Use of Recurrent Neural Networks for Mean Blood Pressure Prediction Based on Impedance Cardiography Measurements

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In this paper we tried to predict value of mean blood pressure (MAP) basing on time series of measurements: maximum of Z first time derivative, (dZ/dtma), ejection time (ET), basal impedance Z (Z0) stroke volume (SV) and heart rate (HR) obtained non-invasively for every heartbeat with impedance cardiography (ICG). Continuous non-invasive measurements of MAP was accomplished with blood pressure monitor that uses the volume-clamp method. We used signals recorded in 10 young, healthy subjects, when performing three minutes handgrip test followed by two minutes of recovery.

We used simple neural network model being a combination of the long short-term memory layer with the dense output layer. We divided data into sequences (data from 10 cardiac cycles and subsequent single MAP value as desired output). The best result, expressed as the mean absolute error, obtained with the neural network used by us was 0.4 after normalization of data.

This result may indicate that the neural network used in this study was unable to predicted MAP value from ICG signal or that this signal do not provide sufficient information for correct estimation of MAP.

1. Introduction

Some Autonomic Nervous System, (ANS) tests use circulatory response to stimuli such as head-up tilt or handgrip to estimate the changes in sympathetic and/or parasympathetic activities. The activation of the sympathetic branch may cause an increase in total peripheral resistance (TPR). Activation of the sympathetic branch of ANS, as well as inhibition of parasympathetic one may increase heart rate (HR).

Mean arterial pressure (MAP) is a product of stroke volume (SV), HR and TPR:

$$MAP = SV * HR * TPR \quad (1)$$

ANS is responsible for a quick change of MAP [1]. In order to evaluate correctly the participation of both branches in pressure response we should measure, besides HR and MAP, also SV and TPR. During ANS tests, these variables should be measured continuously and noninvasively. Impedance cardiography (ICG) allows to obtain SV and HR from changes in thorax electrical impedance and ICG can be easily performed in Holter condition. When being able to predict MAP, TPR could be calculated.

MAP [2,3] could be measured noninvasively and continuously with blood pressure monitor that uses the volume-clamp method. However, measurement of blood pressure with this method requires finger cuff, what limits time of continues recording, as during measurement finger artery remains occluded. Use of cuff is also uncomfortable for a subject.

In this paper we tried to predict the subsequent value of MAP basing on time series of impedance cardiography measurements maximum of Z first time derivative, (dZ/dtmax), ejection time (ET), basal impedance Z (Z0) stroke volume (SV) and heart rate (HR)

Prediction of MAP based on ICG could significantly simplify and reduce cost of ANS tests as devices that allow the continuous measurement of blood pressure are expensive compared to impedance cardiography apparatus.

2. Method

2.1. Experimental protocol

Ten healthy, young people, 4 women, and 6 men participated in the study. Characteristic of the population is shown in Table 1. Subjects performed 3 minutes handgrip test at 30 % of maximal voluntary contraction (MVC) in supine position. MVC was obtained before trial; subjects were asked to clench a hand with maximal force on hand dynamometer (DR4-CA JBA Staniak, Poland). When performing handgrip subjects received feedback to help them maintain desired force of contraction.

Table 1: Characteristic of the population, mean ± standard deviation.

Age [years]	23,5±2,6
Body mass [kg]	72,3±12,7
Height [cm]	176±5,5

During experiment ICG signals were recorded (RM–23; device built in IBSPiE, Warsaw University of Technology), blood pressure was measured non-invasively from cuff on finger with Finapres Nova device (Finapres Medical Systems, Holland).

Signals analysis was performed off-line. For each cardiac cycle MAP value was calculated from blood pressure curve. From ICG dZ/dtmax, ET and Z0, value of SV was calculated with Kubicek formula.

2.2. Model

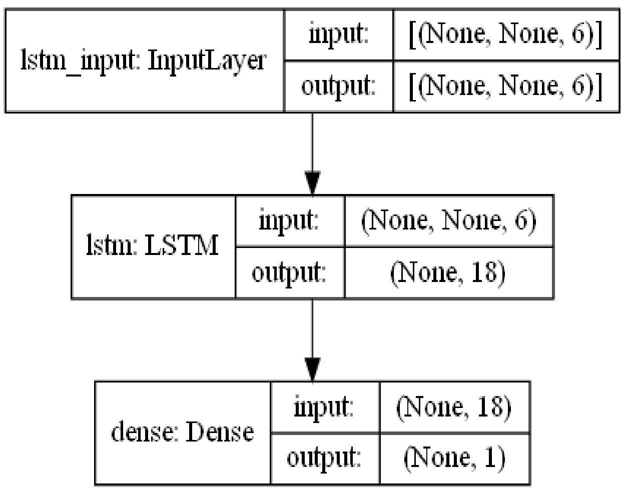

Figure 1. Plot of neural network model. Network contains one input layer, one LSTM layer and one Dense layer with one neuron for prediction of MAP value based on input time-series.

We implement our model in Keras library [4]. Our approach is based on code example of time series forecasting weather [5].

Our model is shown in Figure 1. It contains one LSTM layer (18 neurons, dropout=0.05, recurrent dropout=0.02) for analysis of our input time series and one output Dense layer (with default parameters) for prediction of MAP.

We randomly divided data into sequences, ten past values of the input: dZ/dtmax, ET, Z0, SV and HR were used for prediction of current MAP value. Sequences from all patients were combined in one dataset. 80% of dataset was used for training and 20% for validation. MAP value and all input parameters were normalized.

3. Result

For training, we use RMSprop optimizer, with 'mae' as loss function. We train our model for 50 epochs with 50 steps per epoch. Progress of training of the model is shown on Figure 2.

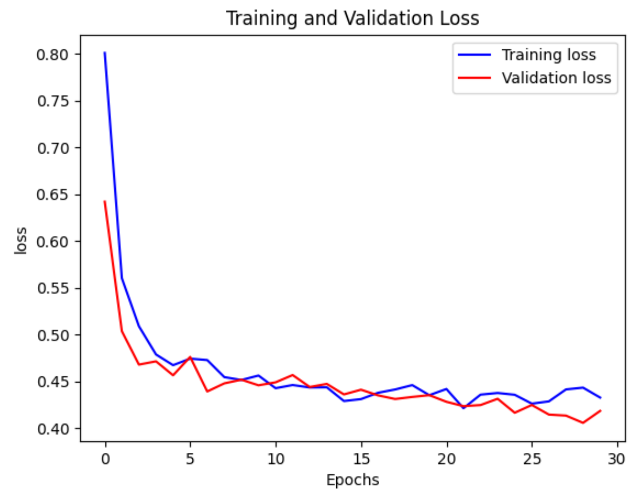

Figure 2. Visualized loss function changes for training and validation with progress of training epochs.

The best result, the mean absolute error, in the evaluation of our model was 0.4.

4. Discussion

Loss value at 0.4 is unsatisfactory. The performance of our model is poor, so our model cannot be used for prediction of MAP based on ICG signals.

One possible reason of unsatisfactory performance of our model is an insufficient data set; 10 recordings from 10 patients, each of about 5 minutes duration, provide only about 300 independent non-overlapping sequences.

Our recording was made during handgrip test when blood pressure rises in response to hand contraction. Depending on handgrip force level, cardiovascular response can vary [6]. For low level of contraction force MAP rise, and after same time stabilize. For higher level, above 20% of maximum voluntary contraction, blood pressure response becomes non-stationary – blood pressure rises continuously during the whole trial. These phenomena do not support generalization of our model, as hemodynamic condition can change during recording.

Watanabe et al. [7] shown that cardiovascular response for stimulus is individually specific. In some persons rise of MAP results from HR rise, in others is due to TPR rise and still in others due to SV rise. In general, cardiovascular response can be combination of rise or drop of all of the parameters. Training and generalization of neural network model seems impossible for our very small dataset. Before final conclusion concerning model suitability can be made, training of the model should be performed on at least 10 or even 100 times bigger dataset.

Kwon et al. [8] tried to predict stroke volume based on arterial blood pressure. Their model showed a correlation with sample data as r=0.95 and MSE =2.13. Their model was based on convolutional neural network. Their result shows that neural network can be trained to recognize the link between blood pressure and blood flow (stroke volume) and subsequently TPR.

In this paper we present results of our first attempt to predict MAP based on ICG signal stemming from changes in aortic volume. Our results are not satisfactory; model and dataset need to be improved

We believe that attempts to utilize ICG signal to predict essential cardiovascular parameters are worth perusing, as they can help eliminate continuous blood pressure monitoring with volume clamp method thus reducing cost and complication of performing ANS tests.

Acknowledgments

This work was supported in by the Warsaw University of Technology Grant 504/04663/1142/43.050001

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