

Fuzzy Logic Intelligent Systems and Methods in Midwifery and Obstetrics

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ABSTRACT

Background: Fuzzy logic can be used to model and manipulate imprecise and subjective knowledge imitating the human reasoning. **Objective:** The aim of this systematic review was to analyze research studies pertaining to fuzzy logic and fuzzy intelligent systems applications in midwifery and obstetrics. **Methods:** A thorough literature review was performed in four electronic databases (PubMed, APA PsycINFO, SCOPUS, ScienceDirect). Only the papers that discussed fuzzy logic and fuzzy intelligent systems applications in midwifery and obstetrics were considered in this review. Selected papers were critically evaluated as for their relevance and a contextual synthesis was conducted. **Results:** Twenty-nine papers were included in this systematic review as they met the inclusion and methodological criteria specified in this study. The results suggest that fuzzy logic and fuzzy intelligent systems have been successfully applied in midwifery and obstetrics topics, such as diagnosis, pregnancy risk assessment, fetal monitoring, bladder tumor, etc. **Conclusion:** This systematic review suggests that fuzzy logic is applicable to midwifery and obstetrics domains providing the means for developing affective intelligent systems that can assist human experts in dealing with complex diagnosis and problem solving. However, its full potential is not yet been examined, thus presenting an opportunity for further research.

Keywords: Fuzzy Logic, intelligent systems, midwifery, obstetrics, diagnosis, pregnancy risks.

1. BACKGROUND

Over the last few years, Fuzzy Logic has experienced a growth in popularity, as its ability to solve numerous problems in the field of medicine has proven to be outstanding (1). From 2005 until 2017, there has been a 12.5% increase in the research papers dealing fuzzy intelligent systems in medical domains such as in medical diagnosis, pregnancy risk and feature extraction. Fuzzy logic is utilized to imitate the complex ways in which people process information by building intelligent systems and establishing a mode of reasoning that depends on vague, subjective, or imprecise knowledge rather than mere precision. (2) set the foundations of fuzzy logic by defining fuzzy sets, which represent concepts from the universe of discourse. A fuzzy set is associated with a membership

function, which maps elements from the variable's universe of discourse to a value within the [0-1] interval depicting the level of truth in a logical statement, and they may take several shapes eg, trapezoid, triangular or that of normal distribution. Therefore, a statement is not always true or false but instead can be partially true or false, depending on its membership function degree. The triangular fuzzy sets are preferred due to their solid theoretical basis and simplicity (3). The membership function of triangular fuzzy set (a,m,b) can be calculated according to the following equation (4):

$$|f_a(x) = \begin{cases} \frac{x-a}{m-a} & , a \leq x < m, m \neq a \\ \frac{b-x}{b-m} & , m \leq x \leq b, m \neq b \\ 0 & , otherwise \end{cases}$$

where a, m, b are real numbers. An example of the triangular fuzzy set “pregnancy risk” that can take three values, ie, *Low, Moderate, High* is shown in Figure 1.

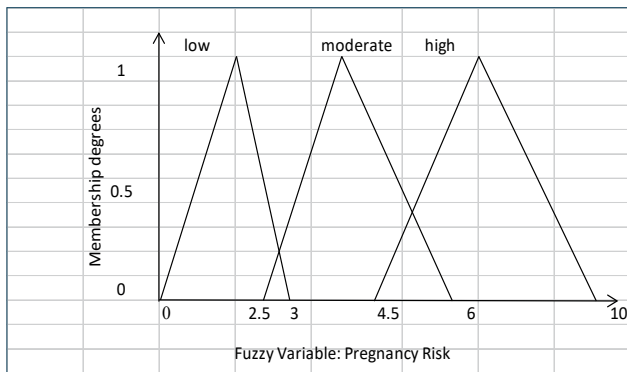


Figure 1. Example of fuzzy set “pregnancy risk”

Despite of its popularity in many domains, none of the studies have conducted an overview of fuzzy logic and fuzzy intelligent systems use in midwifery from a broad perspective.

2. OBJECTIVE

The aim of this paper was to provide a systematic review of the fuzzy logic applications in midwifery.

3. METHODS

A comprehensive literature analysis in four electronic databases (PubMed, APA PsycINFO, SCOPUS, ScienceDirect) was performed in order to identify relevant research studies. This systematic review was done according to the Systematic Reviews and Meta-Analysis (PRISMA) method. As for the studies eligibility criteria, the literature review considered only primary studies in English language without geographical limitations, published during the period 2003-2021 and relevant to fuzzy logic applications and fuzzy intelligent systems in midwifery and obstetrics domains.

Searching terms were ‘fuzzy logic’ OR ‘fuzzy intelligent systems’ ‘fuzzy inference systems’ AND ‘Obstetrics’ OR ‘pregnancy’, OR ‘pregnancy risks’ OR ‘COVID’ OR ‘Perinatal distress’ OR ‘postpartum period’ OR ‘fetal’ OR ‘breast feeding’ OR ‘cervical’.

This review focuses on studies that only discuss fuzzy logic methods and fuzzy intelligent systems applied in obstetrics and midwifery domains in a broad range of topics. Selected research studies were all critically evaluated, and a contextual synthesis of results was performed.

4. RESULTS

Initially 140 research papers were identified. Following the evaluation of the articles’ titles, keywords, and abstracts with respect to their relevance to this systematic review, 75 papers remained for further analysis. By screening the papers’ full-text and removing duplicates

29 studies remained for this systematic review. Any disagreements were resolved by discussion between the review authors. The process followed for the literature analysis, is shown in Figure 2.

5. DISCUSSION

Diagnosis and monitoring of pregnancy risk factors

Many obstacles arise when dealing with pregnancy risk assessment due to domain’s complex nature and the inherited uncertain knowledge. Thus, fuzzy logic can become a trust-worthy ally to the fight against pregnancy risk factors.

In 2015, Umoh and Nyoho (5) constructed a fuzzy logic model that depends on clinical observations, medical diagnosis, and experts’ knowledge, in order to assess pregnancy risk. Their model can become a helpful tool for both obstetricians and gynecologists for making decision as well as for educating women to begin their antenatal clinic as soon as possible. For model evaluation, 25 pregnant women were studied, and the results were processed by the domain experts. The system considered three input variables: Existing Health Conditions (EHC), Lifestyle Factors (LSF) and Condition of Pregnancy (COP). Domain experts’ knowledge was employed construct a 27-rule base that determines the output parameter values (low, moderate, or high pregnancy risk). The system proved its accuracy since a simulation of fluid instillation sonography using MATLAB was performed and its results fell within the experts’ pre-defined limits.

The postpartum hemorrhage (PPH) is widely recognized as a common cause of maternal death. (Doomah et, al, 2019) (6) claim, there is currently no effective method

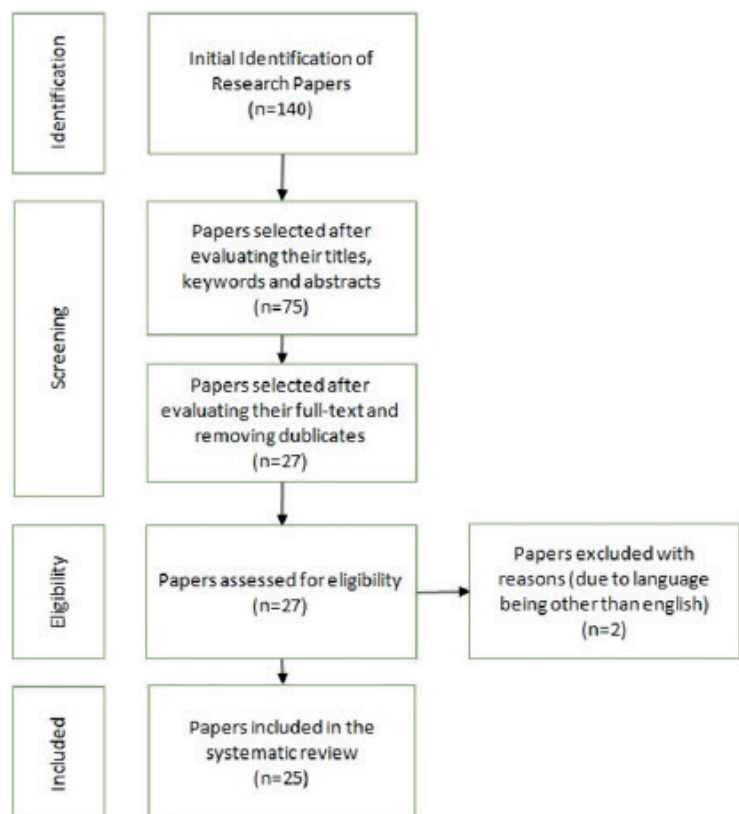


Figure 2. The Process for Identifying and Selecting the papers for the systematic review

to predict its risk of occurrence, so they developed a fuzzy system that assesses PPH by applying the Mamdani inference method using MATLAB. The system was evaluated by analyzing data from 1705 patients, returning a Negative Predictive value (NPV) of 99.72%, and Specificity of 87.48%.

Tayal et al, (2018) (7) also claimed the effectiveness of data mining, machine learning and fuzzy logic methods when assessing pregnancy risks.

Continual monitoring of mother and the fetus health status is important, for taking precautionary measures that protect their health. Uterine contractions can guide physicians to choose a particular therapy. Tiwari et al, (2014) (8), developed a fuzzy intelligent system (with prediction accuracy of 98%) that takes into consideration important diagnostic parameters of uterine activities and categorizes contractions as normal, suspicious, or abnormal, thus safeguarding the mother to contact her doctor only if it is urgently needed.

Caesarean or Normal Delivery

Inappropriate choice of delivery endangers the safety of both mother and baby. By using age, blood pressure, pelvic size, fetal weight, breech presentation, and cesarean history as input Siregal et al, (2020) (9) developed a fuzzy intelligent system to predict the most suitable delivery method ie, caesarean, or normal delivery. The system was evaluated by analyzing data from 30 people returning, as claimed by the authors, a 100% accuracy in its predictions.

Fetal distress during pregnancy

Lakhno, Guzmán-Velázquez and Díaz-Méndez (2018) (10) developed a fuzzy system to trace fetal distress during pregnancy. Electronic fetal monitoring is crucial, as it allows the evaluation of fetal well-being and ensures a proper perinatal outcome. However, the level of accuracy of existing electronic fetal monitoring methods does satisfy.

Therefore, Lakhno, Guzmán-Velázquez and Díaz-Méndez (2018) (10) suggested a fuzzy system which uses cardiotocography (CTG) and heart rate variability (HRV) in order to enhance precision in fetal distress evaluation. ROC curves and Spearman correlation of HRV and CTG were employed in order to increase the levels of specificity (Sp) and sensitivity (Se) when the assessing fetal distress. Sp and Se are calculated as follows:

$$S_p = \frac{VN}{VN + FP}$$

$$S_e = \frac{VP}{VP + FM}$$

(where VN=true negatives, FP=false positives, VP=true positives, FN=false negatives)

The fuzzy logic system considered four inputs: Stress index (SI), mode amplitude (AMO), short term variability (STV) and long term variability (LTV) and a single output (status of fetal well-being). The fuzzy logic system was highly reliable, as out of the 188 datasets examined, 84 pregnancies with fetal distress were detected (true posi-

tives), whereas only one was falsely diagnosed as normal (false negative). Meanwhile, 103 normal cases were correctly assessed (true negatives). Therefore, the fuzzy logic system's precision reached an outstanding 98.8% in tracing fetal distress, and 100% precision in assessing normal pregnancies.

Antenatal care

Multiple imaging techniques, starting from Computer Tomography (CT) to Magnetic Resonance Imaging (MRI) and Ultrasound (US) are used for antenatal care and enable experts to predict delivery time, and detect abnormalities at an early stage. Many applications of two-dimensional medical imaging are unable to tackle speckle noise and object contours, thus leading to segmentation inconsistencies.

Meenakshi, Suganthi and Sureshkumar (2019) (11) proposed a three-stage hybrid algorithm to properly segment ultrasound fetal kidney images and detect shape and contour. Meenakshi, Suganthi and Sureshkumar (11) first used the hybrid Mean Median (Hybrid MM) filter to diminish speckle noise. Then they employed a modified fuzzy C-means clustering, to observe the organs' shape and contour. Finally, texture features acquired from segmented images, assisted in detecting abnormalities. The system's evaluation, using fifty ultrasound fetal images, returned an accuracy level of 86% when detecting congenital disorders and predicting gestation period.

The risk of neonates' death

In 2014, Chaves and Nascimento (12) created a fuzzy logic computational linguistic model, in order to determine death risk of neonates hospitalized to a Neonatal Intensive Care Unit in Brazil. The model used the Mandani inference, and considered as input the birth weight, gestational age, 5th -minute Apgar score and inspired fraction of oxygen. The system's single output referred to the estimation death risk, and its accuracy reached a favorable 81.9%

Obstetrics fistula

Babalola, Aderemi, Kayode and Jacob (2017) (13) focused on obstetrics fistula, a life-threatening injury that occurs during birth. Due to the vague character of its clinical symptoms, researchers built a FCM (Fuzzy C-means) system to diagnose obstetrics fistula. The model's knowledge base holds information regarding the demographic details of the patients, the symptoms of the childbirth injury in question and data. The knowledge base is constantly assessed by forward chaining. The system proved to be an efficient tool that helps experts in clustering the patients into groups regarding obstetrics fistula.

Fetal heart defects and Fetal monitoring

Ahmadih and Asl (2017) (14) dealt with fetal heart defects, as 0.8% of newborns are known to suffer from such potentially fatal matters. Unfortunately, these defects are not traceable immediately after birth and could eventually create irreparable damage to the growth of the baby. Almadih and Asl (14) presented a noninvasive method in order to distinguish the fetal's electrocardiography (FECG) from the maternal one (MECG) during antenatal care, by employing Type-2 adaptive neuro-fuzzy inference systems that seem to operate better than Type-1

fuzzy methods and polynomial networks methods, in cases where uncertainty prevails. Type-1 fuzzy methods are able to separate the maternal and fetal heart signals in ambiguous cases, however the proposed method can even distinguish the heart signals in cases where the two of them fully overlap, rendering it an even more useful model.

Meenakshi, et, al, (2019), (11) and Czabański, et, al, (2013) (15) focused on electronic fetal monitoring that usually includes analysis of fetal heart rate signal (FHR), uterine contractile activity and fetal movement. Researchers gave priority to FHR signals this time, as these signals can manifest whether a fetal's central nervous system operates appropriately. They employed the weighted fuzzy scoring system (WFSS), which constitutes an alteration of the scoring system currently employed in qualitative evaluation of FHR recordings and compared its results to neonatal outcome assessment. Czabański, Jeżewski, Horoba and Jeżewski (2013) (15) created the knowledge base by applying the following rule:

$$\forall 1 \leq i \leq I, R^{(i)}: \text{if}(x_{0j} \text{ is } A_j^{(i)}) \text{ then } y^{(i)} = p^{(i)}$$

(Where I = number of rules, x_0 = vector of quantitative parameters of FHR signal ($t=9$), $A_j^{(i)}$ =linguistic value (normal, suspicious, pathological), $y^{(i)}$ =rule output, $p^{(i)}$ =number of points distributed to a given range).

Based on FIGO (Fédération Internationale de Gynécologie et d'Obstétrique) there are 25 different ranges ascribed to all existing signal features and therefore the rules base of the fuzzy system above consists of 25 rules (each one representing a single range). The accuracy of the system was verified concerning fetal state evaluation, especially regarding the Apgar scores and the pH level measurements attributes, as values were almost identical.

Udo and Oparaku (2015) (16), investigating pregnancy risk factors referred to fetal heart rate monitoring. Most computerized systems that are employed do not achieve the highest performance possible, as they are not able to deal with imprecision effectively. Udo and Oparaku (16) therefore proposed fuzzy logic inference system, with rules acquired from medical observations, making the categorization criteria more flexible and increasing knowledge by means of training. A simulation that was performed indicated however, that the specific system is not efficient when it comes to making accurate diagnosis.

Das et, al (2020) (17) proposed rule based fuzzy intelligent system in order to assist the identification and classification of labor from 'toco' signal. The proposed automated fuzzy system helps the obstetrician experts to identify the status of the fetus, determine the fetal well-being and determine the stage of labor.

Labor

Fuzzy logic provided valuable help during the time of labor, in times of urgency. For instance, a pivotal decision obstetricians need to make is whether to proceed with natural birth or whether to perform a surgical de-

livery instead. Due to the vague character of the factors that should be considered, Stylios and Georgopoulos (2010) (18) developed a system using a fuzzy cognitive map (FCM) to resemble the reasoning of experts. The system consists of 12 concepts including decisions for normal delivery, emergency caesarian section, FHR evaluation, assessment of liquor color, duration of labor contrasted with progress of labor, contraction of the uterine, medication, diastole of cervix, evaluation of cervix commutation, position of placenta, position of fetus and contra-indication. Because Stylios and Georgopoulos' (18) system combines both experts' knowledge and fuzzy techniques, it could facilitate decision-making and help eliminate the dangers that may arise for the fetal and the mother during labor.

In 2019, Amuthadevi and Subarnan (19) concentrated on the analysis of amniotic fluid index (AFI), and the shape and contour features during different stages of pregnancy, and they proposed a fuzzy approach in order to assist in predicting abnormalities regarding the weight of the neonatal, head circumferences and probable need of intensive care after labor. The evaluation of these variables would guide decision-making regarding delivery, but also prevent premature delivery and increase the number of live births. For this purpose, ultrasound images were employed and based on the features acquired, the state of the amniotic fluid was categorized as oligohydramnios, borderline, normal or hydramnios, informing experts both on the state of the fetal and the mother's health. The computer-aided diagnosis system was assessed against experts' opinions regarding firstly the AFI's state and secondly regarding the shape feature and contour points juxtaposed with gestational age. In both cases the system exhibited great levels of precision, (a 94% agreement with the medical practitioners' opinions, and an average corresponding value of 92.5%, in the second case).

Reis et, al, (2004) (20), proposed a fuzzy inference system that aims to predict the need for advanced neonatal resuscitation efforts in the delivery room. This system assesses the risk of need of taking advanced neonatal resuscitation measures by considering the maternal medical, obstetric, and neonatal characteristics to the clinical conditions of the newborn.

Fetal Development

Kaur, Kaur and Singh (2021) (21) used fuzzy techniques to measure fetus' development. They proposed a new algorithm (neuro-fuzzy based on genetic algorithm), which they tested experimentally. As a first step, they employed the normal shrink homomorphic technique to process the ultrasound image. Then, they used gray level co-occurrence matrix (GLCM) in order to acquire the features and finally they developed the system, in order to label the fetal's development as normal or abnormal. Results indicated a 97% level of precision.

Bladder Tumor Detection

(FCMs) constitute one of the state-of-the art artificial intelligent techniques, they combine both fuzzy logic and neural networks, and they enable decision making in complex systems with high levels of imprecision. Stylios and Georgopoulos (2010) (18) developed a FCM related to

delivery decision-making, Papageorgiou, et, al, (2003a) (22) and Papageorgiou, et, al, (2003b) (23), developed two similar FCMs, to detect bladder tumors, a quite demanding task mainly due to its complex categorization. In both FCMs researchers employed 9 concepts for tumor categorization.

They used an Active Hebbian learning (AHL) algorithm to train the FCM and a Nonlinear Hebbian Learning (NHL) algorithm in the first and the second case respectively. The AHL algorithm's precision reached 89.43% and 97.78% regarding tracing benign and malignant tumors, whereas for the NHL algorithm corresponding percentages reached 91% and 95% respectively. In a later study performed on the same topic, Papageorgiou, et, al, (2006a) (24) compared the learning methods, by using again the AHL algorithm and applying the Bayesian statistical decision method. 128 samples were categorized into three groups with accuracy rates of 72.5%, 74.42% and 95.55% for tumors of I, II and III degrees respectively.

Papageorgiou, et, al, (2006c) (25) combined support vector machines (SVM) with FCM, in order to distinguish low-grade tumors from high grade ones. Papageorgiou, et, al, (2006b) (26) and Groumpos (2011) (27) utilized FCMs, and decision trees (DT) to distinguish benign from malignant tumors. This system can use both quantitative and qualitative input data. For quantitative data, a DT is employed, and an inferential learning algorithm produces the suitable fuzzy rules, which upgrade the FCM. For qualitative data, the experts' knowledge and NHL algorithm are needed to construct and train the FCM. Experiments showed that the FCM model reached an average of 80% in sensitivity and 90% accuracy, for tracing/categorizing bladder tumors.

Developing a computational fuzzy language for Obstetrics

Clinical decision support systems have been developed as complementary tools for physicians to deal with newly discovered medical knowledge. In order to represent such knowledge specialized languages have been developed. The most recent one is the (2.10) version of Arden Syntax for Medical Logic Systems, an International Health Level 7 (HL7) standard. In their research, Seitenger, et, al, (2016) (28) discuss the merits of adding fuzzy logic features in the latest (2.9) version, in order to model knowledge in environments of imprecision. The authors tested the specific version of the computerized language, based on two implemented prototypes, one of which concerned the field of obstetrics.

6. CONCLUSION

In this paper, we reviewed multiple uses of fuzzy logic techniques focusing on obstetrics and midwifery. With regard to implications for practice, applications of fuzzy logic techniques span across many midwifery activities. The implementation of fuzzy logic intelligent systems and methods enable medical practitioners to deal with uncertainty and imprecise information inherited in many problem domains related to effective monitoring, diagnoses, and treatment of various midwifery and obstetrics issues. A variety of fuzzy methods are applied including

fuzzy inference systems, fuzzy clustering, and fuzzy cognitive maps. Amirkhani et., al. (2017) (29), provide a comprehensive review of FCMs applications in medicine in general, including bladder tumor diagnosis and choosing the suitable delivery mode. The fuzzy systems found in the literature exhibit high performance in their accuracy results in most cases more between 70%-95%. Research wise it is argued that as fuzzy logic offers opportunities for further research as it is expected to provide more knowledge in the field within the next years and the development of fuzzy logic inference systems and methods such as FCMs, fuzzy multi-criteria analysis is anticipated to advance.

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