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A novel medical decision support system based on fuzzy cognitive maps enhanced by intuitive and learning capabilities for modeling uncertainty

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ABSTRACT

In this paper, an active Hebbian learning (AHL) for intuitionistic fuzzy cognitive map (iFCM) is proposed for grading the celiac. This method performs the diagnosis procedure automatically, and it is more suitable for specialists in better understanding and assessment of the disease. Our approach shows potential in confronting hesitancy through considering experts' uncertainty in modeling. In this study, we propose an automatic computer-aided diagnosis system based on iFCMs to determine the grade of celiac disease. By relying on the knowledge of experts, the key features of disease are extracted as the main concepts, and the iFCM model for the complex grading system is designed as a graph with eight concepts. The results obtained by applying our proposed method (iFCM-AHL) on the dataset verify the ability and effectiveness of this model. The proposed iFCM by considering hesitation of experts in modeling process and property of less sensitive to missing input data, not only increase accuracy in detecting the type of disease, but also obtain a higher robustness, in dealing with incomplete data. The obtained results have been compared with the findings of the FCM, interval type-2 fuzzy logic system, untrained iFCM and five extensions of the FCM. Comparative results show that our approach offers a robust classification method that produces better performance than other models.

1. Introduction

In this paper, the soft computational technique of fuzzy cognitive map (FCM) has been employed to provide a more robust and intelligent approach for reasoning and the presentation of knowledge; which is necessary for decision support systems. By combining the features of fuzzy logic and neural networks, the FCMs establish a knowledge-based graph [1]. The hidden causal relationships in data reflect some stable mechanisms which can be used in diagnosis. These causal relationships can be modeled by an FCM. Owing to features such as simplicity, handling of conflicting knowledge, and directed graph for the modeling and deduction of knowledge, the FCMs have attracted a great deal of interest [2]. FCMs have been

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employed for modeling complex systems in fields such as engineering [3], medicine [4], environment [5], robotics [6], industry [7], and in applications such as the prediction of time series [8,9], and pattern recognition [10,11].

Several extension models have been presented for the FCM. One of these models is the dynamic cognitive network (DCN), which defines the dynamic causal relationships between the FCM concepts and expresses these causal relations in the framework of Laplace [12]. Another extension proposed in [13] is the rule-based FCM (RBFCM), which has a good ability in defining the non-constrained relationships by using the monotonic causality concept. RBFCMs are cognitive maps which, contrary to FCMs, use the fuzzy variables defined by the fuzzy membership functions to express the system concepts. In [14], as an extension of the FCM, fuzzy grey cognitive maps (FGCMs) have been proposed for multi-concept environments, in which the relationships between concepts are defined according to the theory of grey systems. As an extension of the FCM, the timed automata-based FCM (TAFCM), which includes a temporal concept, enjoys an important status in many of the real-world applications [15]. Intuitionistic FCM (iFCM) is another interesting extension of the FCM, which has the advantages of both the FCM and intuitionistic fuzzy set (IFS) [16]. Atanassov [17] modified fuzzy set theory, and proposed the IFS, which is leveraged to objectively evaluate goods, services, or persons by considering membership degree, non-membership degree, and hesitancy degree.

Since diagnostic procedures in medical practices are accompanied by a great deal of uncertainty, iFCM can play an important role in decision-making related to medical diagnosis. So, it is used in this paper for a medical application. In this application, for the first time, the grading of celiac disease (CD) in tissue form is analyzed and modeled by means of an iFCM. In this procedure, by considering all the cytological and structural factors for the mucosal membrane of small intestine, we offer a knowledge-based computational method for classifying CD.

CD includes the digestive manifestations and inflammatory reactions of small intestinal mucosa, which occur as a result of the body's auto-immunity response to gluten [18]. Degree of uncertainty that the specialists may have is also considered in defining the relationships between FCM concepts; therefore, an additional factor regarding the knowledge and opinions of experts is established in this approach.

Due to the massive increase in number of unlabeled data, unsupervised learning algorithms attract the interest of researchers. Theoretically, the problem in the development of exact methods, which are objective evaluation oriented, in the past 50 years resulted in the development of several unsupervised algorithms [19]. Since FCM is most often used in unknown models, the use of supervised learning algorithms is not a suitable choice. Therefore, Hebbian-based methods [20–22], which are among unsupervised algorithms, are usually used for FCM training, especially when there is knowledge from experts on the investigated problem domain and relatively low number of available data (small datasets).

Thousands of measurements/samples (large datasets) are typical employed in the literature for training neural networks and other machine learning models. Based on the literature, artificial neural networks and other machine learning algorithms are not able to perform well and even sufficiently in classification problems where a limited amount of data is available [23,24].

We motivated to apply the proposed advanced iFCM with its learning capabilities for classification tasks concerning cases with small datasets, due to insufficient performance of neural networks and other machine learning algorithms on classifying cases with limited number of data.

Learning algorithms are used to systematically improve the quality of FCMs and to increase the efficiency of the relevant intelligent decision-making system. In this work, active Hebbian learning (AHL) algorithm is employed to better adapt the model to the examined system.

AHL is an unsupervised learning algorithm based on the Hebbian learning rule. This algorithm provides an activation sequence for concepts, which is determined by medical experts. In diagnostic processes, especially in medical diagnosis, the order of investigating the main features of a disease is highly important; and medical specialists examine these features with regards to the priorities they have in diagnosis, before making their final decision on a particular disease. In the AHL, this order is considered as an activation sequence for concepts, in which the concepts are ranked according to the priorities they have in diagnosis, as determined by an expert. Therefore, considering the order of importance is one of the main advantages of AHL, and this algorithm can mathematically model such an order.

The main objective of training iFCM weights, using Hebbian rule-based methods, is the utilization of available data and different modifications of Hebbian rule to update the weights obtained from experts' knowledge. Using this method iFCM converges into the expected scopes defined by the problem.

The rest of this paper is organized as follows: Section 2 describes the structure and functioning of the iFCM. AHL algorithm is proposed for iFCM model in Section 3. Section 4 deals with the designing of iFCM models for determining the grade of CD. The performances of these designed models are evaluated and their achieved results are presented in Section 5. The comparison between the applied models are presented in Section 6. And finally Section 7 concludes this article.

2. Intuitionistic FCM

IFS is a generalized fuzzy set that its members (expressed as x) to be specified by using both the membership and non-membership definitions for the set.

IFSs are mostly suitable for handling ambiguous and uncertain systems. An IFS A is defined as follows:

$$A = \{\langle x, \mu_A(x), \gamma_A(x)\rangle | x \in U\} \tag{1}$$