A Fuzzy Cognitive Map Based Differential Diagnosis System for Dysarthria and Apraxia of Speech

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Abstract

This paper presents a soft computing system for differential diagnosis of the dysarthrias and apraxia of speech based on the well accepted dysarthrias' classification system used by speech and language pathologists. Since an accurate diagnosis is a very challenging task for the clinician, the under development system based on Fuzzy Cognitive Maps will be used as a "second opinion" or training system. The system was tested using published case studies and real patients and examples are presented here.

Keywords: Fuzzy Cognitive Maps, Differential Diagnosis, Knowledge-Based Systems, Decision Support Systems.

1. Introduction

As speech and language pathologists (SLPs) have become increasingly computer literate and technology advances have progressed and have established their important role in the SLP field, the need for more sophisticated computerized systems to assist them in the diagnosis and treatment of speech, language, voice and swallowing problems has increased as well.

Dysarthria is a term that is used to describe a group of disorders of oral communication resulting from disturbances in muscle control over the speech production mechanism due to damage to the central or peripheral nervous system [1-2]. Neurological impairment in the form of paralysis, weakness, or lack of coordination of the muscles that support speech production, can result in different forms of dysarthria. Darley et al. [1-2] identified seven forms of dysarthria: spastic, flaccid, ataxic, hypokinetic, hyperkinetic chorea, hyperkinetic dystonia, and mixed dysarthria.

Apraxia of speech is defined as "a neurogenic speech disorder resulting from impairment of the capacity to program sensorimotor commands for the positioning and movement of muscles for the volitional production of speech. It can occur without significant weakness or neuromuscular slowness, and in the absence of disturbances of conscious thought or language" [3].

The differentiation between the dysarthria types can be a challenging task for a SLP, since many speech and oral motor characteristics of the dysarthrias are overlapping [3-4]. Additionally, despite the fact that the distinction between AOS (Apraxia of Speech) and dysarthria is usually an easier process, differentiation between AOS and ataxic dysarthria or the establishment of a co-occurrence of both AOS and a dysarthria type can be challenging as well [3]. One of the most widely used and accepted systems [4-5] for the differential diagnosis of the dysarthria types is the DAB system or the Darley, Aronson and Brown [1-2] system.

According to the survey of Simmons and Mayo [4] of 100 certified SLPs working with patients with motor speech disorders, the majority (60%) of them reported that they have been using the DAB classification system of dysarthrias in their clinical practice. The importance of knowing the type of dysarthria is outlined in the same survey where the majority (68%) felt that knowing the specific type of dysarthria was helpful in treatment design. Seventeen per cent of those surveyed felt that there were some difficulties associated with the use of the DAB classification system, such as too many parameters to remember, overlapping symptoms etc., while 15% felt that clinicians' lack of experience with dysarthric patients contributed to difficulties in dysarthria differential diagnosis.

The goal of the present study was to create a computerized, easy to use and quick version of the DAB system, which can be used as a "second opinion" tool to assist the diagnostic process as well as a training tool for SLP graduate students.

In particular, this paper presents an artificial intelligence differential diagnostic system for the major dysarthria types and AOS, which was based on the DAB classification system [1-2] and supplemented by Duffy's description of AOS characteristics [3], and constitutes a decision support system (DSS). The specific artificial intelligence technique used in the Dysarthria-AOS DSS system is Fuzzy Cognitive Maps

(FCMs). The system was tested using 10 published case studies and 3 patients. The examples of patients are presented here.

1.1. Fuzzy Cognitive Map Diagnostic Systems

Fuzzy Cognitive Maps (FCMs) are a soft computing tool that is a result of the synergy of fuzzy logic and neural network methodologies and is based on the exploitation of the integrated experience of expert-scientists. It is a knowledge-based methodology suitable to describe and model complex systems and handle information from an abstract point of view [6]. In other words, this means that FCMs follow the method of human reasoning in making decisions. Artificial intelligence techniques such as FCMs have been successfully used to model complex systems that involve discipline factors, states, variables, input, output, events and trends. These modeling techniques can integrate and include in the decision-making process the partial influence of controversial factors, can take under consideration causal effect among factors and evaluate the influence from different sources, factors and other characteristics using fuzzy logic reasoning. Thus, these methods are ideal for Decision Support systems in Medical Informatics where humans use mainly differential diagnosis based on fuzzy factors some of which are complementary, others similar and others conflicting, and all are taken into consideration when a decision is reached [7-9]. Each factor has a different degree of importance in determining (or influencing) the decision, which increases the complexity of the problem.

The graphical illustration of a FCM is a signed, weighted graph with feedback that consists of nodes and weighted arcs [6],[10]. Nodes of the graph are the *concepts* that in the case of a MDSS FCM are two kinds: the factors and the diagnoses. Directed, signed and fuzzy-valued weighted *arcs*, which represent the causal relationships that exist between the concepts, interconnect the FCM concepts, as shown in figure1.

Fuzzy Cognitive Maps have been successfully used to develop Medical Decision Support Systems including differential diagnosis of other speech and language disorders [11-13].

In a FCM-MDSS each factor-concept is characterized by a fuzzy value that represents a qualitative measure of the concept's presence in the patient. Patient information which can be factor concepts are experimental results, test results, physical examinations and other descriptions symptoms and measurements of physical qualities, which are described in fuzzy linguistic values and are converted through defuzzification to a numerical value in the interval [0,1]. A high numeric value indicates the strong presence of a factor-concept.

The weights of the arcs in the FCM-MDSS represent the contribution of each factor to each of the diagnosis. These are described with linguist values that can be defuzzified and transformed to the interval [-1,1]. It should be noted that a negative weight value from a factor to a diagnosis indicates that the presence of a factor tends to decrease the probability of that particular diagnosis. This representation makes the updating of the structure of the graph easy, as new information becomes available or as more experts are asked. This can be done, for example, by the addition or deletion of an interconnection or a concept.

The FCM-MDSS runs according to the algorithm described in [11] and when an equilibrium region is reached the FCM ceases to interact.

A major advantage of fuzzy cognitive maps is that they can reach conclusions even when information is incomplete or even conflicting. This is very important in the diagnosis of dysarthria and apraxia because frequently important information may:

- be missing (e.g. it may not be possible to conduct certain tests)
- be unreliable, they may be a result of unreliable measurement techniques
- be vague or conflicting, there may be more than one logical ways to interpret them
- be difficult to integrate with other information.

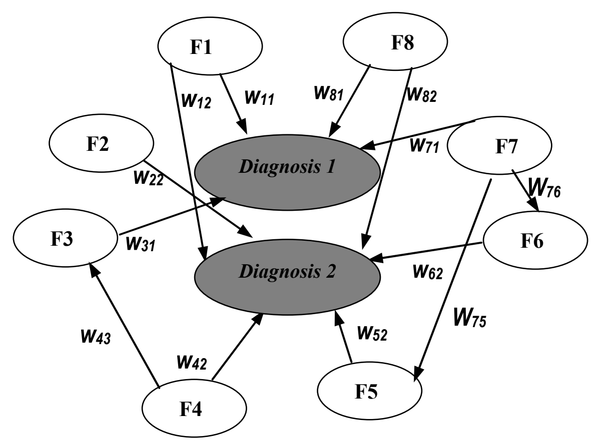

Fig. 1: FCM Medical Decision Support System.

2. Methodology

This study was a pilot study that aimed to test the functioning of the under development system. The test cases of this study were:

- 10 published case studies [3]
- 3 male patients (2 diagnosed with dysarthria – 66 and 70 years old - and 1 with AOS -72 years old) – post stroke

For the patients videotapes were viewed by a speech and language pathologist (with approximately 10 years of experience in Motor Speech Disorders) who was asked to reevaluate independently the patients (without knowing the initial diagnosis).

The patients were evaluated during four types of tasks: a) oral motor examination, b) reading a Greek passage, c) sustaining the vowel /a/ and d) counting from 1 to 10.

3. Description of Differential Diagnosis System

In the DAB model oral motor findings and speech characteristics may be a) present but generally not distinguishing, b) distinguishing when present or c) not usually present. In the application presented here, the factor concepts are the oral mechanism findings and the speech characteristics of the DAB model. Therefore, in the FCM model each oral motor finding and speech characteristic (input node) is connected to the output nodes (classification/diagnosis) through the assignment of the corresponding qualitative (linguistic) values of medium (M), high (H), and 0.

The factor concepts, as mentioned earlier, are the factors which contribute to a diagnosis. These are the inputs to the Dysarthria-Apraxia differential diagnosis system, since the value of each factor concept is a linguistic/fuzzy value (e.g., low, medium, high, very high, etc.) decided upon by the SLP relating to the severity of the oral motor finding or speech characteristic in a patient. The decision concepts are the outputs of the system including the major dysarthria types (flaccid, spastic, ataxic, hypokinetic, hyperkinetic and mixed) and AOS. Mixed dysarthria was inferred by the model whenever more than one dysarthria diagnosis was concluded.

In this system 89 factors were used as the factor concepts. Of these 31 were oral-motor characteristics and 58 were speech characteristics (See [3] for a complete set of the factors used).

Table I represents an example of some of the weights between factors and diagnoses since it is not possible to show all 89 factors here and their connection to each of the 7 possible diagnoses.

In this FCM system, shown in figure 2, interaction between factors has not been explored since the system having 7 possible diagnoses outputs which are not mutually exclusive (since mixed dysarthria can occur or there can be a co-occurrence of dysarthria and apraxia) is already rather complex. Additionally, in this first approach we were interested in showing the feasibility of the FCM-DSS technique in this particular area of differential diagnosis.

Table I Examples of Fuzzy Values of Weights between Factor Concepts and Diagnosis Concept

Factor	***Flaccid Dys.***	***Spastic Dys.***	***Ataxic Dys.***	***Hypokinetic Dys.***	***Hyperkinetic Dys.***	***Apraxia of Speech***
Dysphagia	M	M	0	M	M	0
Hyperactive gag	0	H	0	0	0	0
Low pitch	0	H	0	0	M	0
Distorted vowels	0	0	H	0	H	M
Irregular AMRs	0	0	H	0	H	0
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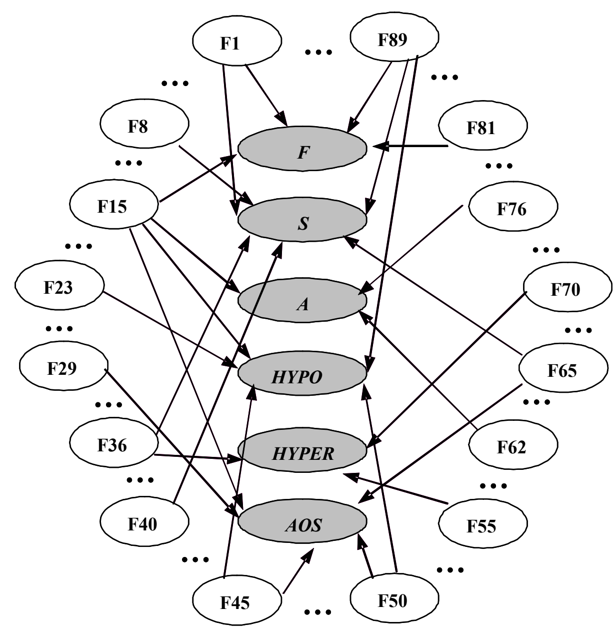

Fig. 2: Diagram of Differential Diagnosis System of Dysarthria and Apraxia of Speech.

For the ten published cases and the three patients the results of the FCM algorithm were run based on the factor inputs and the weights. The diagnosis concepts were initialized at 0. The final values of the each of the diagnosis concepts for the 3 patients are shown in Table II. The diagnosis concepts with values greater than 0.900 were the final diagnoses and are in italics in Table II. The final diagnoses of the FCM system are compared to the initial diagnosis provided by the SLP and match in all three cases. In the patient cases described here, none were found to have mixed dysarthria or co-occurrence of dysarthria and apraxia of speech.

Table II Comparison of Diagnosis provide by SLP and Dysarthria-Apraxia FCM DSS

Initial Diagnosis of Case by SLP	**Output Values of Differential Diagnostic System** ***Resulting Diagnosis***					
	Flaccid Dys.	Spastic Dys.	Ataxic Dys.	Hypok. Dys.	Hyperk. Dys.	Apraxia of Speech
Case 1 Ataxic Dys.	0.5622	0.8081	***0.9170***	0.5000	0.8355	0.6225
Case 2 Flaccid Dys.	***0.9284***	0.6900	0.5156	0.6514	0.5312	0.5312
Case 3 AOS	0.5467	0.7432	0.8936	0.7186	0.8727	***0.9975***

4. Conclusions and future considerations

This paper presented an under development system for the differential diagnosis of dysarthrias and AOS based on Fuzzy Cognitive Maps using a well known clinical model [3] as an expert knowledge basis for the structuring of the FCM. Preliminary trials with 10 published case studies and 3 patients revealed encouraging results regarding the correct use of the model.

Due to the complexity of the system having 89 factor concepts and 7 output diagnoses, no interaction between factors was included in this version of the system. It will be extended to include interaction between the factors, thus leading to an improved FCM Differential Diagnostic Model. After completion and pilot trials the system will be tested with a larger sample of patients and by 5 different SLPs.

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