A Multimedia Environment for the Speech and Language Impaired

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Abstract: **This paper discusses an under development Intelligent Multimedia Environment for the Speech and Language Impaired to support people with special needs to improve their performance and intervene in their Speech and Language disabilities. This environment supports speech and language therapy professionals to perform speech and language tests, validate the results, use differential diagnosis methods to provide therapists with a diagnosis of the disorder, and suggest an appropriate intervention plan. It is an integrated environment supporting even people with severe speech and language disorders by providing them a suitable, easy-to-use, and health-safe communication environment to alert hospital and other medical centers for life at risk.**

1. INTRODUCTION

Speech is highly vulnerable to disruption and a large number of people have a communication disorder that adversely affects their own and their families' lives. Disorders of speech and language have severe repercussions on people's ability to participate fully in their intellectual, economic, social and cultural lives.

In recent years, computer technology has revolutionized the analysis of speech production and speech perception in both research diagnostic and therapeutic settings. The latest results in computer technology and digital speech processing facilitate the construction of systems that improve the quality of speech learning and training effectively [1]. Multimedia software programs can transform spoken words into graphics and sound effects leading to speech therapy tools that motivate speech impaired patients to articulate speech and produce sounds with their own voice [2]. Animated displays and audio playback refine and simplify the process by focusing on the speech signal and by making feedback information clear and meaningful. Such systems provide direct and indirect feedback concerning the acoustic and articulatory characteristics of the patient's productions[3]. Clinicians can set objectives and targets, document progress and assess clients. Other multimedia programs contain a series of exercises using pictures, spoken or printed words to facilitate lexical comprehension and vocabulary development. They may use a hierarchy of visual, written, spoken cues to facilitate single word production It has been shown that specific measures of language function can be broadly, positively, and significantly influenced by computer-based language therapy in speech and language impairements such as chronic aphasia [4-6].

An effective tool is being developed for the individuals with speech and/or language disorders in order to enhance their treatment, provide intelligent feedback of their progress and for severe cases, ultimately empower them with a communication device that will ensure secure living conditions. An adaptable multimedia rehabilitative tool based on advanced signal processing and neural networks is being designed to enhance the treatment of people with speech and language disorders such as: articulation/phonological disorders, dysarthria, apraxia, developmental dyspraxia, aphasia, voice disorders, and stuttering [7]. This is supplied with a decision support system for speech and language therapists, based on intelligent techniques that and will provide feedback of the patient's communication progress and assist in the intervention planning for cognitive and language disorders, such as aphasia (many types), specific language impairment (SLI), language delay, and learning disabilities [8].

2. GENERAL ARCHITECTURE

The overall structure of the system consists of three main interconnected modules, as shown in Figure 1. The first module called **Logo_Therapy** contains the adaptable multimedia rehabilitative tools for the treatment of people with a wide variety of speech and language disorders. The second module **Logo_DSS** is a decision support tool to consult the speech therapist concerning an intervention plan and to differentially diagnose difficult to discern speech and language impairements. The third module **Logo_Comm** is an advanced information (communication) system with proper interfaces based on low power wireless technology (IR, RF or IR/RF), and having special communication features and biosensors for vital signs monitoring so as to ensure safe living conditions for severely speech and language impaired individuals.

2.1 The Logo_Therapy Module

The Logo_Therapy Module deals primarily with speech and voice disorders. It is an adaptable multimedia rehabilitative tool that utilizes advanced signal processing

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and neural networks to enhance the treatment of people with speech and language disorders such as: articulation disorders, dysarthria, apraxia, developmental dyspraxia, aphasia, voice disorders, and stuttering. Here, the system interacts with the patient and ask him to produce some target speech sounds, that are recording. The recorded signal is analyzed and recognized by comparing it to the features of sounds in the data bank and the system performs detailed speech recognition. Visual cues (animations) are presented to the patient in order to see and hear how the corresponding sound is produced through the human vocal tract and better understand what he/she must do to correctly produce the sound. Figure 2 depicts a snapshot of the system presenting to the patient the correct way to pronounce the letters.

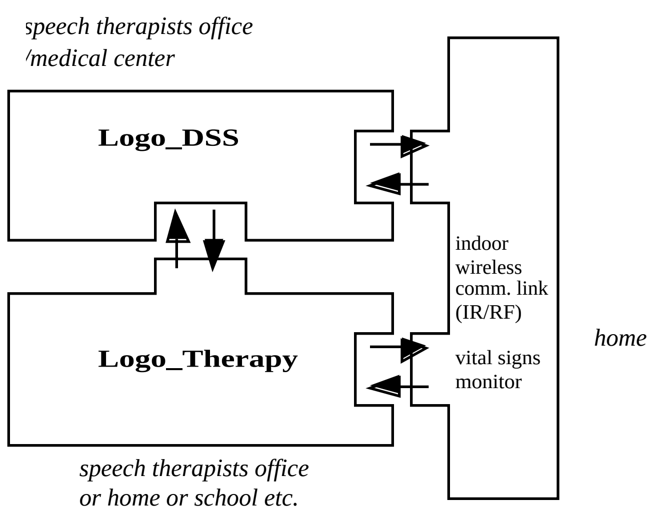

Figure1 The overall architecture of the system

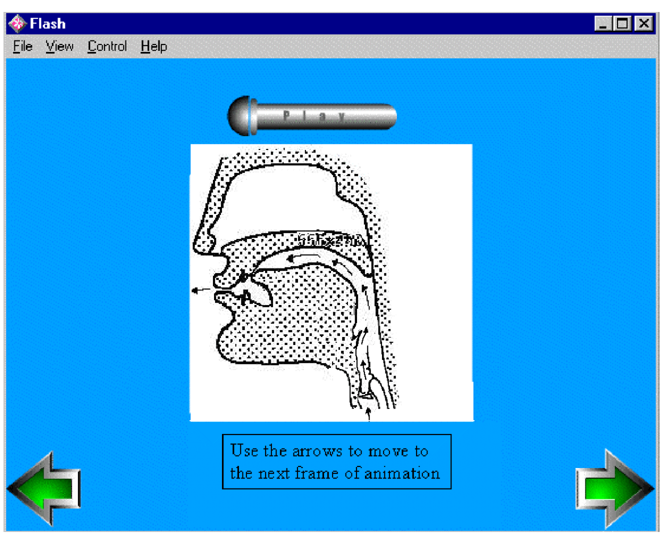

Figure 2. Snapshot of one of the speech/language tools of the Logo_Therapy Module.

All speech sounds that human can produce are included in the International Phonetic Alphabet (IPA), a standard set of symbols for transcribing the sounds of spoken languages. In the IPA, sounds are classified according to their place and manner of articulation in the vocal mechanism. The interesting part is that each sound has a unique place on the chart and all sounds of all languages are represented. In normal speech recognition, the systems are designed in such a way to recognize words based on a rather wide allowable variability to allow for intra-speaker and inter-speaker variability. In the Logo_Therapy module it is necessary to recognize accurately the produced sound, so that the sound is categorized correctly with reference to the IPA chart. This is achieved using time-frequency joint domain representations. Such representations allow estimation of quantities such as envelope, group delay, instantaneous frequency, delay spread, frequency spread, etc. which can lead to extraction of important features leading to classification of sounds based on the IPA model. Such quantities can also be used in the evaluation of pitch, jitter, shimmer, and other voice qualities.

2.2 The Logo_DSS Module

The Logo_DSS module performs multi-discipline decision-making tasks. It includes the diagnosis and treatment procedure of the speech and language impairments that are characterised by complexity and require expert therapists to intervene and provide the best solution and treatment schedule. The sophisticated Soft Computing methodology of Fuzzy Cognitive Maps is used for the design of the Intelligent Decision Support System inspired from discipline theories as the combination of Neurofuzzy systems, knowledge based methodologies, expert based systems and other soft computing techniques.

Generally, Logo_DSS, is an advanced decision support system to stand beside the therapist mainly based on intelligent soft computing techniques that provide:

- Classification of the speech and language impairment
- Differential diagnosis of the impairment
- Feedback of the patient's communication progress
- Intervention planning for cognitive and language disorders, such as Aphasia (many types), specific language impairment (SLI), language delay, learning disabilities, etc.
- Alarm signals and firing of the Logo_Comm module for emergency situations.

It is a classifier and diagnostic tool that can effectively deal with the different types of information existing and describing the decision making process within speech and language disorders. This information is either numerical data such as results of medical tests, results of the treatment as well as qualitative, imprecise and uncertain linguistic data that could be in the form of linguistic conditional rules and causal relationships among concepts and terms of he systems.

2.3 The Logo_Comm Module

The third module of the under development multimedia system, Logo_Comm, (shown in Figure 3) will be developed in the near future. It is consisted of an indoor wireless communication link used by severely speech and (language) impaired individuals as well as vital sign monitoring biosensors, so that medical professionals, family, friends, etc. can be alerted when a remotely located severely speech and language impaired individual is in need of emergency medical attention.

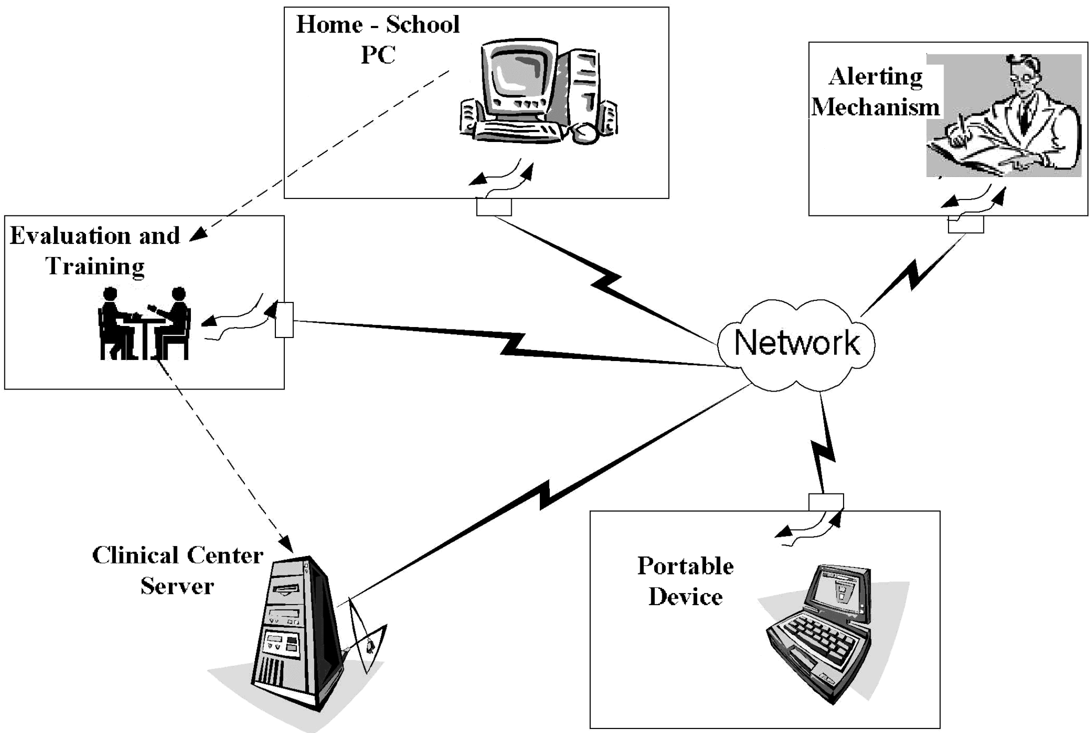

Figure 3. Indoor wireless links and overall network configuration for Logo_Comm

3. DIFFERENTIAL DIAGNOSIS MODEL

In this section a novel part of the Logo_DSS module is described, which is a differential diagnosis tool to support the speech and language professionals in their decisions. The differential diagnosis tool is based on Fuzzy Cognitive Maps.

3.1 Fuzzy Cognitive Maps

Fuzzy Cognitive Maps (FCM) is a soft computing methodology, a synergism of Fuzzy Logic and Neural Network methodologies and is based on the exploitation of the integrated experience of expert-scientists. The graphical illustration of FCMs is a signed, weighted graph with feedback that consists of nodes and weighted arcs. Nodes of the graph are the concepts that correspond to variables, states, factors and other characteristics incorporated in the model, which describe the behavior of the system. Directed, signed and weighted arcs, which represent the causal relationships that exist between the concepts, interconnect the FCM concepts. Each concept represents a characteristic, state or variable of the system; concepts stand for events, actions, goals, values, and/or trends of the system being modeled as an FCM. Each concept is characterized by a numeric value that represents a quantitative measure of the concept's presence in the model. A high numeric value indicates the strong presence of a concept. The numeric value results from the transformation of the real value of the system's variable, for which this concept stands, to the interval [0,1]. Values in the graph are fuzzy, so weights of the arcs are described with linguist values that can be defuzzified and transformed into [-1,1].

Between concepts, there are three possible types of causal relationships that express the type of influence of one concept on the others. The weight of an interconnection, denoted by W_{ij}, for the arc from concept C_i to concept C_j, can be positive, ($W_{ij} > 0$), which means that an increase in the value of concept C_i leads to the increase of the value of concept C_j, and a decrease in the value of concept C_i leads to the decrease of the value of concept C_j. Or there is negative causality ($W_{ij} < 0$), which means that an increase in the value of concept C_i leads to the decrease of the value of concept C_j and vice versa. When, there is no relationship from concept C_i to concept C_j, then ($W_{ij} = 0$). [9-10] When the Fuzzy Cognitive Map models a system, FCM concepts take their initial values and then the system is simulated. At each step, the value of each concept is determined by the influence of the interconnected concepts on the corresponding weights:

$$A_i^{t+1} = f\left(\sum_{\substack{j=1 \\ j\neq i}}^{n} W_{ji} A_j\right) \qquad (1)$$

where C_i^{t+1} is the value of concept C_i at step t+1, A_j is the value of the interconnected concept C_j at step t, and W_{ij} is the weighted arc from C_j to C_i and $\boldsymbol{f}$ is a threshold function.

The major advantage of fuzzy cognitive maps is that they can handle even incomplete or conflicting information. This is very important in the diagnosis of language/communication disorders because frequently important information may : i) be missing, ii) be unreliable, iii) be vague or conflicting, and/or iv) be difficult to integrate with other information.

3.2 Description of a Differential Diagnosis Model

To better illustrate the idea behind the LOGO_DSS model, an example is discussed where a Fuzzy Cognitive Map is implemented for thedifferential diagnosis of specific language impairment from dyslexia and autism [11].

SLI is a significant disorder of spoken language ability that is not accompanied by mental retardation, frank neurological damage or hearing impairment. Children with SLI face a wide variety of problems both on language and cognitive levels [12].

Dyslexia, or otherwise, specific or developmental dyslexia, constitutes a disorder of children that appears as a difficulty in the acquisition of reading ability, despite their mental abilities, the adequate school training or the positive social environment [13].

Autism is a developmental disorder and pathologically it is defined as an interruption or a regression at a premature level of a person's development . The main idea in autism is the impaired or limited relation that exists between the autistic person and its environment. [14]

Inside the Logo_DSS module there is the Fuzzy Cognitive Map depicted in Figure 4, consists of two different types of concepts. The three central concepts (disorder concepts) correspond to the three disorders that are studied in the current differential diagnosis model: specific language impairment, dyslexia and autism.

The second types of concepts, factor-concepts, are symptoms and cause factors to the disorder concepts, and they are considered as measurements that can determine the result of the diagnosis. The direction of interconnections between the concepts is shown in Figure 4 by the arrowed arcs. This shows in a simple way which concept influences another concept. However, due to limited space and in order to make the figure simpler, the sign and weights of the connections are not illustrated in Figure 4. These are described and can be determined from Table 1. Table 1 describes the existing relationship between factor-concepts and disorder concepts. This relationship may be a positive or negative dependence between factors and disorders, while the degree of the relationship is described by a linguistic value. A positive connection (+) implies that the given factor increases the probability of diagnosis of the connected disorder. Lack of connection between a factor and a disorder suggests that no influence of that factor on the disorder has been found, yet. A negative (-) connection between the factor and the disorder implies that the existence of the given factor must lead to reduction of the probability of diagnosing the particular disorder.

Apart from describing the direction of causality between two concepts and the sign of causality, the degree of cause and effect between two concepts must be determined, since, we do not expect that all factors have the same weight for a given disorder, nor the same weight for each disorder. Each expert describes the degree of influence for each interconnection using a linguistic variable. Thus, each expert of the group of experts suggests a linguistic weight for each interconnection, so a set of linguistic weights for each interconnection is assigned. This set of weights for each interconnection is integrated, using a sum combination method and then the defuzzification method of Center of Area (CoA) is used and a numerical weight for this interconnection is produced, which belongs to the interval [-1,1]. However, the major strength of Fuzzy Cognitive Maps is their ability to describe systems where there are feedback relationships and relationships between the factor concepts.

Interrelations between factors concepts have also been found and are shown in Figure 4 and have a fuzzy a weight of +low.

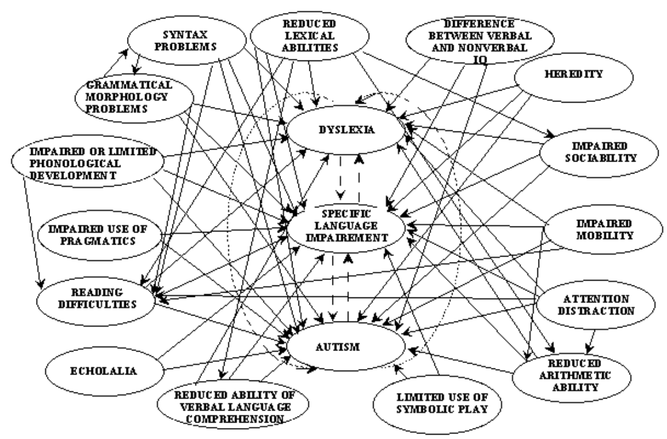

Figure 4. FCM Differential Diagnosis Model of SLI from Dyslexia and Autism

The proposed Fuzzy Cognitive Map of Figure 4 has also connections (arcs) between the disorder concepts. These are not cause-effect connections but they are inhibitory connections that ensure the competition between the disorder nodes so that only one of them may dominate and be considered the correct diagnosis with the highest probability.

4. OVERALL PROPOSED INTEGRATED SYSTEM

This proposed integrated system could be used for a wide range of speech and language impairments (from mild to severe) which includes intelligent feedback of the patient's communication progress for the profession of speech and language therapy/pathology that will provide the therapist an additional (apart from his/her own) intervention plan as well as secure living conditions in the home for the severely speech and language impaired.

In conclusion the overall system provides: interactivity, intelligence, multmodality, accountability, adaptability, mobility, scalability/expandability and autonomy.

TABLE I QUALITATIVE CONNECTION BETWEEN FACTOR-CONCEPTS AND DISORDER-CONCEPTS

Factor- Concepts	**Disorder-Concepts**		
	A. SLI	**B. Dyslexia**	**C. Autism**
1. *Reduced Lexical Abilities*	+ VERY-VERY HIGH	+ MEDIUM to HIGH	+VERY-VERY HIGH
2. *Problems in Syntax*	+ VERY-VERY HIGH	+ MEDIUM to HIGH	+ VERY HIGH
3. *Problems in Grammatical Morphology*	+ VERY-VERY HIGH	+ MEDIUM to HIGH	+ VERY HIGH
4. *Impaired or Limited Phonological development*	+ HIGH	+VERY-VERY HIGH	+ MEDIUM
5. *Impaired Use of Pragmatics*	+ MEDIUM to HIGH	NONE *	+VERY-VERY HIGH
6. *Reading Difficulties*	+ MEDIUM to HIGH	+VERY-VERY HIGH	- HIGH
7. *Echolalia*	+ VERY LOW	NONE	+VERY-VERY HIGH
8. *Reduced Ability of Verbal Language Comprehension*	+ MEDIUM	+ LOW	+VERY-VERY HIGH
9. *Difference between Verbal and Nonverbal IQ*	+VERY-VERY HIGH	+VERY-VERY HIGH	+ MEDIUM to HIGH
10. *Heredity*	+ MEDIUM to HIGH	+ HIGH to VERY HIGH	+ HIGH
11. *Impaired Sociability*	+ MEDIUM to HIGH	+ MEDIUM	+VERY-VERY HIGH
12. *Impaired Mobility*	+ MEDIUM	CASE DEPENDENT	+VERY-VERY HIGH
13. *Attention Distraction*	+ MEDIUM	+ MEDIUM to HIGH	+VERY-VERY HIGH
14. *Reduced Arithmetic Ability*	+ MEDIUM to HIGH	CASE DEPENDENT	CASE DEPENDENT
15. *Limited Use of Symbolic Play*	+ MEDIUM	NONE *	+VERY-VERY HIGH

*Inadequate or conflicting research information has been found for the factor.

5. SUMMARY

The multimedia environment under development will provide effective tools to individual with speech and/or language disorders that will enhance their treatment provide intelligent feedback of their progress and for severe cases, ultimately empower them with a communication device that will ensure secure living conditions.

The overall structure of the system consists of three main interconnected modules: Logo_Therapy, Logo_DSS and Logo_Comm.

An example of one of the parts of the Logo_DSS was discussed which is a novel application of the Fuzzy Cognitive Maps for differential diagnosis of speech and language impairment.

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