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A NEW MATHEMATICAL MODEL FOR FUZZY COGNITIVE MAPS -APPLICATION TO MEDICAL PROBLEMS

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Abstract. The aim of this study is to construct a Medical Decision Support System by using a new evolutionary type of classic Fuzzy Cognitive Map, the one of Dynamic Fuzzy Cognitive Knowledge Network (DFCKN), which is focused on dynamic aspects of the variables. Applications to Medical problems are presented.
Keywords: Modelling, Dynamic Fuzzy Cognitive Knowledge Networks, Fuzzy Cognitive Maps, Meniscus Injuries.

EXTENSIVE SUMMARY

Nowadays, practical dynamic systems have become more and more complex. The concept of complex dynamic systems (CDS) arises in many scientific fields, technological areas and every day's problems. Examples of these systems are: energy networks, health, energy storage and distribution, hybrid power systems with different renewable energy sources, robotics, artificial intelligence systems, gene regulation and health delivery, safety and security systems. Modelling and controlling complex dynamic systems is a very difficult and challenging task. **Different modelling approaches basically focus on the interaction between (microscopic) subsystems and the emergence of new qualities at the (macroscopic) system level.**

However these models are not sufficient to describe the dynamic behavior of these systems. The need for new advanced and innovative approaches has become obvious. Theories of Fuzzy Cognitive Maps (FCMs) are proposed and mathematically formulated, the last 30 years, as a new way to model and control complex dynamic systems [1–3].

In this new model, the new calculation rule should be comprised by two equations. These equations will consist not only of the inputs and outputs of the system but also the states. The dynamic combination of the three concepts, States, Inputs and Outputs will constitute the Dynamic Fuzzy Cognitive Knowledge Network.

The basic calculation rule that computes the value of each concept at every simulation step is the following:

$$A_i(k+1)=f\ \{k_1A_i(k)+k_2\sum_{\substack{j\neq i\\ j=1}}^{N} A_j(n)W_{ji}\}, \qquad (1)$$

where k represents time, N is the number of concepts and:

- Ai (k+1): the value of the concept Ci at the iteration step k+1
- Ai(k): the value of the concept Cj at the iteration step k
- Wij : the weight of interconnection from concept Ci to concept Cj
- k1: the proportion of the contribution of the previous value of the concept in the computation of the new value
- k2: the influence of the interconnected concepts in the configuration of the new value of the concept Ai
- f: the sigmoid function

$$f=\frac{1}{1+e^{-\lambda x}}\ , \qquad (2)$$

where $\lambda>0$ determines the steepness of function f. In most applications k1 and k2 are set equal to one. The FCM's concepts are given some initial values which are then changed depending on the weights; the way the concepts affect each other. The calculations stop when a steady state is achieved, the concepts' values become stable. Nevertheless, there are some drawbacks that should be overcome. The existing idea of a single calculation rule for all the concepts creates problems. Firstly, all concepts are treated in the same way regardless their nature. That causes a big issue in which we should define initial values for the output on advance.

This major drawback has been raised by the author of this article is that concepts of an FCM include everything: states, inputs, outputs, constraints and all other parameters which are going to be examined regardless their nature [4]. However this is not mathematically correct and logical in any scientific approach. For example in classic FCM theories some concepts are not being affected by others thus they have to stay static through the whole iteration process. However due to the current approach, each value in Eq.1 changes after the first iteration which is not correct. In addition having all variables in one "concept vector" and changing them in each iteration step k is also not truth in the real problems and mathematically not correct. Why the inputs and outputs of the CDS must change at every iteration step k? For example on a health treatment of a patient, why the inputs (concepts) (e.g. the medication dose of a drug that is given every morning) and the outputs (e.g. the blood test results (concepts) that are monitored (every two or three days) must be changed when the "health conditions" (concepts) of the patient are monitored every second or every hour? However this is the case using classic FCM theories.

This makes our tool difficult to use because we want a final unknown diagnosis, and the procedure of random definition of the output values complicates the method and affects the entire process. In addition, changes in the values of concepts could not be imported into the system for real time testing purposes. Also, there is a high degree of difficulty to adjust each different problem to this existing model.

These reasons are enough to examine the possibility of a new, more comprehensive and flexible model. New models for FCMs have been proposed obtaining excellent results and providing new ways to overcome the drawbacks and deficiencies of today's FCMs theories

The new proposed model uses the basic classical theory of FCM with the difference that the system main variables are not treated in the same way. The procedure of constructing the FCM is remaining the same. First of all experts should define all together the basic system variables-concepts. But the main change is that after this procedure, "concepts-variables" should be divided into three categories, using the main classical theories of state space models. The three categories are:

A. State Concepts: The concepts describing the dynamic operation of the system, *x*
B. Input Concepts: The inputs of the system, *u*
C. Output Concepts: The concepts describing the outputs of the system, *y*

The concept of the state of a dynamic system refers to a minimum set of variables, known as state variables, which adequately describe the system and its response to any given set of inputs. The inputs concern signals that stimulate the system. The output variables of the system constitute those that should be examined only for their behavior. The mathematical description of the system and the combination of initial states and inputs are sufficient to provide information about both the future states and outputs.

The discrete time nonlinear dynamic system is the following:

$$\mathbf{x}(k+1)=f[\mathrm{A}\mathbf{x}(k)+\mathrm{B}\mathbf{u}(k)], \tag{3}$$

$$\mathbf{y}(k)=g[C\mathbf{x}(k)+D\mathbf{u}(k)], \tag{4}$$

where $u(k)\in R^r$ is an exogenous known input vector, $x(k) \in R^n$ is a state vector, $y(k)\in R^m$ is the output vector in time variable "k". Nonlinear functions $f(\cdot)$ and $g(\cdot)$ can be approximated using nonlinear activation functions. In addition matrices A, B, C and D are the connection weight matrices, associated with the fuzzy state, input and output vectors. More specifically, matrix A is a weight matrix that connects the states between them and it corresponds to the weight matrix of classic FCM but now it connects only the states of the system. Matrix B is a new weight matrix which represents how each input influences the states one by one. Matrix C is the weight matrix of the interrelationship between the states and the outputs and matrix D depicts the direct influence of the inputs to the outputs respectively. Matrices A, B, C and D must be decided by experts, describing the linguistic interrelationships between vectors. The exact procedure is the same as in the construction of a classic Fuzzy Cognitive Map [2]. Experts should define all these interconnections in their natural language using linguistic variables and after a defuzzification method of Center of Area (COA), the matrices will be filled with numeric values. It must be pointed out that the matrices A, B, C and D are not constant and can be changed using learning algorithms [3] and [8].

The algorithm that describes the new model step by step follows:

Step 1: Ask experts to define the basic concepts.

Step 2: Separate them into Fuzzy States, Inputs and Outputs.

Step 3: Experts construct weight matrices between Outputs-States, Outputs-Inputs,

States-States, States-Inputs, using linguistic variables.

Step 4: Convert weight matrices into numeric values using a defuzzification method.

Step 5: Detect initial states in time unit “k”.

Step 6: Compute Initial Output in “k” from Eq. (3).

Step 7: Detect new Input in our system in time unit “k”.

Step 8: Compute new States in time unit “k+1”, with Eq. (2).

Step 9: Compute new output in “k+1” according to Eq. (3).

Step 10: Renew the input value in “k+2”.

Step 11: Repeat steps 8-10 until desired time variable is reached.

The proposed new model is based on the extensive paper by the two authors, [7] and it is referred as Dynamic Fuzzy Cognitive Knowledge Network (DFCKN).

This DFCKN model was used in order to model meniscal tear. The choice of modeling meniscal tear was influenced by the fact that they is among the most common and clinically challenging musculoskeletal disorders. It is also risk factor for subsequent development and progression of knee osteoarthritis (OA) at least 4-fold rate, while often asymptomatic meniscal tears can cause considerable disability and pain, prompting substantial resource utilization. Magnetic Resonance Imaging (MRI) is of utmost importance for accurate noninvasive evaluation of internal pathologies of the knee. However, it is still an expensive diagnostic tool and new evidence suggests a significant amount of false positive results especially regarding the medial meniscus pathology. The evolutionary model of FCM can exploit the knowledge of the physicians and model the whole process the exact way that the physician makes the examination, in a simple way with no need of a large number of data. Furthermore system’s complexity is reduced because the total number of concepts is divided in three categories and large systems with more than 50 interrelationships between them are replaced by the new one, allowing us to better react on the system.

In the examined sample of real patients, 16 out of 17 diagnosed by meniscal tear according to our model [7]. By continuing with the remaining 16 patients during second level simulations, 10 cases were positive for degenerative injury and the rest 6 for acute injury. Patients symptoms and risk factors were crucial to the whole procedure. The cases were further analyzed in order to examine the influence of the Daily analgesics (NSAIDs) through time in the course of patients. Considering that they are following physician’s orders, the results show full rehabilitation for some of them and stable state for the rest. This was not possible in the previous method with classic FCM. Time was a vague value that did not exist in the basic equation that describes FCM and instant iterations could not give us any useful information for the evolution of the disease.

REFERENCES

1. **Kosko B.** Fuzzy cognitive maps. International journal of man-machine studies, 1986 24(1), pp. 65-75.

2. **Groumpos P. P.** Fuzzy cognitive maps: Basic theories and their application to complex systems. In Fuzzy cognitive maps,2010, pp. 1-22.

3. **Anninou A. P., Groumpos P. P.** Non linear Hebbian learning techniques and fuzzy cognitive maps in modeling the Parkinson's disease. In Control & Automation (MED), 2013 21st Mediterranean Conference on 2013, pp. 709-715.

4. **Groumpos P., Gkountroumani V.** A New Control Strategy for Modeling Wind Energy Systems Using Fuzzy Cognitive Maps. Journal of Energy and Power Engineering, 8(11).

5. **Mpelogianni V., Groumpos P.P.** A revised approach in modeling fuzzy cognitive maps. In Control and Automation (MED), 2016 24th Mediterranean Conference on 2016, pp. 350-354.

6. **Vergini, E., Groumpos P. P.** New concerns on fuzzy cognitive maps equation and sigmoid function. In Control and Automation (MED), 2017 25th Mediterranean Conference on 2017, pp. 1113-1118.

7. **A New** Approach of Dynamic Fuzzy Cognitive Knowledge Networks in Modelling Diagnosing Process Of Meniscus / A. P. Anninou, et al. In the 20th World Congress of the International Federation of Automatic Control IFAC, Toulouse, France.2017.

8. **Papageorgiou E. I., Stylios C. D., Groumpos P. P.** Active Hebbian learning algorithm to train fuzzy cognitive maps. International Journal of Approximate Reasoning, 37. 2004. p.p. 219-249.

METADATA

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