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An ANFIS Perspective for the diagnosis of type II diabetes

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Abstract. In this paper, we have detected on diabetes disease, which is a very common and important disease using Principal Component Analysis (PCA) and adaptive neuro-fuzzy inference system (ANFIS). The aim of this study is to improve the diagnostic accuracy of diabetes disease combining PCA and ANFIS. Firstly, we will introduce soft computing(SC) methods and briefly refer to the applications of these methods in medicine. After, an intelligent diagnostic system for diabetes will then be developed on the PCA and the ANFIS. The structure of ANFIS with PCA intelligent system for diagnosis of diabetes is composed by two processes: In the first process, it is used PCA to find that the distinct classes of T2DM subjects and controls. Second, features of two classes(healthy and T2DM patients) obtained in first process are given to inputs of ANFIS classifier.

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1. Introduction

In past decades, it has been well known that the conventional computer methods have been implemented and successfully applied in many real world problems. Conventional computational approaches are based on analytical methods derived from physical models and are still widely used today. However, it is very difficult to use these approaches in today's complicated industrial systems. Generally, conventional systems are called "hard computing(HC)" and as the name imply this type of computing uses precise data. For example, is it possible to express the level at which gold prices will reach or fall after 1 month by using data on past period gold prices? We can get certain results from this process with hard computing, but we cannot know how accurate these results can be. There are many external factors that affect the gold prices, so we cannot know for sure the correctness of the results we get.

In these types of computing and analyzes, new computational methods are needed to remove problems emerging from hard computing and get more accurate results. This new type of computing is called soft computing(SC).

In the emergence of computational intelligence systems, SC's innovative thinking has made a major contribution. The idea underlying SC is to create a cognitive approach model of human intelligence. SC is the establishment of conceptual consciousness in machines. In contrast to the HC methods, SC is more tolerant of uncertainty, imprecision, partial accuracy, and approximation.

Table 1.

HC	SC
It is a conventional computation method and requires a certain designed model.	Tolerant to imprecision modeling.
Generally, it takes a very long computation time.	It produces results in shorter times.
Ideal model is not suitable for real world problems that cannot be designed.	Suitable.
It requires complete accuracy.	It can work with partial accuracy.
Precise and completely accuracy.	Imprecise.
It requires high cost for the result.	Lower cost.

While Zadeh [39] speaking of SC, he said that in environments where uncertainty and imprecision exist, there is a computational approach inspired by humans' reasoning and learning abilities. If we look at SC in the frame that Zadeh says, we can see that SC contains methods such as fuzzy logic(FL), neural Networks(NNs), genetic algorithms(GAs). As shown in the Table 2, each method has its own advantages and disadvantages.

Table 2. [17]

Methods	Advantages
Neural Network(NNS)	Learning and adaptation
Fuzzy Set Theory(FST)	Knowledge representation via fuzzy if-then rules
Genetic algorithm(GAs)	Systematic random search
Conventional AI	Symbolic manipulation

1.1. **Diabetes.** One of the most important health problems in both developed and developing countries is diabetes and its incidence is rising. Diabetes mellitus is a group of metabolic diseases. A diabetic patient has high blood sugar, either because not enough insulin is produced by the pancreas, or because cells do not respond to the produced insulin [10]. In 2030, it is estimated that 552 million people worldwide will suffer from diabetes mellitus.

Diabetes is a disease in which the body does not produced or properly used the insulin hormone. Insulin is a hormone that is needed to convert sugar, starches and other food into energy needed for daily life. The cause of diabetes continues to be a mystery, although both genetics and environmental factors such as obesity and lack of exercise appear to play major roles.

There are two major types of diabetes; type 1 and type 2. Type 1 diabetes is usually diagnosed in children and young adults, and was previously known as juvenile diabetes. In type 1 diabetes, the body does not produced insulin. Insulin is necessary for the body to be able to use sugar. Sugar is the basic fuel for the cells in the body, and insulin takes the sugar from the blood into the cells.

Type 2 diabetes is the most common form of diabetes. In type 2 diabetes, either the body does not produce enough insulin or the cells ignored the insulin. Insulin is necessary for the body to be able to use the sugar. Sugar is the basic fuel for the cells in the body, and insulin takes the sugar from the blood into the cells. When glucose builds up in the blood instead of going into cells, it can cause two problems: cells may be starved for energy and over time, high blood glucose levels may hurt eyes, kidneys, nerves or heart [31].

In this study, we have developed and evaluated an effective classification approach to rapidly identify those at high risk of type 2 diabetes mellitus (T2DM) using the ANFIS with PCA model in adult population, particularly in rural residents.

2. Soft computing methods and applied to medicine

2.1. **Fuzzy logic.** Fuzziness has revolutionized many areas such as science, engineering, medicine. This concept was initiated by Zadeh[37]. Not only Zadeh discovered this concept, but he also developed the infrastructure of today's popular forms of use such as relations of similarity, decision making and fuzzy programming in a short time.

In logic, we can find only two answers for each proposition: True and False. When we want to define the set theory, we are talking about the characteristic function of the membership of an x element of a set A. For each elements of universal set X, the function that generates the values 0 and 1 is called the characteristic function.

We can answer the question "What is FL approach?": FL is a computation-based approach to the truth of the real world problem, which is far more than true-false or 0-1 in Boolean logic. FL has become applicable to medical science together with the first article expressing its applications in biology [38].

Modern medicine is faced with the challenge of acquiring, analyzing and applying the large amount of knowledge necessary to solve complex clinical problems. In medicine, it is possible to work rarely with precise definitions, descriptions or assertions. In medical diagnosis, there is rarely a sharp boundary between diseases. The appearance of more than one disease in the patient at the same time destroys the symptom pattern of the disease and makes the diagnostic and therapeutic decision more difficult. The assignment of laboratory test results to normal or pathological ranges is arbitrary in borderline cases. The intensity of pain can only be described verbally and depends on the subjective estimation of the patient. In describing the diseases, precise relationships between symptoms and diseases can very seldom be found [2]. Many expressions such as frequent, typically, not obligatory, $40-70\%$, almost always seldom, almost proving etc are fuzzy terms and common medical descriptions.

Nowadays, fuzzy logic has a wide range of applications in medicine ([1, 4, 7, 23, 26, 32, 33, 36]). And also, to calculate volume of brain tissue using magnetic resonance imaging (MRI) system [8], to analyze functional MRI data [22], to detect breast cancer [12, 30], lung cancer [29], to visualize nerve fibers in the human brain [3], to represent quantitative estimates of drug use [24], to analyze diabetic neuropathy [20], to detect early diabetic retinopathy [40], etc.

2.2. **Neural networks.** With the development of computer technology, human beings do almost all of their processing on these innovative technologies and enable new methods to be found. The definition of artificial neurons was first given by McCulloch and Pitts in 1943. After these initial definitions, the rapid progress of information technology affected the development of NNs. In the 1980s, the idea that a machine could be thought of as a human being was introduced, and in the 1990s Artificial Neural Networks technology developed rapidly ([14, 19, 25, 28]).

NNs are algorithms produced by sampling the shape of the human brain. NNS can collect information about samples, make generalizations, and then decide on those samples using information learned in comparison with samples that they have never seen before. Because of these learning and generalizations, NNs find wide application in many scientific fields and demonstrate their ability to solve complex problems successfully. NNs according to another definition, parallel and distributed information processing structures, which are inspired by the human brain, interconnected by weighted links and each comprising processing elements having their own memory, in other words, computer programs that mimic biological neural networks.

The advantages of using NNs can be expressed as follows:

· Set the rules by giving input and output information during learning,

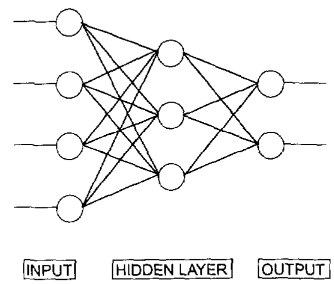

Figure 1. Neural Networks structure, layers

· Benefit from experience,

· The calculation is cumulative, asynchronous and parallel after learning,

· Memory is allocated and spread out over the network,

· There is error tolerance.

NNs have various applications in medical science ([5, 6, 9, 15, 18, 21]).

2.3. **Genetic algorithms.** Conventional search methods suggest a solution to the problem, and try to get better solutions by changing it. On the contrary, evolutionary algorithms create a population of solution of applicants, and this population evolves over time. The closeness of an applicant's solution is a function which depends on the application. A solution applicant may represent with a computer programming such as a set of parameters, a rule, a rule group, or tree structure. In both cases, the algorithm calculates how strong each candidate is, and accordingly determines the next-generation parent or individuals to be destroyed. Then, they apply genetic search processors (restructuring and mutation) to parents to create a reasonable new generation. This cycle is repeated every time creating stronger individuals.

The randomized global search paradigm, called Evolutionary Computation (EC), contains several variations:

· Evolutionary Strategies (ES), addressing continuous function optimization,

· Evolutionary Programs (EP), generating finite state automata that describe strategies or behaviors,

· Genetic Algorithms (GAs), providing continuous and discrete function optimization, system synthesis, tuning, testing, etc.

· Genetic Programming (GP), evolving computer programs to approximately solve problems, such as generating executable expressions to predict time series, etc.

The most widely known of these is GAs. GAs are numerical optimization algorithms inspired by both natural selection and natural genetics.

The genetic algorithm(GAs) is a search and optimization method with the definition of describing the purpose of the algorithm very well, which can produce interesting and successful results that are basically based on the natural evolutionary process. In GAs, it is important that the method is applied to the problem rather than the itself.

The emergence of the Genetic Algorithm approach was at the beginning of the 1970s. In the 70's, studies on machine learning were influenced by the evolution and change in living things, and the transfer of the genetic evolution process into the computer environment was considered. Evolution is a process that enables them to "adapt to" the long-term environment and make them "the best" over time. In the computer language, sequences and subsequences are used to realize this natural process. Sequence populations contain genes of applicants. When we refer to the applicant here, all the elements in the solution space are understood. Each element is represented by a sequence of bits in the length that can cover all elements. Applicants generate a population and every applicant has an eligibility value.

In general, the GAs begin to search for a situation where there is no or very little knowledge of the solution. The solution depends on the interactivity and genetic operators that surround it. The GAs start parallel to the search, starting from independent points, so it is less likely to be fitted to the optimal solutions. Therefore, GAs are known as the best optimization technique for complex search problems as "multiple subset of solutions".

2.4. **ANFIS.** Adaptive Network Based Fuzzy Inference System (ANFIS) is a hybrid artificial intelligence method that uses parallel computing and learning ability of artificial neural networks with fuzzy inference system(FIS). Along with the hybrid learning algorithm, ANFIS sets out the input output structure reflecting human knowledge with fuzzy if-rules. It was developed in 1993 by Jang[16]. The idea of the emergence of the method is the need to provide an integrated and effective solution by combining the learning of neural networks with the advantage of fuzzy if-rules that reflect human thought and knowledge. Fuzzy if-rules are the rules that can be expressed as "If condition A is the result of B", it is also the basis of FISs. Structurally, the FIS have the ability to reflect human thought and reasoning ability in fuzzy and uncertain environments. The FIS can also model the reasoning process and the quantitative direction of human knowledge without using precise numerical analysis when using fuzzy if-rules.

Adaptive networks are used for system identification. Adaptive networks are best used to model the unknown system identified by the given input-output data sets, with optimal network structure and parameter sets. ANFIS can assign all possible rules according to the structure created for the problem dealt or allows the rules to be assigned by the expert with the help of the data. Enabling to create rules or be able to create rules of ANFIS means to take to take advantage of expert opinions.

Adaptive networks consist of directly connected nodes. Each node represent a transaction unit, and the inter-node links specify the causal relationship between the joined nodes. All or some of the nodes are adaptive. This expression means that the output of the nodes is based on the editable parameters associated with those nodes. The learning rule specifies how these parameters should be updated to minimize a predicted error. The error measure is a mathematical representation that indicates the difference between the output of the network and the expected output.

The most important feature of ANFIS is the hybrid learning algorithm proposed by applying the gradient descent and least squares method together. This learning algorithm is also the basis of ANFIS's superiority over other methods.

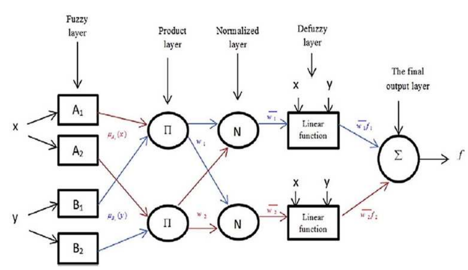

Figure 2. ANFIS Architecture

2.4.1. *ANFIS architecture.* ANFIS architecture is an adaptive network and uses supervised learning on the learning algorithm. For simplicity, we assume the fuzzy inference system under consideration has two inputs x and y and one output z. Suppose that the rule base contains two fuzzy if-then rules of Takagi and SugenoÆs type [34]:

Rule 1 : If x is A_1 and y is B_1, then $f_1 = p_1x + q_1y + r_1$,

Rule 2 : If x is A_2 and y is B_2, then $f_2 = p_2x + q_2y + r_2$.

Then ANFIS architecture is shown in Figure 2. The node functions in the same layer are of the same function family as described below:

Layer 1. (Fuzzy Layer) Every node i in this layer is a square node with a node function

$$O_i^1 = \mu_{A_i}(x),$$

where x is the input, to node i, and A_i is linguistic label associated with this node function. We can denote the node in the $i-$th position of the $k-$th layer by (k,i), and its node function by O_i^1 (or node output).

Layer 2. (Product Layer) Every node in this layer is a circle node labeled $\prod$ which multiplies the incoming signals and sends the product out. For instance,

$$\omega_i = \mu_{A_i}(x) \times \mu_{B_i}(x), \quad i = 1, 2.$$

Each node output represents the firing strength of a rule.

Layer 3. (Normalized Layer) Every node in this layer is a circle node labeled N. The i-th node calculates the ratio of the $i-$th ruleÆs firing strength to the sum of all rulesÆ firing strengths:

$$\overline{\omega}_i = \frac{\omega_i}{\omega_1 + \omega_2}, \quad i = 1, 2.$$

Layer 4. (Defuzzy Layer) Every node i in this layer is a square node with a node function

$$O_i^4 = \overline{\omega}_i f_i = \overline{\omega}_i (p_i x + q_i y + r_i),$$

where $\overline{\omega}_i$ is the output of layer 3 and (p_i, q_i, r_i) is the parameter set. Parameters in this layer will be referred to as consequent parameters.

Layer 5. (The Final Output Layer) The single node in this layer is a circle node labeled $\sum$ that computes the overall output as the summation of all incoming signals, i.e.,

$$O_1^5 = \textit{overall output} = \sum_i \overline{\omega}_i f_i = \frac{\sum_i \omega_i f_i}{\sum_i \omega_i}.$$

Briefly, the first layer in ANFIS structure performs fuzzy formation and second layer performs fuzzy AND and fuzzy rules. The third layer performs the normalization of the membership functions and the fourth layer is the conclusive part of fuzzy rules and finally, the last layer calculates the network output.

There are adaptive and consequent parameters sets in ANFIS structure. In fact, when the simulation has been conducted correctly, provided that both sets of parameters are estimated so as the model error function has the lowest value in training and experimental sections. These parameters are obtained two passes: In first pass, we assume that the adaptive parameters set are constant and the consequent parameters set are calculated by least square error algorithm; this pass is called forward pass. In the second pass which is named backward pass, the consequent parameters are assumed to be constant and the adaptive parameters set is obtained by gradient descent algorithm. When we obtained the parameters sets of the model, we can calculate the value of the model output for each orderly pair of training data and compare them with values that have been anticipated by the model. Consequently, the error function of the model instruction is determined. After considering the appropriative of this error function, the training process is stopped and the final model is achieved[16].

In the forward pass of the learning algorithm, consequent parameters are identified by the least squares estimate. In the backward pass, the error signals, which are the derivatives of the squared error with respect to each node output, propagate backward from the output layer to the input layer. In this backward pass, the premise parameters are updated by the gradient descent algorithm [11, 13, 41]. Two passes in the hybrid learning algorithm for ANFIS shown in Table 3.

Table 3. Two passes in the hybrid learning procedure for ANFIS

-	Forward Pass	Backward Pass
Premise parameters	Fixed	Gradient descent
Consequent parameters	Least square	Fixed
Signals	Node outputs	Error signals

2.4.2. *Learning algorithm.* In the ANFIS structure, it is observed that given the values of premise parameters, the final output can be expressed as a linear combination of the consequent parameters. The output f in Figure 2 can be written as

$$\begin{aligned} f &= \frac{\omega_1}{\omega_1+\omega_2} f_1 + \frac{\omega_2}{\omega_1+\omega_2} f_2 \\ &= \overline{\omega}_1 f_1 + \overline{\omega}_2 f_2 \\ &= (\overline{\omega}_1 x)p_1 + (\overline{\omega}_1 y)q_1 + (\overline{\omega}_1)r_1 + (\overline{\omega}_2 x)p_2 + (\overline{\omega}_2 y)q_2 + (\overline{\omega}_2)r_2, \end{aligned}$$

where f is linear in the consequent parameters $\{p_1, q_1, r_1, p_2, q_2, r_2\}$.

3. Methods

The dataset which consists of T2DM disease measurements contains two classes(healthy and T2DM patients) and 30 people(15 healthy and 15 T2DM patients). The age range of selected people is between 22-46.

All the people (healthy and T2DM patients) were choosen from Turkey, Istanbul, Beykoz district, Gumussuyu suburb health center. The selected district is especially a rural settlement. In this district, the life style of the adult population is suitable for rural life rather than urban life. The inhabitants of the Gumussuyu suburb usually consist of persons who emigrated from Anatolia.

Six features such as age, waist circumference, nutritional habits, activities, genetics and body mass index(BMI) were investigated for all healthy and T2DM patients.

The PCA is a method applied to state the information expressed in the data set in alternative form. The PCA is a multivariate technique and is used to eliminate dependence structure among variables, to reduce dimension, to determine and evaluate regions close to each other in view of development level. The PCA is the oldest and most known technique of multivariate analysis. By the PCA, fewer new variables or principal components are built, which we can call the components of the variables. The principal components are independent of each other. Thus, the dependence structure between the variables is also eliminated. Hence, it can seen that the PCA technique is a simple means of projecting data obtained.

ANFIS has a hybrid learning algorithm. This system is Sugeno type fuzzy model put in the as part of adaptive systems to simplify learning and adaptation and is used to determine the parameters of the membership function of Sugeno type fuzzy inference system. A combination of least squares and back propagation methods are used for training FIS membership function parameters to model a given set of input/output data [17, 27, 34, 35]. An important issue with ANFIS is the difficulty of implementation as the number of inputs increases. This is because of that the rule number increase very much. This is why PCA is used in such studies because it reduces the number of entries of the disease dataset and makes it applicable. In this study, the our ANFIS model is performed with MATLAB 2013a.

4. Results and discussion

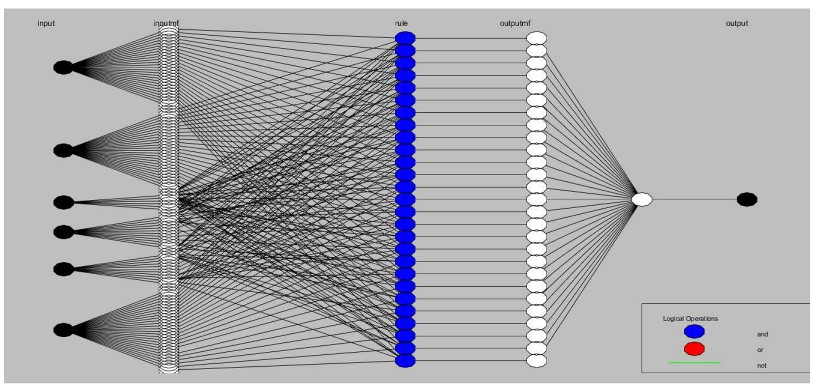

Figure 3. ANFIS structure designed

In the present study, the ANFIS with PCA correctly classified of all participants (healthy and T2DM patients), showing a successfull classification rate of 82.16% by using the 10-fold cross validation. In spite of that, the PCA classifies already known patterns, and therefore provides relatively optimistic classification, which makes it a suitable method for a first estimation to distinguish between T2DM patients and controls but not for classifying their unknown patterns.

The ANFIS approach together with PCA for T2DM has been successful in providing healthy and patient classification. Our system can be combined with the software of medical decision-making tools. The benefit of such systems is that they

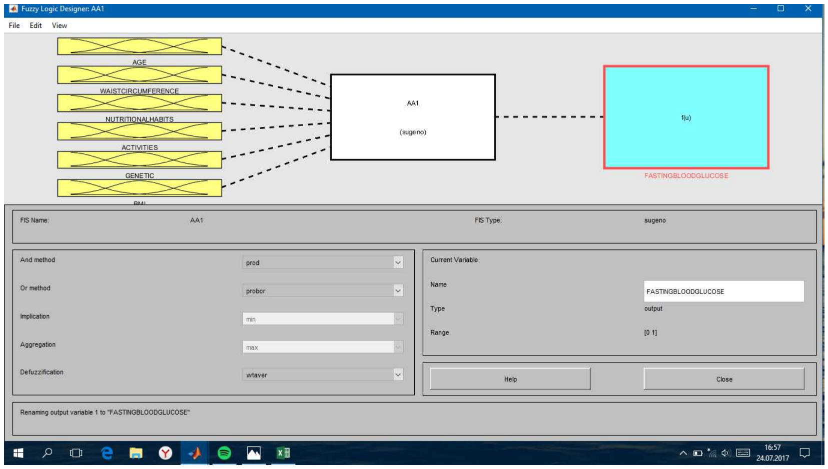

Figure 4.

help the physician to make decisions without being skeptical.

In medicine, many diagnostic questions can be answered in yes or no, black and white terms. When it comes to determining the best treatment plan for each patient, however, there are many more shades of gray.

In this study, for the diagnosis of diabetes disease, a novel hybrid system based on PCA and ANFIS is proposed. The physician's estimate of the probability that a patient has a particular disease is a principal factor in the determination of whether to withhold treatment, obtain more data by testing, or treat without subjecting the patient to the risks of further diagnostic tests. It is believed that the prepared ANFIS with PCA system may be useful for physicians to make decisions about their patients. The results show that Principal Component Analysis and Adaptive Network Based on Fuzzy Inference System classifier (ANFIS with PCA) based a learning method can assist in the diagnosis of diabetes disease.

In recent years, innovations derived from soft computing methods along with statistical techniques have also begun to be applied in all areas of life. In the research reported in this paper, ANFIS with PCA was applied on the task of diagnosing diabetes disease and the most accurate learning methods was evaluated. Experiments were conducted on the diabetes disease dataset to diagnose diabetes disease in a fully automatic manner using ANFIS with PCA. The results show that ANFIS with PCA system is useful for diagnosis of T2DM disease and may help physicians.

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