 50% calculated determinants according to the Levenberg-Marquadt Method. The neural network was learned to return "1" for the parameters of this chosen person (as the correct answer) and to return "0" for randomly selected parameters of the other persons. By using linear function in the output layer, the output of the neural network ranged between 0 and 1 while testing. Thanks to that the higher value of the output indicates the higher similarity of considered persons gait. It should be mentioned that in all cases in the middle hidden layer 'tansig' was defined as activation function.

3. Results

Recognition level of the individuals was assessed by Root Mean Square Error (RMSE) calculated according to the following formula:

$$RMSE = \sqrt{\frac{\sum_{n=1}^{m}(x - x_n)^2}{m}} \tag{1}$$

where: x – value in the response matrix (“1” in this approach), x_n – network output value (value ranged between “0” and “1”), m – number of parameter sets used to test neural network.

In process of testing the designed neural networks, the authors used sets of the parameters that weren’t used to the learning process. There were checked the networks responses for input data for all examined 15 persons, for all 15 created neural networks designated to identifying chosen person. Results that shows level of the recognition one individual against other persons are presented in Table 1.

Table 1. The obtained RMSE of human recognition for each considered person and learned neural network against other persons

		Recognized person (number of the neural network)														
	Person	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Result (RMSE) received for person [%]	1	5.7	11.6	7.8	10.6	9.6	14.4	10.9	8.2	10.5	9.4	14.3	6.2	9.8	15.6	8.2
	2	14.5	2.9	14.7	13.7	8.5	22.1	17.0	11.1	11.5	10.2	15.9	12.9	12.5	12.8	11.7
	3	13.4	10.9	3.4	10.6	8.2	18.4	9.1	12.1	8.3	10.2	19.4	10.1	6.0	11.1	12.8
	4	14.8	12.1	13.3	6.9	12.5	24.8	14.9	13.7	9.3	11.4	13.5	16.6	12.6	14.2	13.6
	5	11.5	10.2	9.2	7.2	5.1	10.7	8.4	7.7	7.9	9.6	9.5	9.4	7.8	10.5	9.3
	6	12.8	10.4	13.0	9.5	11.6	7.5	11.0	12.2	12.0	6.2	14.5	13.4	14.5	13.2	9.2
	7	10.6	10.4	10.3	8.4	9.5	8.2	4.9	9.9	7.3	8.8	10.8	9.6	9.1	7.5	10.6
	8	10.7	6.6	9.4	11.6	8.8	9.3	11.4	3.9	10.6	9.7	14.5	12.1	8.5	11.0	9.6
	9	14.0	12.9	10.6	11.8	6.3	10.4	11.5	9.7	5.3	12.4	18.4	13.1	10.3	12.9	13.1
	10	9.6	8.5	9.5	8.0	8.8	9.3	9.1	8.3	8.9	3.3	9.5	10.8	12.1	8.3	7.9
	11	12.1	11.7	7.7	10.5	7.3	14.2	13.6	10.5	10.6	8.8	4.4	11.3	10.9	10.2	11.8
	12	7.0	10.1	10.4	10.7	9.6	12.8	12.6	7.8	10.6	10.1	14.8	3.8	7.6	13.8	8.9
	13	12.5	9.4	9.3	9.9	8.3	9.8	9.5	8.7	9.1	9.6	14.3	10.6	4.6	9.3	11.2
	14	10.2	11.5	11.0	8.7	10.0	9.3	8.1	9.7	9.3	7.6	13.2	10.6	10.7	5.2	12.7
	15	9.2	8.6	9.3	10.6	8.1	9.0	10.2	8.8	10.3	8.1	8.8	10.0	12.1	10.5	2.8

Based on the data collected in Table 1, one can conclude that in all cases recognized person is represented by the smallest RMSE value. This fact proves that it is possible to identify person based on gait parameters derived from the GRF.

To examine generalising abilities of constructed neural networks, the authors proposed parameter called *‘effectiveness of generalising’*. To calculate that factor, learned neural networks were tested again by putting two sets of gait determinants, where one set was coming from person that network was learned to recognize, and the second set was randomly selected from the other persons. If the RMSE calculated for this two sets was smaller for person chosen to recognize, then it was treated as correct answer. Finally *'effectiveness of generalising'* was calculated as the number of correct answers divided by number of tested pairs of the parameter sets. Results showing ability to generalizing collected for 15 created neural networks are presented in Table 2.

Table 2. Effectiveness of generalising calculated for 15 neural networks learned to recognize chosen person

Number of the NN	Effectiveness of generalising [%]
1	93.14
2	96.97
3	95.74
4	83.33
5	75.44
6	83.78
7	97.22
8	84.91
9	89.19
10	81.58
11	85.00
12	97.00
13	78.26
14	93.75
15	100.00

4. Conclusions

The level of the effectiveness of generalising of the artificial neural networks presented in this study is quite high. The determinants coming from the GRF measurements used in this study as inputs to these artificial neural networks are very good parameters to describe mathematically a way of human walking and to recognize people. In the presented results the smallest RMSE was obtained for person no. 15 (only 2.8%). For the same person also the highest effectiveness of generalising was obtained (100%).

The results presented in this study confirm that people can be recognized based on parameters of the GRF during human gait. It was also shown that the proposed method of people identification has a high level of effectiveness.

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