Fuzzy Relational Equation for Predicting Diabetic Nephropathy

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Abstract—Fuzzy Relational Equation is used to derive medical knowledge from the clinical data which consist of two fuzzy relations on a set of patient and a set of propositions that represent symptoms or diagnosis. In this paper the symptoms are taken along with risk factors to identify the patients suffering from diabetic nephropathy. Fuzzy Systems are being used for solving a wide range of problems in different application domain. Fuzzy Systems allow us to introduce the learning and adaptation capabilities. The fuzzy set framework has been used in several different processes of diagnosis of disease. Fuzzy logic is a computational pattern that provides a mathematical tool for dealing with the uncertainty and the imprecision typical of human reasoning. Fuzzy relational between the symptoms and risk factors for Diabetic based on the expert’s medical knowledge and also related complications due to some common disorder are considered for prediction. This proposed method is an effort to closely imitate a physician’s insight of symptom-disease relations and his approximate reasoning for decision making.

Keyword—Diabetic, Fuzzy logic, Fuzzy Relational Equation, nephropathy.

1. INTRODUCTION

Health and Commonwealth Government have identified diabetes to be a significant and growing global public health problem with the expected incidence in Australia to increase from 4% to 10% [1]. By 2020, the number is expected to double and reach epidemic proportions, even as half the numbers of diabetics in India remain undiagnosed. Diabetes has debilitating consequences on many of the body’s vital organs if remained unchecked and controlled, the biggest problem being that of eyesight. It affects eyes, kidney, heart and every single vital organ of the body [2]. According to the survey of Novo Nordisk, India has the dubious distinction of being the diabetic capital of the world [3]. Home to around 33 million people are affected with diabetes, 19% of the world’s diabetic population is from India. Nearly 12.5% of Indian’s urban populations have diabetes. The number is expected to escalate to an alarming 80 million by the year 2030. Diabetes leads to complications like heart disease, stroke, and neuropathy, poor circulation leading to loss of limbs, blindness, nephropathy, nerve damage and death [4]. In India, diabetic disease is one of the major causes of renal failure.

In this paper Fuzzy Relational Equation (FRE) is proposed which relates symptoms and risk factors of diabetic patient based on the expert’s medical knowledge that is taken to identify the diabetic nephropathy and the results are evaluated.

2. RELATED WORK

Radha et al [5] proposed the fuzzy logic approach for diagnosis of diabetic where the fuzzy logic is taken as a mathematical tool to deal with the uncertainty and imprecision typical of human reasoning. In this approach the knowledge is expressed in linguistic way. Fuzzy membership values are represented using different symptoms to form the relations. Fuzzy relation is applied in few patients’ clinical databases to diagnose whether the patient is diabetic or not.

Sapna et al [6,7] proposed fuzzy relational equation for preventing diabetic cardiovascular disease and diabetic neuropathy. In these methods the risk factors and symptoms of diabetic neuropathy and cardiovascular diseases are used to make the fuzzy relation equation. From the results of the proposed methods it is observed that the expert’s opinion and the clinical research opinion are found to be similar which satisfies the fuzzy relations.

Rama Devi et al [8] proposed a new design methodology of a fuzzy knowledgebase system to predict the risk of diabetic nephropathy in terms of Glomerular Filtration Rate (GFR). This fuzzy knowledgebase captures all the variations of the symptoms and so, it will be useful to infer the exact stage of renal patient as per the expert’s knowledge. The proposed method is used to take proper decision at the right time for giving various types of treatments which ultimately reduces the rate of mortality.

Rajeswari et al [9] investigated a variation to preliminary inquiry information obtained from patients of a diabetic and research center using a fuzzy relation based model. This approach is an attempt to closely replicate a physician’s insight of symptom-disease associations and his approximate-reasoning for conclusion on real time datasets. This method proves to be highly efficient with good accuracy as it models the realistic or linguistic way of the patient. This system also stated that it could assist the diabetologist as a support for classification and further analysis. But in the above system features collected in stage 1 are not satisfied to classify Type 2 diabetic patient from others.

3. FUZZY RELATIONAL EQUATION

A fuzzy relational equation plays a vital role in medical diagnosis. The well-organized data acquisition and illustration are one of the essential challenges for constructing and subsequent use of medical examiner and knowledge based system in clinical observation. Fuzzy relationships can be framed based on the prevalence of symptoms that occur in the disease. The physician’s medical knowledge is represented as fuzzy relation between symptoms and diseases [10] and it was further continued by Czogala et al [11]. An algebraic method for calculating all minimal solution was introduced by Lichun
et al [12] and an analytical method was provided by De Baets et al [13]. The matrix pattern to compute graphically the minimal solutions was proposed by Louh et al [14].

Fuzzy Relation Equation (FRE) is associated with the concept of composition of binary relations. Consider three fuzzy binary relations P(X,Y), Q(Y,Z) and R(X,Z), which are defined on the sets. \( X = \{ x_i / i \in I \} \), \( Y = \{ y_j / j \in J \} \), \( Z = \{ z_k / k \in K \} \), where it is assumed that \( I = N_n \), \( J = N_m \) and \( K = N_l \). Let the membership matrices of \( P, Q \) and \( R \) be denoted by \( P = [p_{ij}] \), \( Q = [q_{jk}] \), \( R = [r_{jk}] \), respectively, where \( p_{ij} = P(x_i, y_j), q_{jk} = Q(y_j, z_k) \), \( r_{jk} = R(x_i, z_k) \) for all \( i \in I(=N_n) \), \( j \in J(=N_m) \) and \( k \in K(=N_l) \). This means that all entries in the matrices \( P, Q \) and \( R \) are real numbers in the unit interval \([0,1]\). The three relations constraints have been assumed between each other in such a way that

\[ P \circ Q = R \quad \ldots (1) \]

where \( \circ \) denotes the max-min composition [15]. This means that

\[ \max_i \min_j (p_{ij} \land q_{jk}) \land r_{jk} \quad \ldots (2) \]

for all \( i \in I \) and \( k \in K \), where \( \land \) and \( \lor \) represents min and max respectively. When \( P \) and \( Q \) are expressed as relation matrices, the calculation \( P \circ Q \) is almost the same as the matrix multiplication, except that \( \times \) and \( + \) are replaced by \( \land \) and \( \lor \), respectively. For this reason, the max-min composition is also called the max-min product. Matrix equation \( (P \circ Q) = R \) encompasses \( n \times s \) simultaneous equation. When two of the components in each of the equations are given and one is unknown, these equations are called fuzzy relation equations.

When matrices \( P \) and \( Q \) are given and matrix \( R \) is to be determined from Equation (1), the problem becomes trivial. It can be solved by performing max-min multiplication operation on \( P \) and \( Q \), as defined by Equation (2). The solution in this case exists and is unique. The problem becomes far from trivial when one of the two matrices on the left hand side of Equation (1) is unknown. In this case the solution is guaranteed neither to exist nor to be unique. Since \( R \) in Equation (1) is obtained by composing \( P \) and \( Q \), it is suggestive to view the problem of determining \( P \) (or, alternatively, \( Q \)) from \( R \) and \( Q \) (or, alternatively, \( R \) and \( P \)) as a decomposition of \( R \) with respect to \( Q \) (or, alternatively, with respect to \( P \)) as problems in various contexts can be formulated as problems of decompositions, the utility of any method for solving the Equation (1) is quite high. A method is assumed for solving Equation (1) only for the first decomposition problem (given \( Q \) and \( R \)). Then, this method can be indirectly utilized for solving second decomposition of problem as well. The Equation (1) can be rewritten in the form as

\[ Q^{-1} \ast p^{-1} = R^{-1}, \quad \ldots (3) \]

employing transposed matrices, the Equation (3) for \( Q^{-1} \) is solved by the above method and then, obtain the solution of Equation (1) by

\[ (Q^{-1})^{-1} \ast \cdot \quad \ldots (4) \]

4. FUZZY RELATIONAL EQUATION FOR DIABETIC NEPHROPATHY

As in the case of heart, long-standing diabetes can also lead to complications in the kidneys. Patients with Type 1 Diabetes have 30-40% chance of developing kidney disorders after 20 years while it is 15-20% in Type 2, but since Diabetes Type 2 is more prevalent, kidney disease is more prevalent in Type 2 than Type 1. In India 11% of deaths in diabetics are due to kidney disorders.

The mechanism of development of these disorders is same as that of the heart. There is deposition of fat on the walls of small and large blood vessels (arteries) of the kidney leading to narrowing of blood vessels and blood flow obstruction. Due to this defect, the blood pressure increases and waste products of the blood accumulate. The danger signals of kidney disorders in diabetes are increased lassitude, breathlessness on exertion, increased urination at night, swelling of the ankle, unstable control of blood sugar (reduced insulin requirements), and increased blood pressure. People with diabetes have a higher risk than normal for kidney disease. The tiny blood vessels in the kidneys that filter out waste products from the blood can get blocked and leaky. Also cigarette smoking can lead to reduced blood flow to the kidney.

Diagnosis
- When kidneys are functionally normal, the urine contains no protein, while in diseased kidneys, urine contains protein which may rise up to 5 gm in 24 hours or even more.
- When the disease is in advanced stage, blood levels of urea and creatinine are very high.
- Due to diseased kidneys, urinary infection may develop as evidenced by pus cells and bacteria in urine.

Treatment
- Proper control of sugar by regular blood sugar monitoring and medicines.
- Treatment of high blood pressure if present.
- Treatment of urinary infection if present.
- In advanced disease of kidney, dialysis (removal of waste products from blood and recirculation of purified blood) or kidney transplant may be required.

Prevention
Following measures in diabetics can prevent this disease:
- Regular monitoring of blood pressure and control whenever necessary.
- Regular monitoring of blood sugar and controlling it.
- Avoid medicines (e.g. painkillers, dyes for x-rays) which affect kidney function.
- Regular 24 hours urinary protein levels and blood tests for kidney function (blood urea and creatinine).
Kidney Function Tests

A number of tests measure kidney function. The microalbumin determines the presence of amounts of albumin (a type of protein) in urine. Even a small amount of albumin may be a sign of early kidney damage. If the test results are positive, medicine is used to protect kidney. A serum creatinine test measures how well the kidney works to clear a muscle waste product called creatinine from blood. Expert’s recommended both a microalbumin and serum creatinine test once a year.

Risk Factors of Kidney Disorder Disease

The risk factors causing kidney disorder are classified into non-modifiable and modifiable risk factors. The non-modifiable diabetic risk factors are the age, sex and family history. The modifiable risk factors are smoking, hypertension, cholesterol, diabetes mellitus, damage of blood vessel, less blood supply to legs and feet etc.

The major risk factors taken as the attributes are:
- H1: High Blood Glucose
- H2: High Blood Pressure
- H3: Smoking
- H4: High Protein Content in Urine
- H5: High Blood Levels of Urea and Creatinine

The main attributes/heads S1,S2,…,S5 related to the symptoms are:
- S1: Increase in Lassitude
- S2: Breathless on Exertion
- S3: Increased Urination at night
- S4: Swelling of Ankle
- S5: Unstable control of blood sugar

(Reduced Insulin Requirements)

The five symptoms heads S1, S2,……,S5 used above are related to the risk factors (H1, H2,……H5) of kidney disorder as the row of fuzzy relational matrix. Using these heads related symptoms to kidney disorder along columns the fuzzy relational equations are formed using expert’s opinion. The expert’s and the clinical research opinion are collected from Diabetes Care Center, Erode. The database of 1050 patients is collected for the implementation.

Certain limits set by the expert’s opinion are as follows:
- H1 ≥ 0.5 High Blood Glucose
- H2 ≥ 0.5 High Blood Pressure
- H3 ≥ 0.5 Smoking
- H4 ≥ 0.5 High Protein Content in Urine
- H5 ≥ 0.5 High Blood Levels of Urea and Creatinine

5. RESULTS AND DISCUSSIONS

Expert’s Opinion

The expert’s opinion of diabetic nephropathy is transformed into the fuzzy relation equation P which is given by

\[ P = \begin{bmatrix} S_1 & S_2 & S_3 & S_4 & S_5 \\ H_1 & 0.7 & 0.5 & 0.4 & 0.5 & 0.4 \\ H_2 & 0.6 & 0.7 & 0.5 & 0.6 & 0.4 \\ H_3 & 0.4 & 0.5 & 0.6 & 0.5 & 0.3 \\ H_4 & 0.5 & 0.6 & 0.5 & 0.4 & 0.6 \\ H_5 & 0.5 & 0.8 & 0.7 & 0.5 & 0.6 \end{bmatrix} \]

where \( Q^T = [0.6 \ 0.8 \ 0.7 \ 0.6 \ 0.6] \). These symptoms are given based on the risk factors of kidney disorder disease and given values for Q. Now P and Q are known in the fuzzy relation equation \( P \circ Q = R \). Using the max-min principle in the equation \( P \circ Q = R, R^T = [0.42 \ 0.56 \ 0.48 \ 0.64] \) is obtained.

In the fuzzy relation, P is considered as weightages of the expert’s, Q is the symptoms of kidney disorder and R is the computed resultant for risk factors. According to the expert’s opinion the kidney disorder risk in diabetic patient is more when fat content is more in blood. Blood pressure is the first risk factor, the second risk followed by smoking, due to increase in blood pressure.

Clinical Research Opinion

The clinical research opinion of diabetic nephropathy is transformed into the fuzzy relation equation P which is given by

\[ P = \begin{bmatrix} S_1 & S_2 & S_3 & S_4 & S_5 \\ H_1 & 0.7 & 0.5 & 0.4 & 0.5 & 0.4 \\ H_2 & 0.6 & 0.7 & 0.5 & 0.6 & 0.4 \\ H_3 & 0.4 & 0.5 & 0.6 & 0.5 & 0.3 \\ H_4 & 0.5 & 0.6 & 0.5 & 0.4 & 0.6 \\ H_5 & 0.5 & 0.8 & 0.7 & 0.5 & 0.6 \end{bmatrix} \]

\( Q^T = [0.6 \ 0.8 \ 0.7 \ 0.6 \ 0.6] \) and \( R^T = [0.42 \ 0.56 \ 0.48 \ 0.64] \). These symptoms are given based on the risk factors of kidney disorder and given values for Q, where \( Q^T = [0.6 \ 0.8 \ 0.7 \ 0.6] \). Hence P and Q are in the fuzzy relation equation, then R is calculated as \( P \circ Q^T = R \). Using the max-min principle in the equation \( P \circ Q^T = R \), i.e., \( R = [0.42 \ 0.60 \ 0.40 \ 0.48 \ 0.64] \) is obtained. According to the clinical research opinion the diabetic patient is badly affected by kidney disorder due to high blood levels of urea and creatinine, high blood pressure is the second risk factor, followed by high protein content in urine, smoking habit, high blood glucose level.

According to the results obtained by clinical research opinion and expert’s opinion kidney can be protected by keeping the blood glucose levels at or near normal, controlling the blood pressure and not by smoking, which leads to reduce blood flow to the kidney. An early sign of kidney problems is protein in the urine. Every year urine test must be done to check the protein level by conducting microalbumin test because kidney can become damaged long before affected by any other symptoms. A serum creatinine blood test is also recommended annually, high creatinine levels are a sign of kidney problems that need medical attention.

6. CONCLUSION

This paper proposed the Fuzzy Relational Equation to predict diabetic nephropathy based on the expert’s medical knowledge. Fuzzy relations are developed by allowing the relationship between elements of two or more sets which is based on an infinite number of degrees of relationship between the extremes of completely related or not related. It is observed that the results obtained by expert’s opinion and the clinical research opinion are found to be similar which satisfies the fuzzy relations.
References


