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Multiclassifier systems applied to the computer-aided sequential medical diagnosis

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ABSTRACT

The diagnosis of patient's state based on results of successive examinations is common task in the medicine. In computer-aided algorithms taking into account the patient's history in order to improve the quality of classification seems to be very reasonable solution. In this study, two original multiclassifier systems (MC) for the computer-aided sequential diagnosis are developed, which differ with decision scheme and the methods of combining of base classifiers. The first MC system is based on dynamic ensemble selection scheme and works in two-level structure. The second MC system in combining procedure uses original concept of meta-Bayes classifier and produces decision according to the Bayes rule.

Both MC systems were practically applied to the diagnosis of human acid–base equilibrium states and compared with some state-of-the-art sequential diagnosis methods. Results obtained in experimental investigations imply that MC system is effective approach, which improves recognition accuracy in sequential diagnosis scheme.

1. Introduction

Multiple diagnoses of the patient's state based on results of successive examinations is one of the most frequent and typical medical diagnosing tasks. Such a task, henceforth called the *sequential diagnosis*, involves dealing with a complex decision problem. With no doubts, there exists a strong dependence between the patient's state at a given time and the preceding states. This relation may have a diversified nature and range. In its simplest case it can be a one-instant-backwards dependence, but in more complex arrangements the current state depends on the whole former course of the disease.

We have to take into account these sequential diagnosing dependencies when we intend to support diagnosing tasks using a computer. In other words, when constructing an appropriate decision algorithm, we must not limit our approach to only the narrow information channel that concerns just the current symptoms, but we have to consider all the available measurement data instead, as they may contain important information about the patient's state at

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a given instant. The measurement data comprise all the examination results obtained so far, the applied treatment procedures, as well as the diagnoses formulated at previous diagnosis instants. Thus the bulk of data is very rich and grows over time from one instant to another. At this point it can be viewed at as both an advantage and disadvantage, depending on the viewpoint. Every medical practitioner will recognize the great usefulness of such data. Performing the sequential diagnosis, he/she will inevitably ask the patient not only about the former symptoms and applied treatment, but about the previous diagnostic statements. On the other hand, however, the lavishness and incremental nature of the available data make it impossible to comprehend them completely, as a result of which fact various simplifications and compromises must be made.

For the purpose of automatic medical diagnosis based on sequential decision scheme, several algorithms have been developed and proposed in the literature [1–4]. For the calculation of decision strategy, various mathematical models are used in algorithms, such as probabilistic model with Markov dependence [5], fuzzy relation approach [6], rough set theory [7], and neural network method [5], among others.

In the last two decades, the multiclassifier systems (MC) are very strongly developed, mostly because of the fact that committee, also known as ensemble, can outperform its members [8–12]. For the classifier combination two main approaches are used: classifiers fusion and classifiers selection. In the first method, all classifiers in the ensemble contribute to the decision of the MC system, e.g. through sum or majority voting [8]. In the second approach, a single classifier is selected from the ensemble and its decision is treated as the decision of the MC system. The selection of classifiers can be either static or dynamic. In the static selection scheme classifier is selected for all test objects, whereas dynamic classifier selection approach explores the use of different classifiers for different test objects [13].

Recently, dynamic ensemble selection (DES) methods have been developed which first dynamically select an ensemble of classifiers from the entire set (pool) and then combine the selected classifiers by majority voting [13]. In this way a DES based system takes advantage of both selection and fusion approaches.

In this study, two original multiclassifier systems for sequential decision (diagnostic) problem are developed. The first MC system works in two-level structure. At the first level, the set of sub-MC systems, dedicated to particular instants of sequential diagnosis, produce decisions on patient's state using DES strategy. At the second level, these decisions are combined by weighted majority voting method with competences of base classifiers as weighting coefficients.

In the second MC system the original concept of meta-Bayes (MB) classifier is applied. In the MB classifier, which creates a probabilistic generalization of a set of base classifiers for particular instants of sequential diagnosis, first a posteriori probabilities for possible patient's states are calculated and next decision is made according to the Bayes rule. In the proposed MC systems, combining mechanisms are constructed using the supervised learning procedure. It means, that so-called validation set must be available, which is basis for calculating in dynamic fashion competences of base classifiers for the first MC system and a posteriori probabilities of patient's states for the second MC system.

Both MC systems were practically applied to the diagnosis of human acid–base equilibrium states and compared with some state-of-the-art sequential diagnosis methods. Obtained results clearly show that MC systems are effective approach to the computer-aided sequential medical diagnosis.

The paper is divided into 5 sections and organized as follows. Section 2 presents fundamentals of sequential diagnosis problem and introduces basic notations. Two developed MC systems are described in detail in Section 3. The experiments conducted and the results with discussion are presented in Section 4. The paper is concluded in Section 5.

2. Preliminaries and the problem statement

We will treat the sequential diagnosis task as a discrete dynamical process. The patient (object) is at the nth instant in the state $j_n \in \mathcal{M}$, where $\mathcal{M}$ is an M-element set of possible states (classes) numbered with the successive natural numbers. Thus:

$$j_n \in \mathcal{M} = \{1, 2, \ldots, M\}. \tag{1}$$

Obviously, the notion of *instant* has no specific temporal meaning here, as its interpretation depends on the character of the case under consideration. The actual measure used may be minutes, hours, days, or even weeks.

The state j_n is unknown and does not undergo our direct observation. What we can only observe is the indirect symptoms (also called features or tokens) by which a state manifests itself. We will denote a d-dimensional symptom value vector by $x_n \in \mathcal{X}$, for symptoms measured at the nth instant (thus $\mathcal{X}$ is the symptom space).

As already mentioned, the patient's current state depends on the history and thus the specificity of the investigated diagnostic task reveals in the form of input data, which are not associated only with the direct symptoms that manifest the current state, but comprise up to an extend the historic information that regards the preceding course of disease. For this case we do not know how far backwards the examined input data should spread into the past; the 'the more the better' rule need not necessarily be true here. As for now, there is no analytical evidence to be used in this issue, whilst any attempts to answer the question are under way of experimental research.

In the general case, we suppose that the decision algorithm at the nth instant takes into account the K-instant-backwards-dependence ($K < n$). It means, that decision at the nth instant is made on the base of vector of features

$$\bar{x}_n^{(K)} = (x_{n-K}, x_{n-K+1}, \ldots, x_{n-1}, x_n). \tag{2}$$

In consequence, the classification algorithm at the nth instant is of the following form:

$$\Psi_n\left(\bar{x}_n^{(K)}\right) = i_n, \quad i_n \in \mathcal{M}. \tag{3}$$

In this study, multiclassifier (MC) system will be applied as classifiers (3) for the particular instances of sequential diagnosis. In the proposed MC systems, both the pool of base