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A hybrid model based on modular neural networks and fuzzy systems for classification of blood pressure and hypertension risk diagnosis

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ABSTRACT

In this paper, a hybrid model using modular neural networks and fuzzy logic was designed to provide the hypertension risk diagnosis of a person. This model considers age, risk factors and behavior of the blood pressure in a period of 24 h, using as a basis the Framingham Heart Study.

Records of blood pressure are collected with the ambulatory blood pressure monitoring (ABPM), a device which takes readings for a period of time of 24 h. A modular neural network was designed, with three modules, of which the first and second modules correspond to the systolic and diastolic pressures and the last one to the heart rate. Each module is trained with the data obtained by the ABPM of different patients, this in order that the neural network learns the different behaviors that the blood pressure may have. Also, different architectures and learning methods are considered to obtain the best possible architecture. In addition, two fuzzy inference systems (FISs) for classification purpose are proposed, the first one for the heart rate level and the second one for the night profile of the patient. These were tested with different types of membership functions and then selecting the FIS that obtained the best results. Furthermore, a third FIS as a blood pressure classifier is also used.

The different proposed methodologies were tested, in the case of the modular neural network to find the architecture that produces better results and in the fuzzy inference systems to find which membership functions were the ideal ones for the case study, in this way obtaining overall good results. For the case of the modular neural network, the learning accuracy in the first module is 98%, in the second module is 97.62% and the third module is 97.83% respectively. For the night profile, the fuzzy system is compared to a traditional system of production rules, and it is noted that the first one gives all correct outputs and the second one just gives 53% of the outputs, this is due to the uncertainty handling that fuzzy systems can provide, which the traditional system cannot because its rules are very strict.

Hybrid intelligent systems for the solution of this kind of complex problems have excellent performance, due to the good learning in each module of the neural network and the classification uncertainty that is well managed by the fuzzy systems, obtaining with this a hybrid combination for achieving good results.

1. Introduction

1.1. Blood pressure and heart rate

Blood pressure (BP) is the force exerted against the walls of the arteries as the heart pumps blood, which is necessary for the blood to circulate through the blood vessels and provide the oxygen and nutrients necessary to all organs in order that the body can function properly (Rosendorff, 2013).

BP actually has two components: *Systolic Pressure*, which corresponds to the maximum value, measuring the force of the blood in the arteries when the heart contracts (beats), *Diastolic pressure*, which corresponds to the minimum value, measuring the strength of blood in the arteries while the heart is relaxed (filling with blood between the heartbeats) (Rosendorff, 2013).

In adults, normal blood pressure is defined as a systolic pressure below 139 mmHg and a diastolic pressure below 89 mmHg. It is normal for blood pressure to change, being lower at night with sleep and higher in the early hours of the morning (Rosendorff, 2013).

The Heart Rate (HR) is the number of times the heart contracts per minute. Normal heart rate undergoes healthy varia-

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Table 1
Definitions and classification of office blood pressure levels (mmHg).

Category	Systolic		Diastolic
Optimal	< 120	and	< 80
Normal	120–129	and/or	80–84
High Normal	130–139	and/or	85–89
Grade 1 hypertension	140–159	and/or	90–99
Grade 2 hypertension	160–179	and/or	100–109
Grade 3 hypertension	≥ 180	and/or	≥ 110
Isolated systolic hypertension	≥ 140	and	< 90

tion, due to certain conditions, such as exercise, body temperature, body position and emotions ("American Heart Association," 2015) (MacGill, 2017)

1.2. Hypertension

High blood pressure or hypertension, is the elevation of blood pressure above the normal considered values, which means a systolic blood pressure (SBP) above 140 mmHg or a diastolic blood pressure (DBP) above 90 mmHg (Battegay, Lip, & Bakris, 2005).

Hypertension can be: *Essential hypertension*, which arises with no specific identifiable cause, but with a hereditary history, it may appear in isolation or be part of a complex of alterations that are found in insulin resistance (Beevers, Lip, & O' Brien, 2007) (Carretero & Oparil, 2000). *Secondary hypertension*: this is a type of hypertension that has demonstrable causes, the most frequent causes of this type of hypertension are renovascular disease, endocrine, pregnancy, acute stress, renal failure and coarctation of the aorta, which can produce hypertension, and must be suspected in two situations: Hypertension in young people (< 35 years) and the absence of family history of hypertension (Beevers et al., 2007) (White, 2007).

For the blood pressure levels, the European guidelines for hypertension (Mancia et al., 2013) are used for classification. This is because these guidelines have not been widely used for this type of research, in addition to having more levels of classification in comparison with the American guidelines for hypertension management. The different classes of blood pressure are presented in Table 1, in accordance to the European guidelines for hypertension.

1.3. Ambulatory blood pressure monitoring

The Ambulatory Blood Pressure Monitoring (ABPM) is a non-invasive method for obtaining 24-h blood pressure measurement, which consists of a device connected to a sphygmomanometer cuff, which records the blood pressure of patients in a time interval, typically programmed from 15 to 20 min in the day and every 30 min during the night, and when the period of the reading ends, the information is downloaded into a computer (Guido, 2008) (Grossman, 2013).

1.4. Nocturnal blood pressure profile

The normal circadian profile is characterized by the decrease of between 10 and 20% of the nocturnal BP values compared to the daytime or activity values (dipper profile) (Friedman & Logan, 2009). The absence of a decrease in nocturnal BP < 10% is considered to be a non-dipper pattern. Another way of defining the dipper/non-dipper pattern is by using the night/day ratio, so that dipper patients would have a quotient between 0.90 and 0.80, non-dippers between 0.91 and 1.00, the dipper Extreme (nocturnal BP decrease > 20% of daytime BP) is ⟨0.80 and the riser (mean of nocturnal BP values above the mean of daytime) has a quotient⟩ 1.00 (Feria-Carot & Sobrino, 2011).

1.5. Framingham heart study

In order to provide a patient's risk of developing hypertension, we based our work on the Framingham heart study ("Framingham Heart Study," 2016) for the data. This study began in 1948 and was applied to a group of 5209 men and women from Framingham, Massachusetts ranging from 30 and 62 years old, who not had any cardiovascular disease or had not suffered a heart attack or cardiovascular accident. As time has passed the descendants of the original group have been added, and the objective of the Framingham Heart Study is the identification of the risk factors that influence the development of cardiovascular diseases (Kannel, 2000).

This study is based on a Weibull regression model, which is used to calculate risks in a given time, and for this case, the diagnosis of the risk of developing hypertension in a period of 4 years is given. In this study the variables such as age, sex, body mass index, if the patient has hypertensive parents smoking habit, systolic and diastolic blood pressure are taken into account (Kawada & Otsuka, 2010).

The risk of developing hypertension is given by the following expression:

$$FHS\ predictor\ risk = 1 - exp\left[-exp\left(\frac{\ln(4) - 22.94954 + \ \Sigma\ X\beta}{0.8769}\right)\right] \quad (1)$$

Where:

β: It is the coefficient of regression.
X: It is the level for each variable.

If the gender is female then the variable is assigned a 1, and if it is male is assigned a 0.

If none of the parents is hypertensive is assigned a 0, if one of the parents is hypertensive is assigned 1 and if both are then is assigned a 2 ("Framingham Heart Study," 2016).

1.6. Hybrid systems and soft computing

At present, hybrid systems are a powerful tool for solving complex problems, because two or more soft computing techniques can be used simultaneously to solve a particular problem, and thereby reduce its complexity. In addition, hybrid systems are aimed at improving the efficiency and power of reasoning as well as the expressivity of isolated intelligent systems (Fdez Riverola & Corchado, 2003);(Medsker, 1995).

Soft computing is the opposite of hard computing, in that it is tolerant to imprecision, uncertainty, partial truth, and approximation. On the other hand, "nature-inspired" methodologies are designed to emulate one or more aspects of biological systems, and can be utilized for complementing both hard or soft computing.

For the model to be developed, soft computing techniques, such as artificial neural networks and fuzzy logic are used, since these methodologies have several characteristics in common, including the fact that they are free model estimators that can be adjusted or trained to improve their performance (Medsker, 1995).

1.6.1. Basic concepts

An artificial neural network is an information processing system, which has certain performance characteristics in common with biological neurons. Artificial neural networks have been developed as generalizations of mathematical models of human cognition or neural biology (Samarasinghe, 2007).

In general, the implementation of modular neural networks is based on the "divide and conquer" principle, which consists of the decomposition of a task into less complex and smaller subtasks, so that every task is learned by different experts and then reuse