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Fuzzy Cognitive Maps for Medical Decision Support – A Paradigm from Obstetrics

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Abstract—**Medical Decision Support Systems can provide assistance in crucial clinical judgments, particularly for inexperienced medical professionals. Fuzzy Cognitive Maps (FCMs) is a soft computing technique for modeling complex systems following an approach similar to human reasoning and decision-making. FCMs successfully represent knowledge and human experience, introducing concepts to represent the essential elements and the cause and effect relationships among the concepts to model the behavior of any system. Medical Decision Systems are complex systems that can be decomposed to subsystems and elements, where many factors have to be taken into consideration that may be complementary, contradictory, and competitive; these factors influence each other and determine the overall clinical decision with varying degrees. Here a Medical Decision Support System based on an appropriate FCM architecture is proposed and developed, as well as a corresponding paradigm from obstetrics is described.**

I. Introduction

Fuzzy Cognitive Maps (FCMs) have been successfully employed in the development of intelligent systems, which in turn have been effectively utilized in a variety of application domains. Knowledge and experience is reflected in the creation procedure and the infrastructure of FCMs that are suitable to model the decision-making, reasoning process. In the medical field, the decision is often crucial and must be achieved in a timely manner.

FCMs rely on the expert knowledge of a domain, making associations along generalized relationships between domain descriptors, concepts and conclusions. They are an illustrative causative representation for the description and modeling of complex systems. Fuzzy Cognitive Maps model the world as a collection of concepts and causal relations between concepts, based on the experience and knowledge of experts. An FCM draws a causal graphical representation to model the behavior of any system; it consists of interrelated concepts [1]. FCMs are fuzzy signed directed graphs permitting feedback, where the weighted edge w_{ij} from causal concept C_i to affected concept C_j describes the amount by which the first concept influences the latter, as is illustrated in Fig. 1. The human experience and knowledge on the operation of the system is embedded in the structure of the FCM and the FCM developing methodology, i.e., by using human experts that have observed and know the operation of system and its behavior under varying circumstances.

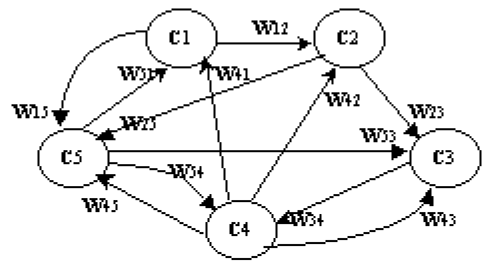

Fig. 1. The Fuzzy Cognitive Map model.

Fuzzy Cognitive Maps have been successfully used to develop Decision Support Systems (FCM-DSS) for differential diagnosis [2], to determine the success of the radiation therapy process estimating the final dose delivered to the target volume [3] and many other applications. FCMs are particularly well suited for such applications since medical systems are complex systems involving inexact, uncertain, imprecise and ambiguous information [4]. For the paradigm from obstetrics, where, in essence, there are two opposing decisions, a FCM approach could support the obstetrician. This is due to that fact that: a) there are many physiologic parameters (for "each" patient) and b) there is a high degree of subsystem interactivity.

This paper is organized in five sections including this introduction. Section II presents a hierarchical structure, which is suitable to model complex medical decision support systems. An example for modeling the labor process using FCMs is presented in section III and the corresponding two-level architecture for Decision Support System is presented in section IV. Section V concludes the paper discussing the further development of the proposed methodology.

II. Hierarchical Structure for Medical Decision Support Systems

A knowledge based system is better suited to accomplish tasks when the nature of the problems and solutions is not well defined or not known beforehand, or there are many different complementary and contradictory options at the same time. In medical applications there are situations involving a significant number of variable factors such as changing characteristics, unexpected events, different combinations of fault and alarm situations, where the approach of a knowledge based system has certain

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advantages and flexibility which make such a method particularly attractive since it is a complex system [5-7].

A hierarchical architecture is proposed where an m-FCM can be used to model the supervisor, which is the Medical Decision Support System (Fig. 2). Here the case where multiple infrastructures are connected as ''systems of systems'' is considered. The m-FCM consists of other simpler Fuzzy Cognitive Maps, each one of them corresponds and models specific sub models of the system (patient's records and information, doctors' physical examination and evaluation, laboratory tests, imaging tests etc). The sub- FCMs communicate with each other as they operate in a common environment, receiving inputs from other FCMs and transmitting outputs to them. Here is the case where the subsystems are loose coupled and variations in one subsystem influence and are reflected in the others. Therefore, the interactions between the sub-FCMs and changes in one may influence the others. In addition, there are concepts representing issues for emergency behavior, estimation and overall decision and etc. The m-FCM is an integrated model of the complex system and it represents the relationships among the subsystems and their models while inferring the final decision by evaluating all the information from them [8-9].

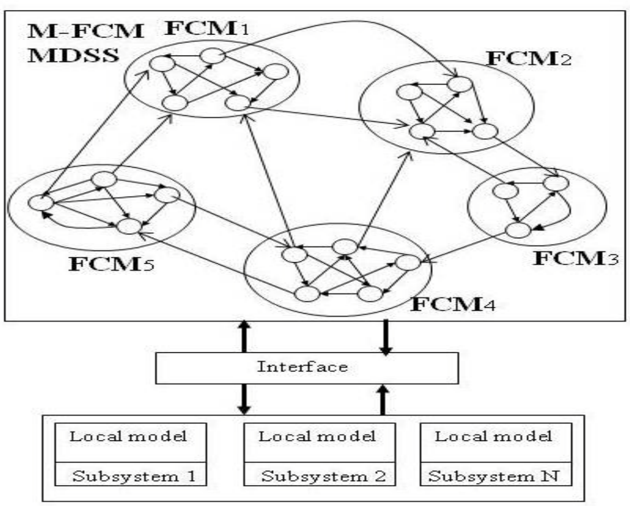

Fig. 2. Hierarchical structure for MDSS.

Consequently, the m-FCM system has a generic purpose, it receives information from all the subsystems in order to accomplish complex tasks, it makes decisions and it can plan strategically. This m-FCM uses a more abstract representation, general knowledge and adaptation heuristics.

III. FUZZY COGNITIVE MAP FOR MODELING LABOR

During the crucial period of labor, obstetricians evaluate the whole situation and they take into consideration a variety of factors in order to conclude. The decision is because the infant will be safer if delivered or the risk to the maternal health of continuing with the pregnancy outweighs the risk to the baby delivery.

The main decision of obstetricians is to determine whether they will proceed with a Caesarian section or a natural delivery based on the physical measurements, FHR and the intepretation of and other essential indications and measurements. The decision, in essence, is based on "weighing" the risks of maternal and/or fetal health complications. Here, is not considered the case of a routine Caesarean section but the case of an emergency Caesarean section when there is a fetal distress (because of abnormal CTG, acidosis, cord prolapse or abruption) or obstructed labor or prolonged labor or delivery at maternal risk. The factors that are taken into consideration in many cases have intrinsic fuzziness, they are described by obstretricians using liguistic terms and they are characterised such as: stable, moderate, intense, increased etc. are used to describe them.

Obstetricians consider a variety of maternal indications and fetal indications; the labor surveillance monitoring has three main components: fetal condition, progress of labor and maternal conditions. These are the subsystems on the sense of section II. Fetal condition is mainly reflected in the interpretation of the Fetal Heart Rate (FHR) signal and some physiological measurements, e.g. color of liquor (meconium) and vaginal examinations. Progress of labor is based on physiological examinations (descent of head, dilatation of the cervix) measurement of the strength and frequency of uterine contractions, the drugs given to augment/induce the labor and the time passed. Maternal conditions are measured by well-being pulse and blood pressure and etc.

Cardiotocography was introduced into obstetrics practice and it has been widely used for antepartum and intrapartum fetal surveillance. Cardiotocogram (CTG) consists of two distinct signals, i.e. the recording of instantaneous Fetal Heart Rate (FHR) and Uterine Activity (UA), which are two biosignals corresponding to fetal condition and progress of the labor. FHR variability is believed to reflect the interactions between the sympathetic nervous system (SNS) and the parasympathetic nervous system (PSNS) of the fetus. Considerable research efforts have been made to process, evaluate and categorize FHR either as suspicious, or pathological or normal. Integrated methods based on Support Vector Machines, Wavelets and other computational intelligence techniques have been proposed to interpet the FHR [10-11].

Here, the development of a Fuzzy Cognitive Map to model the way by which the obstetrician makes a decision for a normal delivery or a caesarean section is investigated. It is a dynamic procedure, where the obstetrician evaluates whether either the mother or the fetus are at serious risk and thus, he/she has to intervene by stopping the physiological delivery and performing an emergency caesarean section instead of continuing with natural delivery [12].

The main parameters that the obstetrician evaluates and constitute the 12 concepts of the FCM model are:

- Concept 1 Decision for Normal Delivery
- Concept 2 Decision for Emergency Caesarian section
- Concept 3 Fetal Heart Rate (FHR) evaluation
- Concept 4 Meconium (Color of liquor) (from clear to mild blood staining and to heavier bleeding)

- Concept 5 Time duration of labor in comparison to progress of the delivery
- Concept 6 Contractions of the uterine (strength and frequency)
- Concept 7 Medication (quantity of oxytocine given to mother)
- Concept 8 Diastole of Cervix (measurement)
- Concept 9 Evaluation of Cervix commendation (4 linguistic values)
- Concept 10 Position of placenta (3 linguistic values)
- Concept 11 Position of fetus (5 linguistic values)
- Concept 12 Contraindication

After the determination of the main aspects that affect the obstetrician's decision on delivery, which are the concepts of the FCM, a team of three experienced obstetricians estimated the degree of influence from one concept to the other following the methodology proposed in [13]. Thus, the Obstetrics Fuzzy Cognitive Map model was constructed, for evaluating labor, as is represented in Fig 3.

IV. Two Level Architecture for Decision Support During Labor

A two level hierarchical structure is proposed for the decision support during labor. In the upper level there is the FCM model previously constructed (Fig. 3). This Supervisory FCM model consists of two FCMs, in accordance with the decomposition idea presented previously in section II.

One green FCM, which receives inputs from the lower level, interacts with the whole FCM and sends back to the lower level a new set of values for Concept 7 (Quantity of the medicine Oxytocine given) and interacts with the rest of the FCM. Fig. 4 presents the overall hierarchical architecture for decision making during labor.

At each step, values of concepts are calculated according to the influence from interconnected concepts. Some concepts can have only external inputs, such as the concept C_3 (FHR), which stands for the evaluation and classification of FHR; this is performed at the lower level by the Support Vector Machine [11]. The interactions among concepts will change values of concepts. New values of some concepts may necessitate some action from the obstetrician; as an example, a new value for concept 7 medication, which involves the given oxytocine, requires pharmaceutical action to the woman. When the system reaches the steady state, the value of the concept for Natural delivery and value of the concept for Caesarian section have to be mutually exclusive and only one suggestion will be the outcome of the system.

This is achieved by means of a competitive fuzzy cognitive map structure (CFCM) as has been developed in [14-15].

In the two-level architecture, at the lower level there are either simple biomedical sensors or more advanced systems such as the FHR classification system based on Support Vector Machines. Thus, in the lower level minimum and maximum thresholds for FHR are detected, as well as FHR variability is monitored along with Uterine Contractions. Pattern detection of specific significant FHR patterns is carried out. Also, information on various physiological parameters is monitored providing alarms etc. These include, for example, maternal pyrexia or fresh bleeding in labor. Information from the lower level is transformed into suitable form through the interface and this information is transmitted to the FCM on the upper level. This supervisor FCM will infer a final suggestion to the obstetrician on how to proceed with the labor. The supervisor FCM, in essence, performs a risk assessment for future events of clinical concern taking into account the real-time lower level information. The top level is a distributed m-FCM with many subsystems interacting.

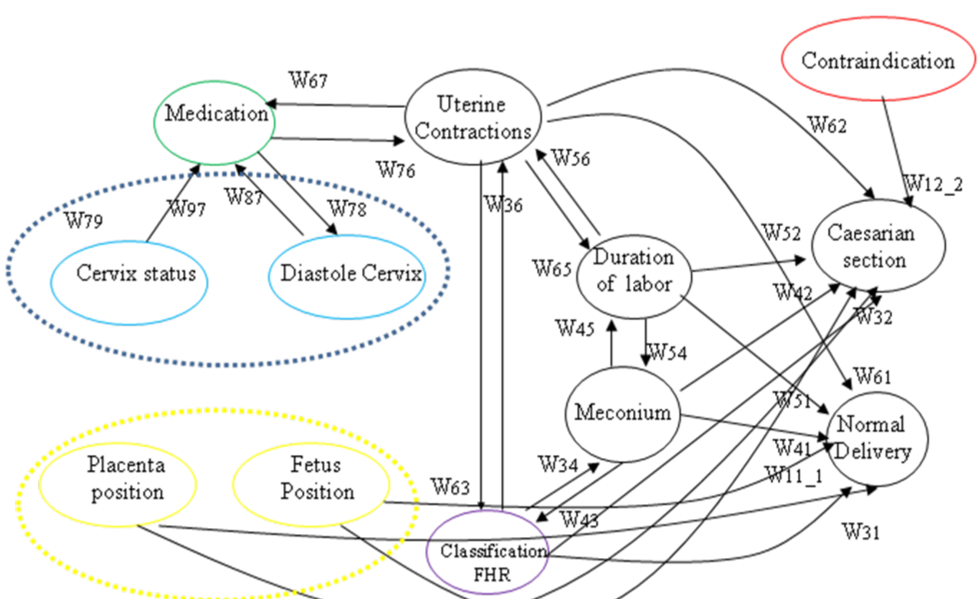

Fig. 3. The FCM for evaluating labor.

V. Conclusion

The area of Medical Decision Support Systems (MDSS) is characterized by complexity requiring the investigation of new advanced methods for modeling and development of sophisticated systems, which must adequately take into consideration the needs of medical practitioners. A MDSS Fuzzy Cognitive Map architecture described here is developed with the consultation and support of experienced obstetricians from an interdisciplinary team and is based on human reasoning approaches [13]. Here a type of Fuzzy Cognitive Map (FCM) incorporated into a hierarchical architecture suitable for complex Medical Decision Support Systems is presented that consists of a distributed m-FCM, where a large number of interacting factors exist. It includes a hierarchical architecture with the m-FCM receiving information from all the subsystems in order to accomplish a task. It makes decisions and it can plan strategically. The presented paradigm is a dynamic decision support tool that may improve safety for the mother, assisting in better, and timelier, decisions to minimize fetal distress and maternal complications.

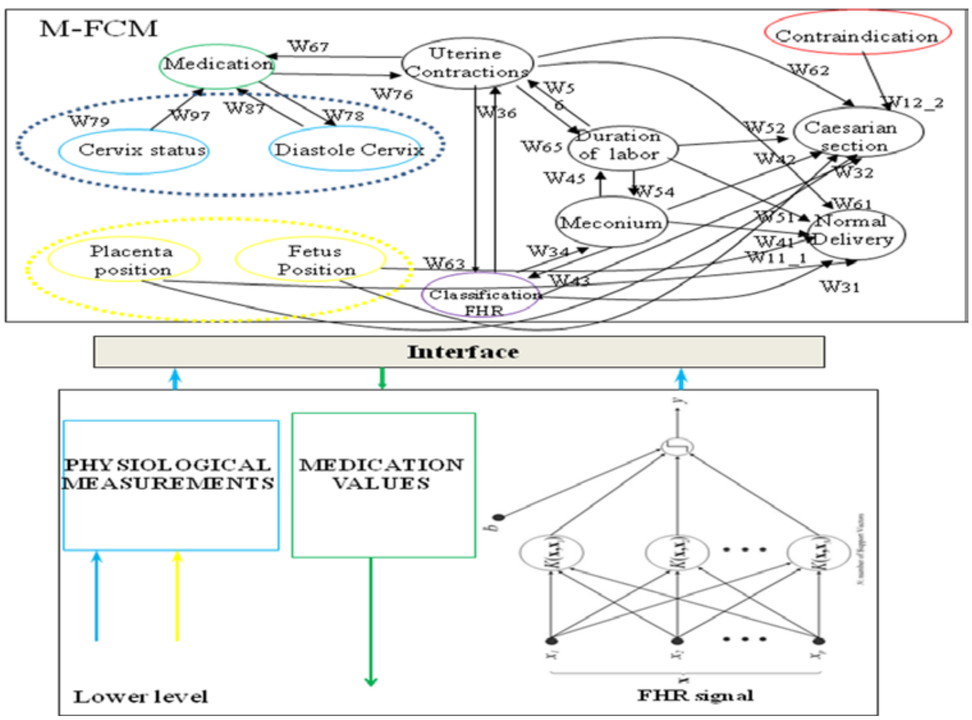

Fig. 4 The two-level Hierarchical structure

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